environmental SCIENTIST

September 2022
Journal of the Institution of Environmental Sciences

Ecosystem restoration

Securing biodiversity, complexity and resilience

EDITORIAL

Restoring resilient, healthy and functioning ecosystems

The case for ecological restoration goes way beyond reasons of biodiversity recovery for the sake of biodiversity alone; it is also fundamental for our health, wellbeing and economy, and tackling climate change. The Dasgupta Review on the Economics of Biodiversity showed that our demands on nature outstrip nature's ability to supply us with the goods and services on which we rely.[1] We not only need to balance our supply and demand, but we need to boost the supply side to compensate for years of overconsumption and damage. In other words, we need to undertake considerable ecological restoration.

What kind of ecological restoration do we need? We know that ecosystems with the full complement of biodiversity and associated ecological complexity are more productive in terms of ecosystem services (particularly in terms of regulating and maintenance services and cultural services) and are more resilient to shocks and change. We also know we want to address the twin crises of biodiversity loss and climate change – an aspiration that is completely achievable if we consider both in restoration design. Some studies have shown us that restoration is not always easy, with levels of biodiversity and ecosystem services in restored ecosystems often below those seen in intact systems.[2] We also know that complexity in restoring degraded nature is an important and often overlooked factor.

But it is possible. Launched last year, the United Nations Decade of Ecosystem Restoration 2021–2030 sets an ambitious agenda aiming to supercharge the restoration of nature across the globe, and the UK has committed to protecting 30 per cent of its land and seas for nature by 2030 to halt and reverse biodiversity loss. Restoration that works best combines the consideration of ecosystem services, ecosystem function and processes, biodiversity, complexity and the needs of people into its design.

Increasing the evidence base for future restoration projects is essential for a successful outcome. We need to know what works, why it works and how we can do it better next time. There is much to learn, which is why research programmes such as Restoring Resilient Ecosystems (RestREco) – an innovative partnership project that aims to examine the essential elements required for ecosystem restoration and with which the authors contributing to this edition are all affiliated – are important.

Fortunately, there are already a number of inspirational nature-recovery projects in the UK that we can learn from. For example, the Alkborough Flats managed realignment on the Humber estuary converted 440 ha of former arable farmland into a mixed landscape of reedbed, wet grassland, intertidal mudflats and arable farmland. This provides flood storage for water, creates wildlife habitat and enables public access as well as allowing for ongoing farming. The realignment was delivered in partnership with the Environment Agency, Natural England, Associated British Ports and North Lincolnshire Council to help solve the problems of accelerating climate change, sea-level rise and the resulting loss of intertidal habitats, and increasing pressure on flood defences. The site is still evolving as natural processes will dictate the matrix of habitats following initial landscaping and breaching of the sea wall.

One size does not fit all, though. Learning from RestREco will provide us with greater insight and a better understanding of what works. Away from the coast and sea, the Trees for Life project in Scotland has been working to bring back Caledonian Forest. With the help of 10,000 volunteers, 1.7 million trees have been planted rewilding 4,000 ha in total. This initial intervention enables the restoration of forests in areas where the natural seedbank no longer remains in the soil.

It is likely that we will need the full complement of restoration management from hands-off rewilding through to intensive land and sea management to restore resilient, healthy and functioning ecosystems. Studies show that ecosystem restoration is both achievable and economically beneficial. We cannot afford to sit tight. We need a step change in our efforts to restore resilient ecosystems for nature and for all our sakes.

REFERENCES

1. Dasgupta, P. (2021) *The Economics of Biodiversity: The Dasgupta Review*. London: Her Majesty's Treasury.
2. Benayas, J.M.R., Newton, A.C., Diaz, A. and Bullock, J.M. (2009) Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. *Science*, 325 (5944), pp. 1121–1124. DOI: 10.1126/science.1172460.

Editorial: Dr Ruth D Waters is Director of Evidence at Natural England. She is a strong advocate for interdisciplinary application of science in uncertain real-world settings. She has expertise in natural capital, valuing nature and the benefits of nature for people. She was the lead scientist in the team supporting Professor Sir Partha Dasgupta on the independent review of *The Economics of Biodiversity*.[1]

Cover design: Nix Ren is a London-based illustrator from China. For more of her work, visit nixren.cargo.site.

CONTENTS

environmental SCIENTIST
The journal of the Institution of Environmental Sciences
Volume 31 No 3 | ISSN: 0966 8411

The environmental SCIENTIST provides a platform to discuss key issues within the environmental sciences, hosting original articles written by professionals, academics and experts working across the sector.

The views expressed in the journal are those of the authors and do not necessarily reflect IES views or policy.

INTRODUCTION

Securing our landscapes and ecosystems for the future

Jim Harris, **James Bullock**, **Kirsty Park**, **Rosie Hails**, **Ben McCarthy** and **Kevin Watts** review how science, policy and practice in ecosystem restoration can reconnect the broken links between humans and nature.

Human transformation and degradation of the natural world are leading us into the Sixth Mass Extinction, with species being lost at an estimated rate of three orders of magnitude greater than the natural background rate.[1] Large-scale habitat loss, unchecked invasive species, overexploitation (e.g. excessive hunting and fishing pressures), pollution and climate change are depleting biodiversity and homogenising landscapes and ecosystems that thrive on biological, topographical and structural heterogeneity. The UK itself is one of the most nature-depleted countries globally and is in the bottom 10 per cent for biodiversity – with only about half of its biodiversity left compared to the global average of 75 per cent – a sobering fact.

We need to tackle biodiversity loss and climate change at the same time. Restoration is critical to society's adaptation to climate change, and nature-based solutions that reverse biodiversity loss and respond to a changing climate are crucial. Such restoration includes securing soil carbon in peatlands and increasing carbon sequestration through reforestation. There is also good evidence emerging that biodiverse systems sequester more carbon than impoverished ones.[2]

Last year saw the launch of the United Nations (UN) Decade on Ecosystem Restoration, with the intention of ramping up action to address these twin issues. However, we must also ask ourselves: what is restoration, and are our current approaches sufficiently sophisticated and nuanced to be effective in the long term? At a national level, we need to ensure that new mechanisms to offset biodiversity losses, such as biodiversity net gain, are effective at creating resilient and functional habitats that halt biodiversity loss and are able to adapt to (and mitigate) a changing climate. Do we have the capacity in our planning system to understand and deliver what is required, going beyond compliance to reversing our current direction of travel?

In this special issue we bring together scientists, policy-makers and practitioners who offer their viewpoints on these issues and address the need for securing ecological complexity and connectivity to establish ecosystems and landscapes that are well-functioning and resilient under ongoing environmental change. The special issue is inspired by the Restoring Resilient Ecosystems (RestREco) project. Funded by Natural Environment Research


© Dzmitrock87 | Adobe Stock

Council, RestREco is considering innovative approaches to restoration, and is building partnerships between universities, research institutes, conservation organisations and industry.

In the first section, focusing on the science of ecosystem restoration, Kirsty Park and colleagues look at the set of complex challenges that we face in the field of ecosystem restoration. Framing our targets is an enduring issue. Aiming to re-create past ecosystems may be increasingly difficult in many places due to climate shifts, and we need to draw on a wide knowledge base to understand the drivers influencing restoration outcomes. James Bullock and colleagues then examine the scientific basis that underpins a shift from restoring carbon copies of past ecosystems to creating complex systems that can adapt and continue to function. Complexity does not involve a whole new way of doing restoration, but a way of reconsidering what we want to achieve, of setting targets and measuring outcomes. As we are in an ecological emergency, the time has come to consider and apply radical new ideas to secure the future.

Elisa Fuentes-Montemayor illustrates the long-term responses of moths to woodland creation (using a 160-year natural experiment), while Oscar Aguinaga and Mark Pawlett take us below the surface to see what is going on in soils – often overlooked, but absolutely critical to understanding and managing systems being restored. We also need to understand the socio-economic trade-offs that arise from the way we manage the land. Should we be wedded to existing restoration standards or be guided by principles and guidelines aimed at embracing complexity and changing our direction of travel from continuing degradation to 'bend the curve' towards a regenerated planet?

In the second section on policy, Ben McCarthy and Jim Harris look at the current UK and international policy framework and how this enables effective action. Simon Duffield and colleagues then explore how we secure resilience to a changing climate in protected sites, while Christopher Nichols and colleagues consider where biodiversity net gain fits into ecological restoration. Finally, Clive Mitchell examines how we can visualise future landscapes, which may look very different to those of the past. The wide variety of aims that different restoration projects might have – for example, for biodiversity, climate change, mitigating flood risk – will also influence how we measure success.

Finally, case studies starting from differing prior land uses – mineral extraction and agriculture – examine how we are implementing restoration. Enrique Moran Montero shows the importance of a flexible approach to restoration and of working with the local community and organisations in an example of how a mineral extraction site became a complex set of restored habitats. Mark Carey and Duncan Hutt, with another mineral extraction example, suggest dramatic ecological recovery can be achieved by implementing well-considered management techniques and having an understanding of landscape function. Vanessa Burton considers woodland creation and explains six key principles to recovery developed by the Woodland Trust, which include working with natural processes and creating habitat mosaics and structural complexity. Rosie Hails and Ben McCarthy then describe how an active research agenda is underpinning the National Trust's approach to restoration. This allows a range of activities to take place, using Wicken Fen as an example where the main goal is to allow or establish ecological processes over a large scale rather than aiming at set targets comprising expected species and habitats. Finally, Isabella Tree describes the Knepp rewilding project, showing how a wait-and-see approach to restoring degraded habitats has led to unexpected and exciting outcomes, as well as inspiring the wider public. Together, these case studies show that the complexity approach to restoration is, to some extent, pushing at an open door. Forward-thinking practitioners are seeking and testing new approaches to restore ecosystems and landscapes.

Looking to the future of ecological restoration, in the UK and globally we need to grasp the nettle of how science does (or does not!) influence practice and policy, and how these in turn feed into the sorts of science conducted. We must also walk into the future hand in hand with achieving net, and then negative, carbon and circular economies. Ecosystem restoration, by reconnecting nature and people, is a core activity in this endeavour. ES

Professor Jim Harris is a systems ecologist interested in system complexity, function and emergent properties – particularly resilience and how the principles learned from ecology can be applied to the Five Capitals of our socio-ecological system. He principally works in soil microbiology, restoration ecology and ecosystem service research in relation to ecosystem processes.

Professor James Bullock (UK Centre for Ecology & Hydrology) is an applied ecologist, concerned with finding solutions to humanity's degradation of the natural world. He researches ecosystem restoration, rewilding and agroecosystems with an emphasis on large-scale, real-world processes and applications. He works on and is leading projects based in the UK, Europe and across the world.

Professor Kirsty Park (University of Stirling) is an applied ecologist interested in the effects of anthropogenic change on biodiversity and developing solutions to mitigate the impacts of humans on wildlife and habitats. She works with a wide range of policy and practitioner organisations, is a Trustee for the Loch Lomond and The Trossachs Countryside Trust, and a member of the Scottish Biodiversity Strategy Programme Advisory Group.

© Gudrun | Adobe Stock

Professor Rosie Hails MBE is an ecologist and Nature and Science Director at the National Trust, holding honorary chairs at Exeter and Cranfield universities. Her role is to develop the Trust's nature strategy and research portfolio and advise on science evidence relevant to Trust decision-making. She is a member of Defra's Science Advisory Council, chairing the Biodiversity Targets Advisory Group, and a member of Defra's Bovine Tuberculosis Partnership. Formerly, she was the Science Director for Biodiversity & Ecosystem Science at the UK Centre for Ecology & Hydrology. She was awarded an MBE for services to environmental research in 2000.

Ben McCarthy is an ecologist working as Head of Nature Conservation & Restoration Ecology at the National Trust. This role involves realising the Trust's ambition for nature and nature-based climate solutions, contributing towards building the evidence and Trust's reputation as a leading UK nature conservation organisation.

Professor Kevin Watts (Forest Research) is a landscape ecologist interested in understanding the impact of woodland creation and restoration on the biodiversity, functioning and resilience of wooded landscapes. His collaborative work utilises spatial models, indicators and simulations to explore and predict potential impacts and inform restoration policy and practice.

REFERENCES

1. De Vos, J.M., Joppa, L.N., Gittleman, J.L., Stephens, P.R. and Pimm, S.L. (2015) Estimating the normal background rate of species extinction. *Conservation Biology*, 29 (2), pp. 452–462. DOI: 10.1111/cobi.12380.
2. Liu, X., Trogisch, S., He, J-S., Niklaus, P.A., Bruelheide, H., Tang, Z., Erfmeier, A., Scherer-Lorenzen, M., Pietsch, K.A., Yang, B., Kühn, P., Scholten, T., Huang, Y., Wang, C., Staab, M., Leppert, K.N., Wirth, C., Schmid, B. and Ma, K. (2018) Tree species richness increases ecosystem carbon storage in subtropical forests. *Proceedings of the Royal Society B*, 285 (20181240). http://doi.org/10.1098/rspb.2018.1240 (Accessed: 7 September 2022).

FEATURE

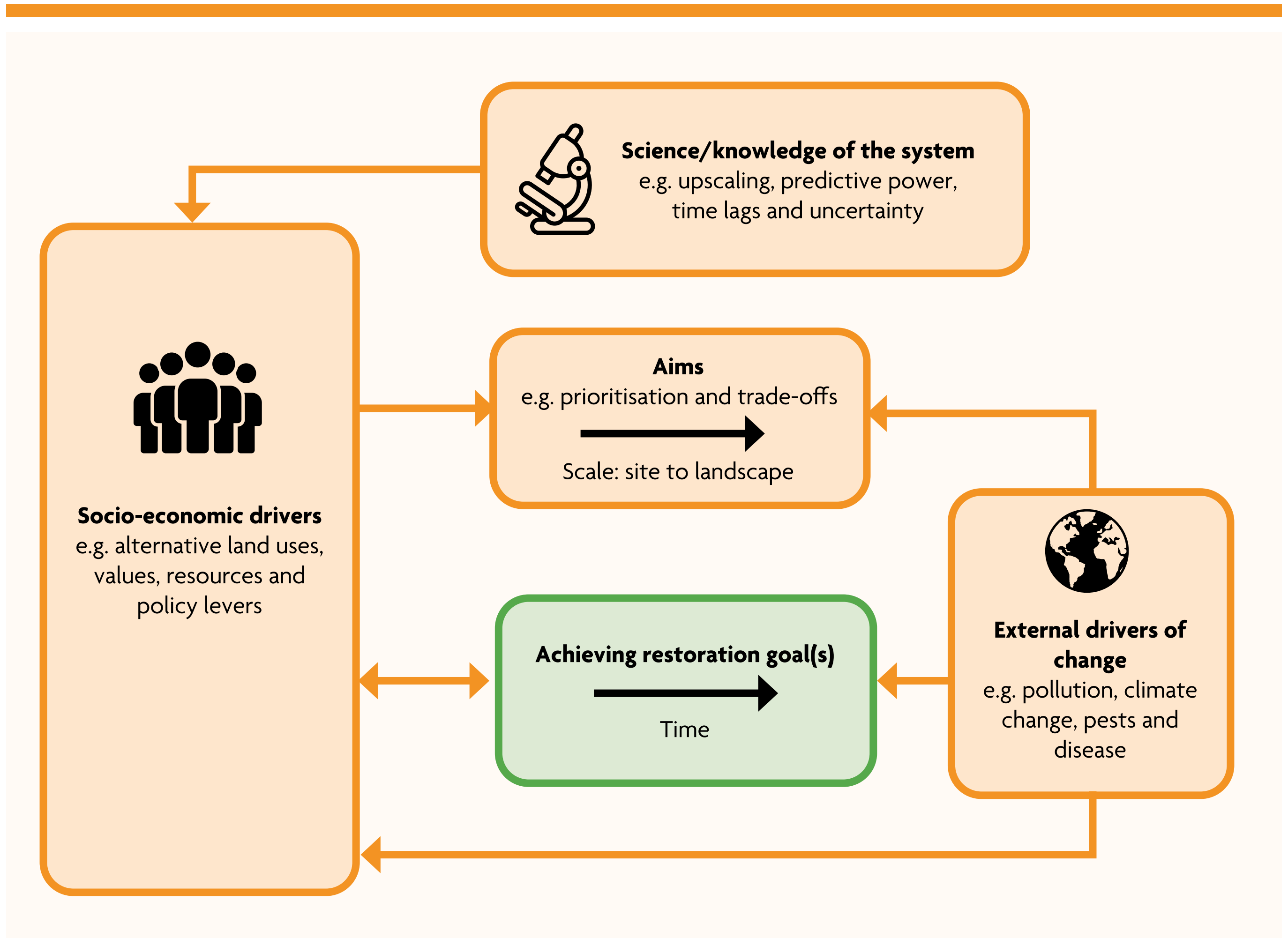
The challenges of ecosystem restoration

Kirsty Park, **Ben McCarthy** and **Jim Harris** examine the drivers and challenges of setting and achieving ecosystem restoration goals.

At first people refuse to believe that a strange new thing can be done. Then they begin to hope it can be done. They see it can be done. Then it is done and all the world wonders why it was not done centuries ago.[1]

While the need and urgency for ecosystem restoration is widely recognised – as reflected in the current United Nations Environment Programme's Decade of Restoration[2] – how to translate such a laudable ambition into tangible biological outcomes is problematic while

© Kirsty | Adobe Stock



▲ **Figure 1. Conceptual figure illustrating the key drivers influencing the success or otherwise of restoration goals.**

fundamental challenges of what restoration means in practice and how to achieve it remain. For example, what interventions will be appropriate to meet the challenges of locked-in environmental change and how can these be translated into tangible actions at a sufficient scale? What are the key issues that remain to be resolved in order to achieve ecological restoration and what are appropriate targets that are fit for the future and work with the current knowledge gaps and inevitable land use choices that society faces (see **Figure 1**)?

"At first people refuse to believe that a strange new thing can be done. Then they begin to hope it can be done. They see it can be done. Then it is done and all the world wonders why it was not done centuries ago."

FRAMING OUR RESTORATION AMBITIONS

Although the aim of restoration sounds like it should be obvious – to bring back or re-establish something of the past – there is increasing scrutiny on whether returning land to some previous habitat type with its suite of characteristic species is always appropriate.[3] Even where this is practically viable, there is little evidence to suggest that such habitats and ecosystems will necessarily be resilient to the future pressures and drivers of environmental change.

This becomes increasingly pertinent as attention shifts to the societal benefits of restored ecosystems and the services they deliver, such as reduced flood risk from restored flood plain functionality. While such nature-based solutions provide opportunities to meet the interdependent crises of biodiversity loss, ecosystem degradation and climate change, the scale of the necessary response brings into sharp focus the effectiveness of our interventions to go beyond halting the loss of biodiversity into a future focus on the science and practice of ecological restoration.

The Making Space for Nature report rightly called for more nature sites to be 'better, bigger, more and joined up' to reverse the decline of UK biodiversity and remains a cornerstone of UK conservation policy and practice.[4] This policy approach remains wholly relevant to mitigating and adapting our extant biodiversity to climate change and other environmental pressures. However, as the review panel concludes, the existing network of sites is insufficient to halt the loss of biodiversity and meet current nature targets. What is more, the scale of the twin biodiversity and climate emergencies requires an accelerated adoption of nature-based solutions and at scale, begging the question: how do we best support and facilitate ecosystem recovery and establishment that is fit for the future, meets fundamental societal needs and secures ongoing public support?

THE KNOWLEDGE BASE FOR ECOSYSTEM RESTORATION

The past 30 years have seen huge advances in the science and practice of restoration ecology. Seminal works by Hobbs and Norton[5] and Whisenant[6] set the scene for much that was to follow – including recognising the importance of managing abiotic barriers prior to biotic interventions,[7] interconnection and feedback loops,[8] the role of soil communities in determining re-establishment of plant communities in restoration sites,[9] and exciting possibilities for using environmental DNA and soundscapes to assess restoration success.[10,11]

As early as the 1990s, practitioners were calling for sound scientific grounds upon which to base decisions.[12] However, inherent uncertainty remains about how to set ambitious yet achievable goals given that ecosystems are dynamic and success is influenced by broader socio-political policies that can have greater sway on land use and land management decisions, especially at a landscape scale.

The effects of restoration can often take many years to be realised, particularly for habitats with slow development times (e.g. woodland), and there may be delayed responses by species to conservation interventions. Such biological time lags can make it difficult to assess the success or otherwise of restoration and disentangling whether success is yet to be realised or whether action has been insufficient or inappropriate is a major scientific and practical challenge. Further use of milestones, or interim targets linked to specific ecological mechanisms at key points in time, will help policy-makers and land managers assess whether the impact of conservation actions are following the desired trajectory and if the interventions are delivering the required outcomes.[13]

While there is an increasing number of landscape-scale restoration studies, the majority of these have been


© Ines Porada | Adobe Stock


© UllrichG | Adobe Stock

carried out at a site level. It is theoretically possible to upscale these interventions but ascertaining the benefits such landscape restoration will deliver with the same degree of confidence as site-level interventions remains problematic. However, the urgency and need for restoration underline the imperative of scaling-up our current restoration activities and so increase the potential benefits for biological diversity and climate change mitigation.

One of the clear challenges of landscape restoration is the competing demands on land use and how best to deploy limited resources to greatest effect. Whatever the goal of the restoration, consideration of trade-offs and unintended consequences is vital if we are to retain public confidence, and it is ultimately for public benefit. Well-publicised examples of ill-considered tree-planting schemes on species-rich grasslands or other open habitats (the antithesis of the 'right tree, right place' philosophy) demonstrate the importance of ensuring that interventions to restore healthier, functioning ecosystems are carefully considered and targeted.

EXTERNAL DRIVERS OF CHANGE

In England, the UK Government's 25 Year Plan to Improve the Environment[14] and new provisions within the Environment Act 2022 such as Local Nature Recovery Strategies may help generate greater clarity on where efforts to restore nature are best placed. The government is also required to report on progress against milestones.

There is a wide range of external drivers that can influence conditions within a restoration area and affect the success of actions taken. These include but are not limited to the extent of historic habitat loss and degradation that will influence both the feasibility of the restoration goal and the remaining species pool within the landscape that can re-colonise restored areas; pollution; effects of invasive species and overexploitation; and increasingly the effects of climate change.[15] For smaller sites in particular, species populations will be small, face a suite of genetic consequences and be prone to local extinction.

SOCIO-ECONOMIC DRIVERS

A key challenge is how to dedicate larger areas for ecosystem restoration while also maintaining or increasing agricultural productivity to meet demand by a growing human population. Areas dedicated for restoration may reduce the area available for other land uses such as food production and forestry, although there are exceptions to this (e.g. agroecology). Evidence from the marine environment demonstrates that when Marine Protected Areas are appropriately implemented fish populations and other biodiversity more widely increase.[16] While a wide range of country-specific policies support restoration activities for the purposes of biodiversity conservation and ecosystem service provision, at the same time many agricultural policies continue to fund and reward environmentally damaging actions (e.g. the EU's Common Agricultural Policy, which supports farmers who cultivate drained peatlands).

In many countries, including the UK, much of the land is privately owned. A key challenge, therefore, can be working with and persuading potentially large numbers of landowners to engage in restoration activities, particularly if resources to facilitate the work are limited or future funding is uncertain. Active restoration work is resource intensive and therefore expensive, so funding is clearly a major challenge and greatly influences the scale and feasibility of restoration actions.

Public perception of landscapes, what is 'natural' and the value placed on the land can also challenge the aim of restoration activities at a variety of scales – from heavily overgrazed but much-loved national parks to overzealous mowing of roadside verges for a 'neater' aesthetic. This can be a particular issue when more passive forms of restoration are employed, as it may be perceived that areas have simply been abandoned. Such values and attitudes also influence the societal narrative around restoration, which in turn will influence politicians and policy levers.

None of the challenges outlined above are insurmountable, and there are many examples of successful restoration initiatives. However, the gap between what is required to restore functioning ecosystems and what is happening on the ground is immense. Perhaps the biggest challenge of all is the long-term, open-ended nature of restoration: there is no definitive end point. In the face of global changes to our world, we therefore need to find an enduring way to integrate the needs of nature with our needs. ES

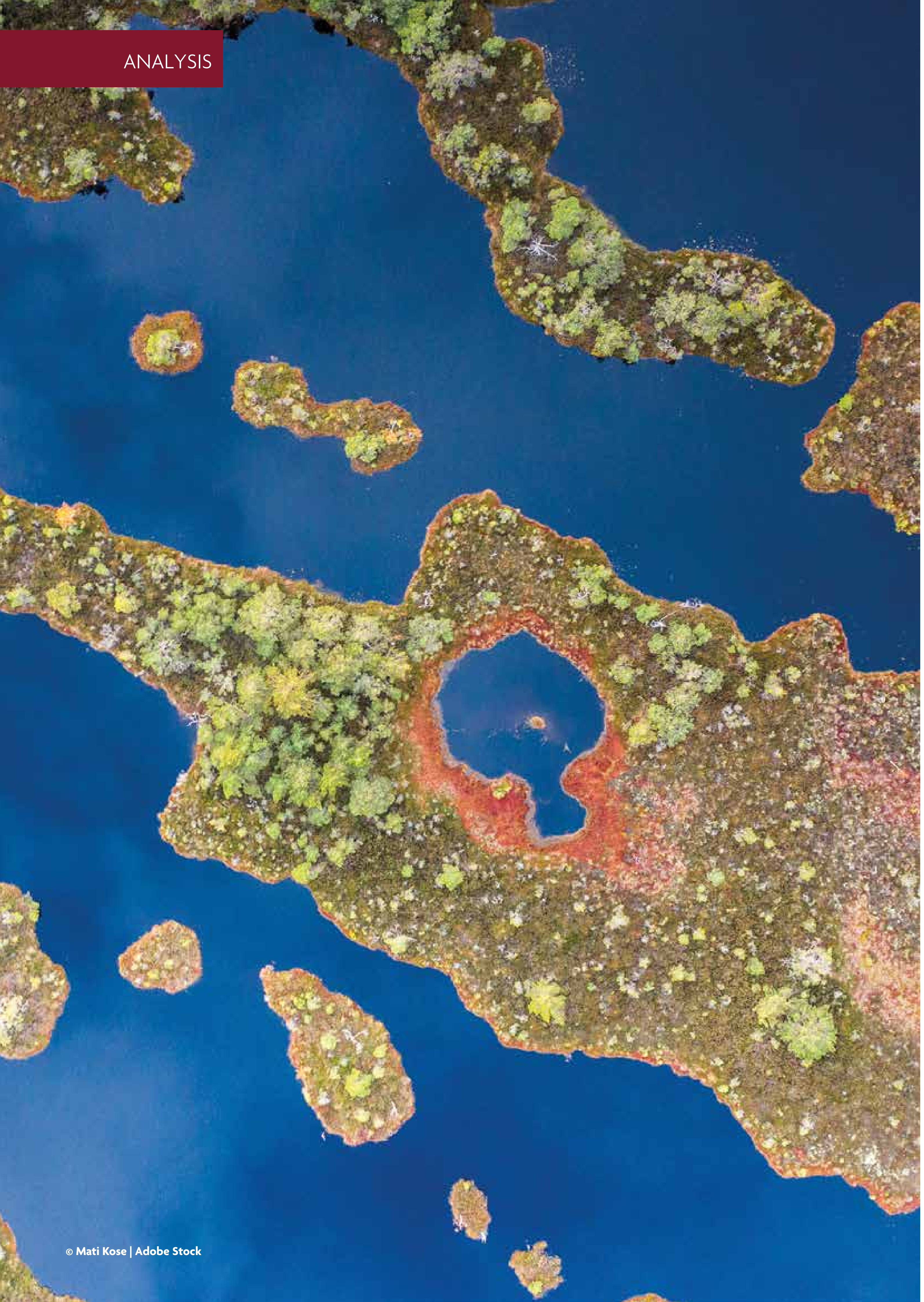
Professor Kirsty Park (University of Stirling) is an applied ecologist interested in the effects of anthropogenic change on biodiversity and developing solutions to mitigate the impacts of humans on wildlife and habitats. She works with a wide range of policy and practitioner organisations, is a Trustee for the Loch Lomond and The Trossachs Countryside Trust, and a member of the Scottish Biodiversity Strategy Programme Advisory Group.

Ben McCarthy is an ecologist working as Head of Nature Conservation & Restoration Ecology at the National Trust. This role involves realising the Trust's ambition for nature and nature-based climate solutions, contributing towards building the evidence and Trust's reputation as a leading UK nature conservation organisation.

Professor Jim Harris is a systems ecologist interested in system complexity, function and emergent properties – particularly resilience and how the principles learned from ecology can be applied to the Five Capitals of our socio-ecological system. He principally works in soil microbiology, restoration ecology and ecosystem service research in relation to ecosystem processes.

REFERENCES

1. Hodgson Burnett, F. (1911) *The Secret Garden.* London: Heinemann.
2. United Nations General Assembly (2019) *United Nations Decade on Ecosystem Restoration (2021–2030).* Resolution A/RES/73/284. Available at: https://digitallibrary.un.org/record/3794317?ln=en (Accessed: 6 August 2022).
3. Bullock, J.M., Fuentes-Montemayor, E., McCarthy, B., Park, K., Hails, R.S., Woodcock, B.A., Watts, K., Cornstanje, R. and Harris, J. (2022) Future restoration should enhance ecological complexity and emergent properties at multiple scales. *Ecography,* 2022 (4). https://doi.org/10.1111/ecog.05780 (Accessed: 1 August 2022).
4. Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J. and Wynne, G.R. (2010) *Making Space for Nature: A Review of England's Wildlife Sites and Ecological Network.* Technical Report to Defra. https://www.researchgate.net/publication/268279426_Making_Space_for_Nature_A_Review_of_England%27s_Wildlife_Sites_and_Ecological_Network (Accessed: 1 August 2022).
5. Hobbs, R.J. and Norton, D.A. (1996) Towards a conceptual framework for restoration ecology. *Restoration Ecology*, 4 (2), pp. 93–110. https://doi.org/10.1111/j.1526-100X.1996.tb00112.x (Accessed: 1 August 2022).
6. Whisenant, S.G. (1999) *Repairing Damaged Wildlands: A Process-oriented, Landscape-scale Approach.* Cambridge: Cambridge University Press.
7. Hobbs, R.J. and Harris, J.A. (2001) Restoration ecology: repairing the Earth's damaged ecosystems in the new millennium. *Restoration Ecology,* 9 (2), pp. 239–246. https://doi.org/10.1046/j.1526-100x.2001.009002239.x (Accessed: 1 August 2022).
8. Suding, K.N., Gross, K.L. and Houseman, G.R. (2004) Alternative states and positive feedbacks in restoration ecology. *Trends in Ecology & Evolution,* 19 (1), 46–53. https://doi.org/10.1016/j.tree.2003.10.005 (Accessed: 6 August 2022).
9. Wubs, E.R.J., van der Putten, W.H., Bosch, M. and Bezemer, M. (2016) Soil inoculation steers restoration of terrestrial ecosystems. *Nature Plants,* 2 (16107). https://www.nature.com/articles/nplants2016107 (Accessed: 1 August 2022).
10. Fernandes, K., van der Heyde, M., Bunce, M., Dixon, K., Harris, R.J., Wardell-Johnson, G. and Nevill, P.G. (2018) DNA metabarcoding – a new approach to fauna monitoring in mine site restoration. *Restoration Ecology,* 26 (6), pp. 1098–1107. https://doi.org/10.1111/rec.12868 (Accessed: 1 August 2022).
11. Borker, A., Buxton, R.T., Jones, I.L., Major, H.L., Williams, J.C., Tershy, B.R. and Croll, D.A. (2019) Do soundscape indices predict landscape scale restoration outcomes? A comparative study of restored seabird island soundscapes. *Restoration Ecology,* 28 (1), pp. 252–260. https://doi.org/10.1111/rec.13038 (Accessed: 1 August 2022).
12. Clewell, A.F. and Rieger, J.P. (1997) What practitioners need from restoration ecologists. *Restoration Ecology,* 5 (4), pp. 350–354. https://www.researchgate.net/publication/230011751_What_Practitioners_Need_from_Restoration_Ecologists (Accessed: 1 August 2022).
13. Watts, K., Whytock, R.C., Park, K.J., Fuentes-Montemayor, E., Macgregor, N.A., Duffield, S. and McGowan, P.J.K. (2020) Ecological time-lags and the journey towards conservation success. *Nature Ecology & Evolution,* 4 (3), pp. 304–311. https://pubmed.ncbi.nlm.nih.gov/31988448 (Accessed: 1 August 2022).
14. Department for Environment, Food and Rural Affairs (2018) *A Green Future: Our 25 Year Plan to Improve the Environment.* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf (Accessed: 6 August 2022).
15. Harris, J.A., Hobbs, R.J., Aronson, J. and Higgs, E. (2006) Ecological restoration and global climate change. *Restoration Ecology,* 14 (2), pp. 170–176. https://doi.org/10.1111/j.1526-100X.2006.00136.x (Accessed: 1 August 2022).
16. Davies, B.F.R., Holmes, L., Rees, A., Attrill, M.J., Cartwright, A.Y and Sheehan, E.V. (2021) Ecosystem approach to fisheries management works: how switching from mobile to static fishing gear improves populations of fished and non-fished species inside a marine-protected area. *Journal of Applied Ecology,* 58 (11), pp. 2463–2478. DOI: 10.1111/1365-2664.13986.


© Mati Kose | Adobe Stock

Restoring complexity for ecosystem functions and resilience

James Bullock, **Ben Woodcock**, **Elisa Fuentes-Montemayor**, **Rosie Hails**, **Ben McCarthy**, **Kirsty Park**, **Emily Waddell**, **Kevin Watts**, **Maico Weites**, **Ross Barnett**, **Sam Rogerson**, **Matt Guy** and **Jim Harris** consider the merits of approaches that restore for ecosystem complexity.

RESTORATION TO WHAT?

Ecological restoration is enshrined in science, policy and the public consciousness as aiming to bring back what has been lost. It is implicitly hoped that in doing so restoration can halt and even reverse the massive global species and ecosystems decline. In such a vision, restoration aims for the recovery of native or indigenous ecosystems that represent an idea of the former state of now-degraded land or water systems.[1] It is also often hoped that restoration to a supposed former state will not only benefit biodiversity but also enhance clean water and air, soil health, food provision, carbon capture, and other ecosystem functions and services essential for human health, wellbeing and livelihoods. As a result, restoration generally has clear targets in terms of the amount and types of ecosystems that should be restored, where and by when.

This framing of restoration suits scientists, policy-makers and planners, as it suggests we can aim at a set target and help avert the ecological crisis by meeting it while ensuring continued wellbeing for (some) humans. Much has been written about whether we can truly understand the past state of ecosystems and if we can effectively restore things by creating a carbon copy of a past ecosystem.[2] Is aiming to create such carbon copies even desirable, or would a different approach that takes account of the reality of global environmental change be more realistic and beneficial, and potentially even be more cost and resource effective?

ANALYSIS

RESTORATION UNDER GLOBAL ENVIRONMENTAL CHANGE

It is quite clear that biodiversity and the ecosystem services it underpins have been severely depleted by human activities.[3] The future may be uncertain, but the projections of threats to biodiversity are alarming. The biggest future threat is arguably climate change, with change to the climate itself and its impacts on biodiversity likely to accelerate over the coming decades. The question arises whether native ecosystems will be able to persist unchanged in these new climates. Projections suggest that whole ecological assemblages will be disrupted, leading to extinction cascades.[4] While it is hoped that many ecosystems will persist in some form, it follows that restoration to create carbon copies of past ecosystems may create a hostage to fortune.

If we do not restore to re-create the past, what should we do? If we accept, reluctantly, that climate change, and possibly other environmental threats, will get worse, how can we approach restoration effectively? Conservation science more generally is recognising the need to move away from its focus on attempting to preserve ecosystems as they once were towards facilitating their adaptation to inevitable change.[5] In other words, we may we need to focus less on the identity of species, communities and ecosystems and how they resemble what was seen in the past and more on creating systems that can function under future conditions. These new forms of restoration also need to be resilient to the shocks and extreme events that are forecast to increase dramatically with a changing climate.

COMPLEXITY AS A NEW TARGET

Ecological theory and evidence lead us to suggest that restoration aimed at creating complex ecosystems could achieve the aims of maintaining functions and enhancing resilience. Complexity is a commonly used term that has been much discussed in ecology. We have distilled earlier research to define ecological complexity in straightforward terms, so that it is applicable at multiple scales and allows empirical measurement. Complexity is the number of components in a system and the number of connections among them.[6] As a result, complexity captures the diversity and flows in a system. *Components* can include species, height classes of vegetation, functional groups of species or, at a landscape scale, habitats. *Connections* include species interactions such as food webs, energy flows among species or, at larger scales, connectivity among habitat patches. This approach to restoration explicitly aims to move degraded (low ecological complexity) systems towards a state of high ecological complexity (restored).

Volumes of research over the last few decades suggest that ecosystem functions and their resilience increase with higher ecological complexity. Higher species or functional group richness at different trophic levels enhance many ecosystem functions such as productivity, pollination, decomposition or nutrient cycling. These functions underpin many ecosystem services such as carbon sequestration, capture of pollutants, pest control and crop pollination. There is also evidence that a greater density of species interactions – for example, more complex food webs – also enhances ecosystem functioning. Resilience of ecosystem functions to perturbation is also enhanced by increased richness and highly connected ecological networks.[7]

ACTIONS TO RESTORE COMPLEXITY

What would restoring for ecological complexity look like in practice and how might it differ from current approaches?

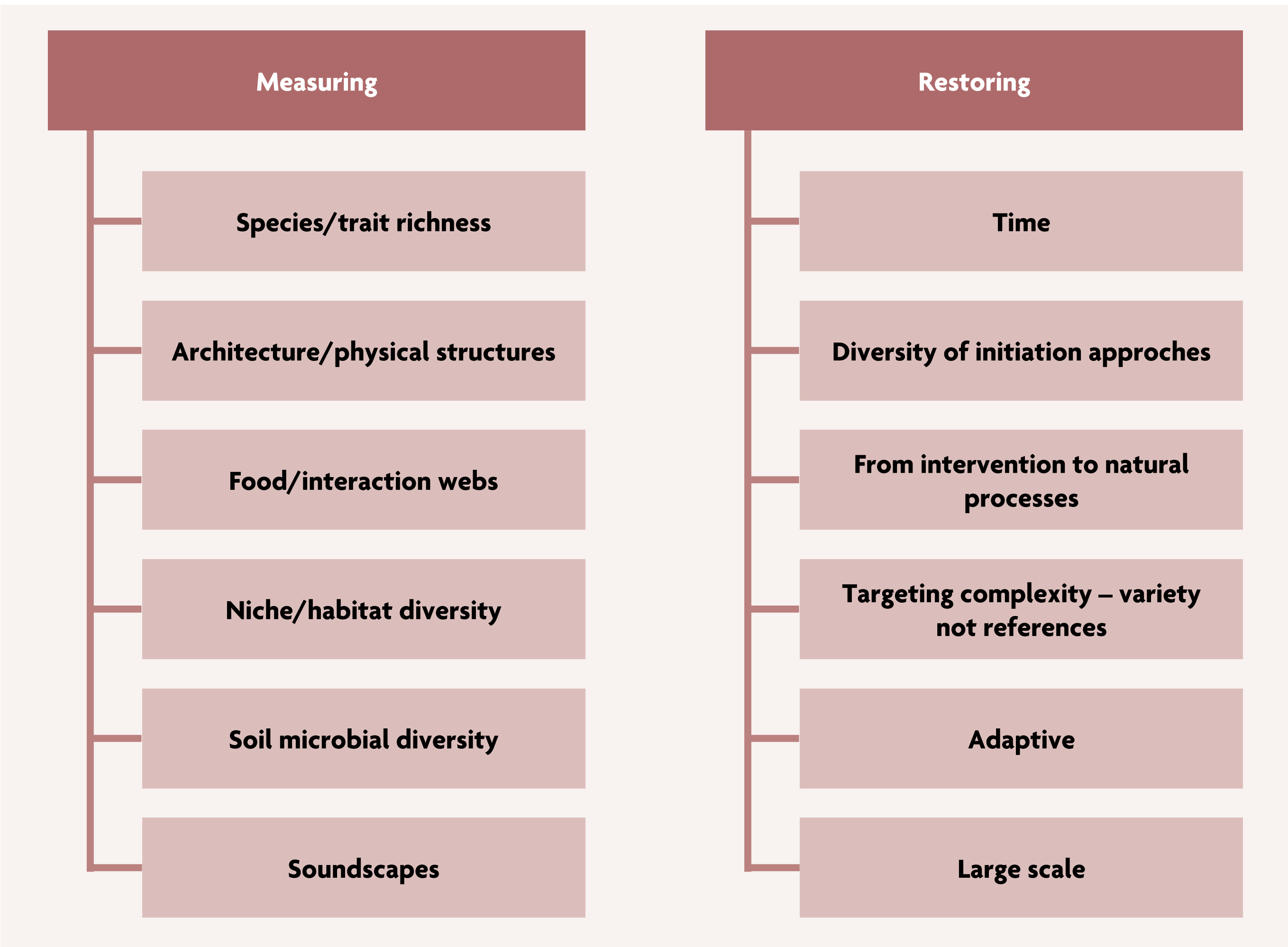
Restoring for complexity may involve many similar actions to those used in traditional restoration. However, the definitions of outcomes and success are more important than the specific activities (see **Figure 1**). Restoring for complexity is less likely to focus on uncommon or rare species but might target key species (e.g. large grazers or predators, ecosystem engineers or keystone species) that provide certain functions or improve the resilience of these functions. In this way, restoring for complexity could borrow some activities from trophic rewilding.

More generally, targeting complexity, functioning and resilience might involve developing an ecosystem that

is bespoke to the local environmental context rather than based on an ideal. Such restoration may be less tied to concepts of 'the correct species' identified as representative of an idealised target community and more focused on species with characteristics that confer resilience to future environmental conditions. Species identity is less important. The focus on establishing rare species in the conventional restoration paradigm has often proved costly and hard to achieve. It is also questionable whether such species can deliver functions or resilience. Given their low abundance or biomass, they may be unable to contribute greatly to ecosystem functions. Furthermore, given their often tenuous grip on habitats, which are even now actively tailored to their benefit, they are unlikely to continue to contribute to ecosystem functions under dramatic shifts in environmental conditions.

An alternative aim could be to establish a range of species, especially considering trophic levels other than plants, from herbivores to predators to soil fauna and flora. There may be a degree of trial and error in doing this to allow environmental filtering of the best-suited species. A diversity of approaches might therefore be used, including allowing natural processes (e.g. regeneration or colonisation) as well as more targeted interventions.

Time is frequently discussed as the most important factor in restoring target ecosystems; it may take many years for the target to be reached. Does the same issue apply to complexity? In general, yes, as ecological interactions and processes require time to develop. But if we are not concerned with achieving a specific target, there is a greater degree of freedom in how we might speed up the enhancement of complexity. Creation of heterogeneity is likely to be key to allow a variety of species to persist while also reinforcing complexity and resilience. An ongoing programme of actions after the initiation of restoration is also likely to be useful. Such actions could range from adding extra species as the ecosystem develops to kick-starting certain key processes through adding dead wood or litter, opening up the vegetation, or damming streams. These actions could be adapted to the local circumstances as the restoration proceeds.



▲ **Figure 1. Ways of measuring and restoring complexity.**

Ultimately, restoring for complexity may be no more onerous than restoring target ecosystems. Indeed, if the necessity to create certain biophysical conditions or to establish characteristic species for the carbon copy approach is removed, restoring for complexity may be the simpler approach.

EVALUATING THE ACHIEVEMENT OF COMPLEXITY

A significant difference from traditional restoration will be in how restoration for complexity is evaluated and deciding what success looks like (see **Figure 1**). In fact, a lack of success using traditional measures may look more positive when considering complexity as a target. For example, an analysis of flood plain meadow restorations showed that the development of the functional structure of plant communities was faster than that of achieving species similarity to ancient grasslands targets.[8]

How do we measure ecological complexity in the field? Traditional measures of restoration success, such as the presence of indicator species, species composition or similarity to target habitats, are unlikely to be useful. There are several existing approaches that could be used, ideally in combination, to assess complexity during restoration:

a) Vertical and horizontal heterogeneity. This includes vertical vegetation structure, the range of vegetation types or heights over space, and the patchiness in vegetation composition. As well as on-the-ground measurement, remote sensing techniques such as lidar can be deployed.

b) Species richness and diversity. Emphasising the need to consider multiple trophic levels – decomposers, herbivores, predators – as well as plants, traditional survey methods might be aided by environmental DNA.

c) Food web structures. While detailed methods can be deployed – such as observing feeding relationships – food webs can also be inferred using species lists and general knowledge of feeding relationships, such as from databases.[9]

d) Soil microbial communities. Some techniques require high skill and expense, but there are also simpler approaches. For example, using phospholipid fatty acid analysis can help determine the overall abundance of different components of the microbial community.[10]

e) Integrative measures of complexity. Soundscapes, for example, can be characterised using acoustic indices to quantify different acoustic attributes from animal communities,[11] and to indicate changes in these communities over time, as well as changes in interactions, diversity and behaviour.

ANALYSIS

© Maria T Hoffman | Adobe Stock

CONCLUSION

A complexity approach need not exclude the traditional carbon-copy paradigm for restoration, but ideally would absorb it into a broader remit. Obviously, a complexity approach to restoration is not a panacea for the depredations of rapid climate change or increases in other environmental threats. But we suggest that advances can be made if restoration emphasises ecological processes over community composition with pragmatic goals that are flexible in setting objectives to restore ecosystems and secure public benefits in a changing world. ES

Professor James Bullock (UK Centre for Ecology & Hydrology) is an applied ecologist, concerned with finding solutions to humanity's degradation of the natural world. He researches ecosystem restoration, rewilding and agroecosystems with an emphasis on large-scale, real-world processes and applications. He works on and is leading projects based in the UK, Europe and across the world.

Dr Ben Woodcock (UK Centre for Ecology & Hydrology) focuses on research on integrating biodiversity into agricultural systems where maintaining farm yield and profitability are critical factors that need to be considered in any future solutions or mitigation measures. His work has focused on insect-mediated ecosystem service provision (pollination and natural pest control) and the restoration of lowland grassland ecosystems to support biodiversity and system resilience.

Elisa Fuentes-Montemayor (University of Stirling) is an applied ecologist and conservation biologist investigating how human activities impact biological communities and ecosystem functioning, with a focus on finding effective ways to conserve and restore biodiversity in human-modified landscapes. Her areas of expertise include animal ecology, woodland ecology, restoration ecology and spatial ecology.

Professor Rosie Hails MBE is an ecologist and Nature and Science Director at the National Trust, holding honorary chairs at Exeter and Cranfield universities. Her role is to develop the Trust's nature strategy and research portfolio and advise on science evidence relevant to Trust decision-making. She is a member of Defra's Science Advisory Council, chairing the Biodiversity Targets Advisory Group, and a member of Defra's Bovine Tuberculosis Partnership. Formerly, she was the Science Director for Biodiversity & Ecosystem Science at the UK Centre for Ecology & Hydrology. She was awarded an MBE for services to environmental research in 2000.

Ben McCarthy is an ecologist working as Head of Nature Conservation & Restoration Ecology at the National Trust. This role involves realising the Trust's ambition for nature and nature-based climate solutions, contributing towards building the evidence and Trust's reputation as a leading UK nature conservation organisation.

Professor Kirsty Park (University of Stirling) is an applied ecologist interested in the effects of anthropogenic change on biodiversity and on developing solutions to mitigate the impacts of humans on wildlife and habitats. She works with a wide range of policy and practitioner organisations, is a Trustee for the Loch Lomond and The Trossachs Countryside Trust, and a member of the Scottish Biodiversity Strategy Programme Advisory Group.

Dr Emily Waddell (University of Stirling) is an ecologist who is interested in the impact of anthropogenic change on forest ecosystems focusing on ensuring these ecosystems are protected and resilient to future environmental change. She has researched both tropical and temperate human-modified landscapes, focusing on both plant and animal communities.

Professor Kevin Watts (Forest Research) is a landscape ecologist interested in understanding the impact of woodland creation and restoration on the biodiversity, functioning and resilience of wooded landscapes. His collaborative work utilises spatial models, indicators and simulations to explore and predict potential impacts and inform restoration policy and practice.

Maico Geert Weites (UK Centre for Ecology & Hydrology) is an ecologist and entomologist who has extensive survey and taxonomic experience in botany and invertebrates in both the UK and mainland Europe.

Ross Barnett (University of Stirling) is an ecologist with widespread interests and experience in restoration, entomology and bioacoustics, with previous research utilising acoustic indices as indicators of climate change-induced phenological changes in Scottish woodlands.

Sam Rogerson (University of Stirling) is an entomologist with experience in studying invertebrates in temperate and tropical woodland and freshwater habitats. Previous research includes working with Science and Advice for Scottish Agriculture to characterise the ecology of spittlebugs in Scotland, a vector of *Xylella* bacteria.

Dr Matt Guy (Forest Research) is a spatial scientist focusing on woodland creation. His background is in ecology, and he has worked on board range of taxa, ecosystems, and settings, including bats as pest control on coffee plantations, invertebrate communities in willow coppice and mammals in small agricultural woodlands.

Professor Jim Harris is a systems ecologist interested in system complexity, function and emergent properties – particularly resilience and how the principles learned from ecology can be applied to the Five Capitals of our socio-ecological system. He principally works in soil microbiology, restoration ecology and ecosystem service research in relation to ecosystem processes.

REFERENCES

1. Gann, G.D., McDonald, T., Walder, B., Aronson, J., Nelson, C.R., Johnson, J., Hallet, J.G., Eisenberg, C., Guariguata, M.R., Liu, J., Hua, F., Echeverría, C., Gonzalez, E., Shaw, N., Decleer, K. and Dixon, K.W. (2019) International principles and standards for the practice of ecological restoration. *Restoration Ecology*, 27 (S1), pp. S1–S46. https://onlinelibrary.wiley.com/doi/10.1111/rec.13035 (Accessed: 7 August 2022).
2. Hilderbrand, R.H., Watts, A.C. and Randle, A.M. (2005) The myths of restoration ecology. *Ecology and Society*, 10 (1), Art. 19. https://www.ecologyandsociety.org/vol10/iss1/art19/ (Accessed: 7 August 2022).
3. Isbell, F., Balvanera, P., Mori, A.S., He, J-S., Bullock, J.M., Regmi, G.R., Seablood, E.W., Ferrier, S., Sala, O.E., Guerrero-Ramirez, N.R., Tavella, J., Larkin, D.J., Schmid, B., Outhwaite, C.L., Pramual, P., Borer, E.T., Loreau, M., Crossby Omotoriogun, T., *et al.* (2022) Expert perspectives on global biodiversity loss and its drivers and impacts on people. *Frontiers in Ecology and the Environment*, (in press). https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/fee.2536 (Accessed: 7 August 2022).
4. Trisos, C.H., Merrow, C. and Pigot, A.L. (2020) The projected timing of abrupt ecological disruption from climate change. *Nature*, 580 (7804), pp. 496–501. Doi: 10.1038/s41586-020-2189-9.
5. Duffield, S.J., Le Bas, B. and Morecroft, M.D. (2021) Climate change vulnerability and the state of adaptation on England's National Nature Reserves. *Biological Conservation*, 254, 108938. https://www.sciencedirect.com/science/article/pii/S0006320720309964 (Accessed: 7 August 2022).
6. Bullock, J.M., Fuentes-Montemayor, E., McCarthy, B., Park, K., Hails, R.S., Woodcock, B.A., Watts, K., Cornstanje, R. and Harris, J. (2022) Future restoration should enhance ecological complexity and emergent properties at multiple scales. *Ecography*, 2022 (4). https://doi.org/10.1111/ecog.05780 (Accessed: 1 August 2022).
7. Oliver, T.H., Heard, M.S., Isaac, N.J.B., Roy, D.B., Procter, D., Eigenbrod, F., Freckleton, R., Hector, A., Orme, C.D.L., Petchey, O.W., Proença, V., Raffaelli, D., Suttle, K.B., Mace, G.M., Martín-López, M., Woodcock, B.A. and Bullock, J.M. (2015) Biodiversity and resilience of ecosystem functions. *Trends in Ecology & Evolution*, 30 (11), pp. 673–684. https://doi.org/10.1016/j.tree.2015.08.009 (Accessed: 7 August 2022).
8. Woodcock, B.A., McDonald, A.W. and Pywell, R.F. (2011) Can long-term floodplain meadow recreation replicate species composition and functional characteristics of target grasslands? *Journal of Applied Ecology*, 48 (5), pp. 1070–1078. https://doi.org/10.1111/j.1365-2664.2011.02029.x (Accessed: 7 August 2022).
9. Gray, C., Figueroa, D.H., Hudson, L.N., Ma, A., Perkins, D. and Woodward, G. (2015) Joining the dots: an automated method for constructing food webs from compendia of published interactions. *Food Webs*, 5, pp. 11–20. https://doi.org/10.1016/j.fooweb.2015.09.001 (Accessed: 7 August 2022).
10. Singh Rawat, V., Kaur, J., Bhagwat, S., Arora Pandit, M. and Dogra Rawat, C. (2022) Deploying microbes as drivers and indicators in ecological restoration. *Restoration Ecology*, e13688 (in press). https://doi.org/10.1111/rec.13688 (Accessed: 7 August 2022).
11. Burivalova, Z., Game, E.T. and Butler, R.A. (2019) The sound of a tropical forest. *Science*, 363 (6422), pp. 28–29. DOI: 10.1126/science.aav190.

The role of woodland creation in enhancing ecological complexity

Elisa Fuentes-Montemayor delves into the lives of moths to understand their role in landscape-level ecological complexity.

Woodland-creation site planted in the early 2000s in Northamptonshire, England. (© Elisa Fuentes-Montemayor)

WOODLAND CREATION AND LANDSCAPE RESTORATION

Large-scale habitat creation plays a crucial role in the restoration of degraded landscapes. In particular, woodland is the focus of many global restoration initiatives because of its importance for biodiversity and climate change mitigation. In the UK, woodland expansion has been a priority for more than a century.

CASE STUDY

Large-scale tree-planting programmes have substantially increased woodland cover from an all-time-low of 5 per cent in the early 20th century to a current 13 per cent, with an aspiration to further increase this to 18 per cent by 2050. Much of this planting has been dominated by non-native coniferous plantations (primarily for timber production), but there has been a gradual shift towards planting more native woodlands with multiple objectives, including environmental, visual and cultural benefits. But despite decades of tree-planting initiatives, we still know relatively little about the effectiveness of woodland creation in the restoration of biodiversity, ecosystem functions and ecological complexity.

THE UNKNOWNS

This lack of empirical evidence derives from the challenges associated with studying landscape restoration over sufficiently lengthy, ecologically realistic spatiotemporal scales.[1] This is particularly challenging when it involves habitats with slow development rates such as temperate woodlands. Additionally, the limited knowledge we do have is uneven, with some taxonomic groups such as vascular plants and vertebrates having been studied more extensively than others. A literature synthesis of local- and landscape-level factors influencing biodiversity in temperate woodland-creation sites in agricultural landscapes highlighted that only 13.5 per cent (14 of 104 studies) focused on invertebrates.[2] This underrepresentation reflects a general trend in the scientific literature where insects and arachnids are reportedly the most understudied groups relative to the number of known species.[3]

This taxonomic bias affects our understanding of how a large proportion of woodland biodiversity responds to woodland creation. For example, we know that ecological continuity (the time over which a site has been continuously wooded) is an important driver influencing some species groups such as vascular plants; yet its effects on animals are rarely studied, with only 10 per cent and 21 per cent of studies reviewed quantifying the influence of ecological continuity (or woodland age) on vertebrates and invertebrates, respectively.[2] For invertebrates, of the few studies that assessed species' responses to ecological continuity, over 60 per cent found a significant positive effect. Studies focusing on invertebrates also tend to focus on assessing the impacts of local-level characteristics, with only a handful of studies investigating the influence of landscape-level factors such as the amount of surrounding habitat, degree of connectivity and type or permeability of non-woodland habitats.[2]

WOODLAND MOTHS AS A CASE STUDY

To address this knowledge gap, a recent study investigated moth community responses to long-term woodland creation on former agricultural land in temperate regions. Moths were selected for the study because they are a biologically diverse group with many species occurring regularly in woodlands (about two-thirds of British macro-moths). Additionally, many moth species have undergone significant population declines over recent decades, with habitat loss and degradation identified among the key factors for this alongside changes in the structure, management and spatial configuration of woodlands. Moths also play crucial ecological roles (e.g. pollination) and are an important food source for many animals such as bats and birds.

Moth responses to woodland creation have received little attention to date. A previous study comparing the vegetation attributes of young (<30 years) woodland-creation sites to those of more mature (>60 years) semi-natural woodlands suggested that moth abundance and diversity are likely to be lower in younger woodlands, and that woodland-creation sites at early development stages are more likely to benefit generalist and highly mobile moth species.[4] However, these studies were conducted over relatively small spatiotemporal scales, especially when considering that temperate woodlands develop slowly and may take centuries to acquire certain vegetation attributes similar to those of mature ancient woodlands.

This recent study examined the response of moth communities to long-term (up to 160 years) woodland creation on former agricultural land, and identified local- and landscape-level attributes associated with high moth abundance and species richness.[5] The study found that woodland-creation sites harboured large numbers of woodland moth species (212 in total) including micro (59 species) and macro-moths (153 species), the former usually having smaller wingspans and therefore a more limited dispersal than larger macro-moths. These moth assemblages were dominated by woodland generalists (around 62 per cent of species versus 38 per cent of woodland specialists), closely mirroring the split of habitat specialism of moths present in the central Scotland study area.

The study found that macro-moths (both generalists and specialists) were more abundant and diverse in younger woodlands, suggesting that these species are relatively quick to colonise newly created woodland patches and can capitalise on early successional woodland habitats characterised by having high tree densities and relatively small trees. Conversely, micro-moth woodland specialists occurred more frequently in older woodland-creation sites, possibly because the longer ecological continuity of these sites has allowed for more colonisation events and thus the accumulation of these relatively low-mobility species over time.

◀ **Figure 1. White-blotch bell moth (*Epinotia trigonella*), a woodland specialist micro-moth in Lanarkshire, Scotland. (© Philip Sansum)**

▲ **Figure 2. Light emerald (*Campaea margaritata*), a woodland specialist macro-moth as found by day in a natural resting position on the underside of oak foliage in Stirlingshire, Scotland. (© Philip Sansum)**

Given that different moth species groups vary in their response to local- and landscape-level habitat characteristics, differences were expected in moth community composition across a gradient of woodland age, with younger woodlands first being colonised by generalists and relatively mobile species and then gradually shifting towards specialists and lower-mobility species dominating more mature woodlands. Interestingly, this was not the case and moth species composition did not change in a particular direction based on woodland age.

However, moth assemblages in younger woodlands appeared similar, while they were rather dissimilar in more mature woodlands suggesting that woodlands gradually diverge and follow different trajectories over time. This was reinforced by observations that species turnover across woodland sites was high. In other words, individual sites hosted unique moth species assemblages and had relatively few species in common (pairs of sites shared on average only 20 per cent of moth species). This may indicate that the colonisation of woodland-creation sites is somewhat stochastic, opportunistic and constrained by the pool of moth species within the surrounding landscape. It also highlights the importance of woodland connectivity for enabling moth species to colonise woodland-creation sites from surrounding areas; in fact, the study found that moth abundance and richness markedly decreased in poorly connected woodlands located more than 400 m away from the nearest woodland patch.

Another component of the study focused on assessing the degree of similarity between moth assemblages in woodland-creation sites compared to ancient woodlands – defined as those areas continuously wooded for at least 250 years, and usually regarded as higher-quality habitat for many species. The study found that ancient woodlands had similar moth abundance and species richness to woodland-creation sites for most groups, except for fewer macro-moth woodland specialist species (which tend to like the smaller tree sizes and higher tree densities characteristic of younger woodlands). However, their species composition was somewhat different, with ancient woodlands and woodland-creation sites each hosting substantial proportions of unique species. Additionally, low levels of nestedness were observed, meaning that moth species in woodland-creation sites are not simply subsets of species found in ancient woodlands.

RESTORING ECOLOGICAL COMPLEXITY

Ecological restoration has historically aimed to re-establish 'indigenous reference' systems or communities, such as plant communities characteristic of ancient woodlands. But more recently there have been concerns that this approach may not necessarily create systems that function at a high level or that are resilient to ongoing global change. As a result, it has been proposed that restoration should be targeted towards enhancing ecological complexity (defined as the number of components in a system and the number of connections among them).[6] Complexity applies at multiple scales and encompasses ecosystem-level variables such as structural heterogeneity (e.g. variation in tree sizes within a woodland) as well as landscape-level metrics including species diversity, heterogeneity among habitat patches and connectivity.

The woodland moth case study exemplifies how woodland creation can contribute to enhancing ecological complexity at a landscape scale; having a mosaic of woodland patches of different ages will increase habitat diversity, which in turn is likely to increase the differentiation in moth species assemblages among local sites, and consequently total species diversity in a landscape. There is evidence that ecosystem functions and resilience are enhanced by complexity. Individual woodland patches, including ancient and restored sites that contain distinctive moth assemblages, should therefore be protected and valued for their contribution to regional moth diversity and to ecological complexity more broadly.

Other animal groups with different life-history traits may respond differently to woodland creation, depending, for example, on their dispersal abilities and degree of habitat specialisation. However, it is likely that increasing complexity at multiple scales will benefit other species too, whether that is hoverflies responding positively to increased structural heterogeneity at the patch level[7] or bats benefiting from improved connectivity at the landscape scale.[8] ES

Dr Elisa Fuentes-Montemayor (University of Stirling) is an applied ecologist and conservation biologist investigating how human activities impact biological communities and ecosystem functioning, with a focus on finding effective ways to conserve and restore biodiversity in human-modified landscapes. Her areas of expertise include animal ecology, woodland ecology, restoration ecology and spatial ecology.

REFERENCES

1. Haddad, N.M. (2012) Connecting ecology and conservation through experiment. *Nature Methods*, 9, pp. 794–795. https://doi.org/10.1038/nmeth.2107 (Accessed: 1 August 2022).
2. Humphrey, J.W., Watts, K., Fuentes-Montemayor, E., Macgregor, N., Peace, A.J. and Park, K.J. (2015) What can studies of woodland fragmentation and creation tell us about ecological networks? A literature review and synthesis. *Landscape Ecology*, 30, pp. 21–50. https://doi.org/10.1007/s10980-014-0107-y (Accessed: 1 August 2022).
3. Troudet. J., Grandcolas, P., Blin, A., Vignes-Lebbe, R. and Legendre, F. (2017) Taxonomic bias in biodiversity data and societal preferences. *Scientific Reports*, 7 (9132). https://doi.org/10.1038/s41598-017-09084-6 (Accessed: 1 August 2022).
4. Fuentes-Montemayor, E., Peredo-Alvarez, V.M., Watts, K. and Park, K.J. (2015) Are woodland creation schemes providing suitable resources for biodiversity? Woodland moths as a case study. *Biodiversity and Conservation*, 24, pp. 3049–3070. https://doi.org/10.1007/s10531-015-0997-2 (Accessed: 1 August 2022).
5. Fuentes-Montemayor, E., Watts, K., Sansum, P., Scott, W. and Park, K.J. (2022) Moth community responses to woodland creation: the influence of woodland age, patch characteristics and landscape attributes. *Diversity and Distributions*, 28, pp. 1993–2007. https://onlinelibrary.wiley.com/doi/pdf/10.1111/ddi.13599 (Accessed: 6 August 2022).
6. Bullock, J.M., Fuentes-Montemayor, E., McCarthy, B., Park, K., Hails, R.S., Woodcock, B.A., Watts, K., Corstanje, R. and Harris, J. (2022) Future restoration should enhance ecological complexity and emergent properties at multiple scales. *Ecography*, 2022 (4). https://doi.org/10.1111/ecog.05780 (Accessed: 1 August 2022).
7. Fuller, L., Fuentes-Montemayor, E., Watts, K., Macgregor, N.A., Bitenc, K. and Park, K.J. (2018) Local-scale attributes determine the suitability of woodland creation sites for diptera. *Journal of Applied Ecology*, 55 (3), pp. 1173–1184. https://doi.org/10.1111/1365-2664.13035 (Accessed: 1 August 2022).
8. Fuentes-Montemayor, E., Watts, K., Macgregor, N.A., Lopez-Gallego, Z. and Park, K.J. (2017) Species mobility and landscape context determine the importance of local and landscape-level attributes. *Ecological Applications*, 27 (5), pp. 1541–1554. https://doi.org/10.1002/eap.1546 (Accessed: 1 August 2022).

CASE STUDY

© jbphotographylt | Adobe Stock

TECHNICAL

Going underground

Oscar Aguinaga and **Mark Pawlett** go below ground to investigate the role of soils in ecosystem restoration practices.

ECOSYSTEM DEGRADATION AND SOIL BIODIVERSITY

Ecosystem degradation is a serious environmental problem worldwide. It leads to loss of habitats, wildlife and natural resources, and when one ecosystem is degraded it affects others, multiplying the effect. One of the main but frequently unseen components affected by ecosystem degradation is soil. This upper layer of earth is fundamental for our own existence and for the conservation of life as we know it.

Soil is more than a mixture of organic matter and rock particles where plants grow. Its biology is extremely diverse, with an estimated 1 billion microbial cells in 10 g of soil[1] including prokaryotes (bacteria), eukaryotes (fungi) and archaea (often referred to as extremophiles because of their ability to survive and adapt in hostile environments). In addition, soil can contain billions of viruses, microfauna (e.g. protozoa and nematodes), mesofauna (e.g. collembola and mites) and macrofauna (e.g. earthworms, termites, ants). It is also very heterogenous; it can show different physical (e.g. texture, structure, porosity, permeability) and chemical (e.g. pH, salinity, nutrient content, organic matter) characteristics within a small area, which generates different soil types with very variable spatial distributions. This heterogeneity contributes to soil's vast biodiversity, as it can host diverse forms of life with different adaptations to the large number of possible environments present in the soil. The diversity of soil microbial communities is immense, and they are key drivers of ecosystem functions and services.

These microbial communities contribute, for example, to soil structure by forming soil aggregates that increase soil stability – thus preventing erosion – improve water retention and affect the rate of organic matter formation. Moreover, microbial metabolic processes transform their microenvironments through enzyme activity, which in turn generates soil nutrient cycling processes and the degradation of pollutants. Plant microbe feedback mechanisms also benefit plant growth and ecological adaptation. For example, microorganisms can generate plant allelopathic (interaction) responses through the production of chemical compounds (often secondary metabolites) that promote plant growth, and symbiotic mycorrhizal fungi contribute to the tolerance of plants to different stresses such as drought and pathogens.

TECHNICAL


© Shaploff | Adobe Stock

Soil degradation involves the deterioration of its physical, chemical and biological qualities and therefore prevents the delivery of specific goods (such as food production) and ecosystem services (such as carbon sequestration and water retention). Around the world, soil degradation is increasingly affecting millions of hectares of land and compromising global food security and favourable environmental condition.

In 1991, the extent of soil degradation around the planet based on human activities was calculated (see **Table 1**).

These calculations made approximately 20 years ago stated that a total of 1.943 million ha were affected. However, new studies have recently warned that 30 per cent (3.9 million ha) of the world's land is already degraded.[3]

These perturbations affect the soil as a habitat, and so the connectivity and complexity of biological systems found below ground, in turn affecting the feedback mechanisms of soil biology with plant roots (such as carbon and nutrient exchange) and thus ultimately influencing above-ground biodiversity.

▼ **Table 1. Soil degradation by human activity**[2]

Human activity	Millions of hectares globally
Deforestation	579
Land overexploitation	133
Overgrazing	679
Agricultural mismanagement	552

SOIL RESTORATION AND UNDERGROUND COMPLEXITY

Historically, restoration practices were focused above ground. Subsequently, the priority was the establishment of an above-ground plant community, often promoted by adjusting soils with organic matter to improve their properties. For example, common techniques for soil restoration include the use of manure, cover crops, organic compost and crop rotation. The measure of restoration success is therefore based on what we can see above ground: plant growth and recolonisation of macrobiota.

However, simply reincorporating the lost biotic and abiotic above-ground components in order to reconstruct soil habitats is not sufficient; successful and lasting restoration also requires reignition of geochemical cycles if plant health is to be sustained. As such, restoration practice is increasingly moving from vegetation establishment to ecosystem reconstruction. Sometimes the most important things are those we cannot see. The hidden biodiversity beneath our feet is critical for restoration success. However, it is not just a matter of adding or promoting microbial growth in degraded soils. Dedicated efforts to recover the complexity and multifunctionality of the underground microbial communities are necessary to achieve proper restoration success.

Microbial complexity, determined as the number of taxonomic groups and the degree of connectivity between them,[4] is crucial for adequate restoration. Microorganisms in soil ecosystems are assembled and each microbial group has a specific role, which leads to functional diversity. For example, heterotrophic microorganisms (those that rely on external carbon sources for growth) can break down complex organic compounds (e.g. chitin, cellulose, lignin), incorporating energy (carbon) into biomass from multiple complex sources. Chemolithotrophic microbes (those that get their energy through the oxidation of inorganic compounds) utilise inorganic substrates (e.g. nitrate, sulphate, iron), which generate a chemical modification of these compounds, promoting nutrient cycling. Both heterotrophic and chemolithotrophic taxa diversity will contribute to soil complexity. Degraded soils have fewer microbial taxa due to the rapid appearance of selection pressures that will induce the loss of certain taxonomic groups, therefore losing diversity and taxa that contribute to key ecological services, as observed in soils impacted by pollutants,[5] grazing[6] and intensive agriculture.[7]

TECHNICAL

Moreover, heterotrophic and chemolithotrophic taxa need to be connected and working together. Heterotrophs will generate simpler and more accessible carbon sources to fuel the metabolism of chemolithotrophs, and the latter will promote the availability of nitrogen and sulphur nutrients to heterotrophs. This connectivity also occurs with other living organisms. Microbes will provide specific nutrients to plants in exchange for root exudates – fluid evolving from the roots that contains multiple constituents and is a rich energy source for many microbial groups. Microbes can colonise the digestive tracts of earthworms and facilitate the decomposition of organic matter, while these invertebrates modify soil porosity enabling the entrance of oxygen and water into the soil's microbial habitats.

Degraded soils also show lower microbial network complexity. For example, molecular and biochemical analysis of microbial composition and soil functions in different soils with different climates and textures showed that soil degradation by erosion produced losses in connectivity and microbial complexity that led to the disruption of ecosystem services.[8]

Microbial complexity based on the type of energy source (e.g. heterotrophs, chemotrophs) is only one example of a large set of biotic process occurring in the soil that promote taxonomic diversity and possible connections – oxygen gradient formation, carbon retention, horizontal gene transfer and predation, among others. These biotic processes that depend on microbial complexity are fundamental for several functions delivered by healthy soils. Microbial complexity is linked to multifunctionality, as the loss of specific taxa can result in the loss of the function that they delivered in the soil. Resilient soils have the capacity to maintain (or restore) their function if they lose species, as they have multiple species that may provide the same function (redundancy).[9] Hence, restoration of soil microbial complexity is crucial for maintaining ecosystem services such as greenhouse gas regulation, water quality and infiltration (flood mitigation), disease suppression, and toxin breakdown (pesticides, contaminated soils).

THE FUTURE OF SOIL RESTORATION

Soil restoration practices should aim to characterise and understand the dynamics of microbial communities. A restoration process should evaluate the microbial successional patterns and increasing complexity in order to assess lasting efficiency and predict the soil ecosystem's response to human disturbance. Shifts in microbial community composition can change the efficiency of ecosystem services and can predict, in the long term, which soil functions are able to recover, and which will be permanently lost.

Recent studies have evidenced sensitive key taxa and specific levels of complexity that can be used as indicators for monitoring soil restoration. For example, intensive conventional agriculture reduces the complexity of fungal networks and reduction of keystone taxonomy groups compared to organically managed agriculture.[10] The biological community can be used to assess the state of an ecosystem and direct the assemblage of plant communities.[11] For this, DNA technology can represent a big advantage. Nowadays, sequencing DNA can be performed on portable devices, and large datasets can be generated with simple procedures. The abundance and distribution of specific functional genes from the overall microbial communities can be calculated to infer potential functions taking place in the soil. Linking microbial DNA information (taxonomic and functional profiles) with environmental data (physical and chemical soil characteristics) can generate insights into the microbial drivers for soil restoration.

However, current environmental DNA technology only gives us a snapshot of microbial traits, such as the number of taxa and functional genes in a sample, estimation of community diversity and inference of functions. Assessment of microbial associations requires novel ecological statistical tools that are currently under development. For this, more validations are needed and more studies of microbial communities in different types and status of soil restoration will contribute to incorporating underground microbial complexity in efficient future restoration schemes.

ES

Dr Oscar Aguinaga of Cranfield University is a microbial ecologist investigating the microbial and geochemical processes involved in the re-establishment of ecological functions and impact attenuation in different degraded ecosystems. His work is mainly focused on coastal wetlands, high-altitude Andean peatlands, woodlands and grasslands.
✉ **oscar.aguinagavargas@cranfield.ac.uk**

Dr Mark Pawlett CEnv is a soil ecologist at Cranfield University and is interested in developing strategies to restore the functional health of degraded soils. His research focuses on increasing our fundamental knowledge of the role of soil microorganisms in securing functional resilience across multiple land uses.
✉ **m.pawlett@cranfield.ac.uk**

© PRILL Mediendesign | Adobe Stock

REFERENCES

1. Roesch, L.F.W., Fulthorpe, R.R., Riva, A., Casella, G., Hadwin, A.K.M., Kent, A.D., Daroub, S.H., Camargo, F.A.O., Farmerie, W.G. and Triplett, E.W. (2007) Pyrosequencing enumerates and contrasts soil microbial diversity. *The ISME Journal*, 1 (4), pp. 283–290. Doi: 10.1038/ismej.2007.53.
2. Oldeman, L.R. (1992) Global extent of soil degradation, in *International Soil Reference and Information Centre Bi-Annual Report 1991-1992*, (pp. 19–36). The Netherlands: ISRIC. https://www.wur.nl/en/Publication-details.htm?publicationId=publication-way-343532383839 (Accessed: 6 August 2022).
3. United Nations Food and Agriculture Organization (2022) *Global symposium on soil erosion: key messages*. https://www.fao.org/about/meetings/soil-erosion-symposium/key-messages/en (Accessed: 16 August 2022).
4. Bullock, J.M., Fuentes-Montemayor, E., McCarthy, B., Park, K., Hails, R.S., Woodcock, B.A., Watts, K., Cornstanje, R. and Harris, J. (2021) Future restoration should enhance ecological complexity and emergent properties at multiple scales. *Ecography*, 2022 (e05780). doi: 10.1111/ecog.05780.
5. Singh, B.K., Quince, C., Macdonald, C.A., Khachane, A., Thomas, N., Al- Soud, W.A., Sørensen, S.J., He, Z., White, D., Sinclair, A., Crooks, B., Zhou, Z. and Campbell, C.D. (2014) Loss of microbial diversity in soils is coincident with reductions in some specialized functions. *Environmental Microbiology*, 16 (8), pp. 2408–2420. https://pubmed.ncbi.nlm.nih.gov/24422656 (Accessed: 6 August 2022).
6. Yang, F., Niu, K., Collins, C.G., Yan, X., Ji, Y., Ling, N., Zhou, X., Du, G., Guo, H. and Hu, S. (2019) Grazing practices affect the soil microbial community composition in a Tibetan alpine meadow. *Land Degradation & Development*, 30 (1), pp. 49–59. https://doi.org/10.1002/ldr.3189 (Accessed: 6 August 2022).
7. Tsiafouli, M.A., Thébault, E., Sgardelis, S.P., de Ruiter, P.C., van der Putten, W.H., Birkhofer, K., Hemerik, L., de Vries, F.T., Bardgett, R.D., Brady, M.V., Bjornlund, L., Jørgensen, H.B., Christensen, S., D'Hertefeldt, T., Hotes, S., Gera Hol, W.H., Frouz, J., Liiri, M., Mortimer, S.R., Setälä, H. *et al.*, (2015) Intensive agriculture reduces soil biodiversity across Europe. *Global Change Biology*, 21 (2), pp. 973–985. https://pubmed.ncbi.nlm.nih.gov/25242445 (Accessed: 6 August 2022).
8. Qiu, L., Zhang, Q., Zhu, H., Reich, P.B., Banerjee, S., van der Heijden, M.G., Sadowsky, M.J., Ishii, S., Jia, X., Shao, M., Liu, B., Jiao, H., Li, H. and Wei, X. (2021) Erosion reduces soil microbial diversity, network complexity and multifunctionality. *The ISME Journal*, 15, pp. 2474–2489. https://doi.org/10.1038/s41396-021-00913-1 (Accessed: 6 August 2022).
9. Soliveres, S., van der Plas, F., Manning, P., Prati, D., Gossner, M.M., Renner, S.C., Alt, F., Arndt, H., Baumgartner, V., Binkenstein, J., Birkhofer, K., Blaser, S., Blüthgen, N., Boch, S., Böhm, S., Börschig, C., Buscot, F., Diekötter, T., Heinze, J. *et al.*, (2016) Biodiversity at multiple trophic levels is needed for ecosystem multifunctionality. *Nature*, 536 (7617), pp. 456–459. https://pubmed.ncbi.nlm.nih.gov/27533038 (Accessed: 6 August 2022).
10. Banerjee, S., Walder, F., Büchi, L., Meyer, M., Held, A.Y., Gattinger, A., Keller, T., Charles, R. and van der Heijden, M.G. (2019) Agricultural intensification reduces microbial network complexity and the abundance of keystone taxa in roots. *The ISME Journal*, 13, pp. 1722–1736. https://www.nature.com/articles/s41396-019-0383-2 (Accessed: 6 August 2022).
11. Wubs, E.R., van der Putten, W.H., Bosch, M. and Bezemer, T.M. (2016) Soil inoculation steers restoration of terrestrial ecosystems. *Nature plants*, 2 (16107). https://pubmed.ncbi.nlm.nih.gov/27398907 (Accessed: 6 August 2022).

FEATURE

The UK and international policy frameworks: a new dawn?

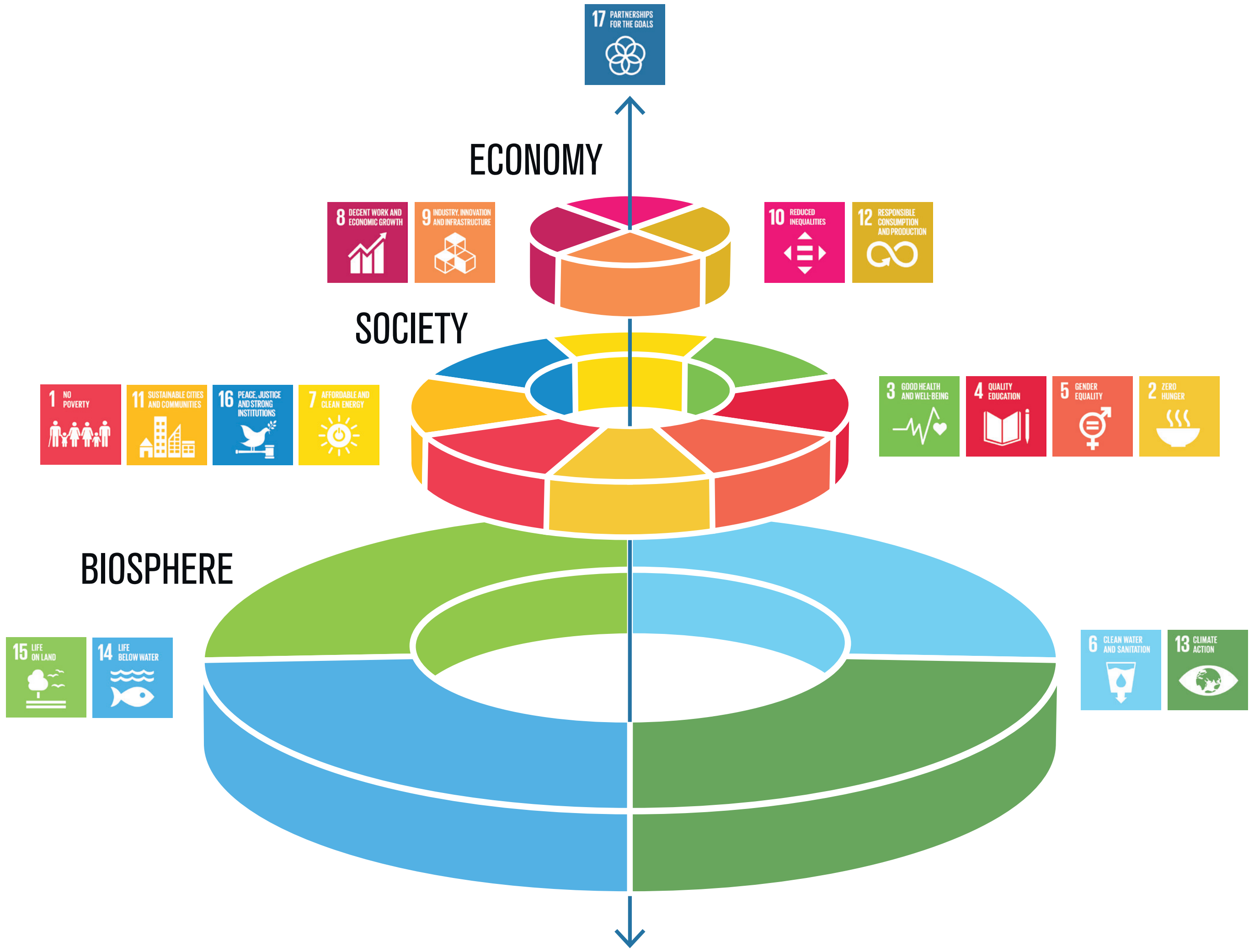
Ben McCarthy and **Jim Harris** consider how policy frameworks can help or hinder ecosystem restoration efforts.

As we edge ever forward through the United Nations' (UN) Decade on Ecosystem Restoration[1] there is increasing attention being paid to the adequacy or otherwise of policy instruments, support tools and methodologies in the field of biodiversity and ecosystem functions and services.[2] Quantitative commitments on restoration under the Rio Conventions[3] and the Bonn Challenge[4] have been submitted by 115 countries; the total area of all restoration commitments by countries is close to 1 billion hectares, almost half of which are in sub-Saharan Africa, but how these intentions are to be turned into reality is not yet clear.[5]

The EU, for example is considering a nature restoration law,[6] which would require Member States to revive forests, wetlands and other seascapes and landscapes transformed by human development. This may act as an exemplar and catalyst for other regions and nation states, holding out for the prospect of legally binding restoration targets. The Society of Ecological Restoration has published principles and standards for ecological restoration,[7] with a clear directive that the goal of ecological restoration is based on native reference ecosystems exclusively; however, this goal is contested,[8] as the lack of such sites in heavily transformed areas, including most of western Europe, coupled with the increasing pressures of climate change make such targets unattainable. Rather, guidelines and principles aimed at restoring ecosystem integrity, and connection with society, is something also worth pursuing and attainable everywhere. This does not, of course, rule out restoration to native systems as the principal priority where possible. How to enshrine this broad approach into law is a real and pressing challenge.

While others cast a light on the future of statutorily protected sites in England, we set out the key biodiversity policy frameworks to support ecological restoration and ask: is it adequate?

The requirement to 'rehabilitate and restore degraded ecosystems and promote the recovery of threatened species' was bound into Article 8 of the UN's Convention on Biological Diversity (CBD) that has provided an overarching global framework in pursuit of sustainable development since 1992.[9] While earlier references to nature conservation can be found – such as the 1979 Bern Convention on the Conservation of European Wildlife and Natural Habitats – it is arguably the CBD and UN's subsequent sustainable development goals – introduced in 2015 – that have brought into sharp focus the fundamental dependence on a healthy global biosphere to support society.



▲ **Figure 1. The sustainable development goals 'wedding cake' model showing the dependency hierarchy: the economy depends on society, which in turn depends on the biosphere. (© Azote for Stockholm Resilience Centre, Stockholm University)**

With growing public awareness and the building of political consensus of the critical need to 'halt, prevent and reverse ecosystem degradation',[1] the UN supported the implementation of the UN Decade on Ecological Restoration in 2020 to halt and reverse ecosystem degradation, aiming to restore ecosystem services and recover biodiversity. This declaration and ensuing policy instrument were reinforced by the influential Dasgupta Review on the Economics of Biodiversity,[10] which made the case that our economies are embedded within nature (rather than external to it) and called for transformative change to 'increase nature's supply relative to current levels' since the economy and society are completely dependent on the biosphere, as recognised by the UN sustainable development goals (see **Figure 1**).

Such economic framing has helped shift policy in Europe and the UK with the advancement of initiatives such as Natural Capital Accounting and new policy instruments that seek to explicitly provide public payment for public goods and incentivise the restoration of biodiversity through mechanisms such as land use change.

The EU's response to the Bern Convention and other international obligations has been the 1992 Habitats Directive, which forms the cornerstone of European nature policy. The directive takes a proportionate and elegant approach to maintaining or restoring habitat types of community interest to meet conservation objectives framed around defined favourable conservation status. The guidance and case law that underpin the directive provide a robust and effective means of protecting sites and species of international importance while making provision, through the setting of conservation objectives, for qualifying features to be 'subject to natural change'. Such provision for natural dynamic processes has been reflected in practice with, for example, the inclusion of bare land to allow rollback of coastal features due to sea level rise.[11]

Closer to home and in the run-up to the CBD COP15, the UK Government signed up to the Leaders' Pledge for Nature with a commitment to protect and effectively manage 30 per cent of the land and sea by 2030. This builds on the Government's 25 Year Plan to Improve the Environment[12] that set out a new and ambitious nature framework for England. The subsequent Environment Act 2022 and associated targets are due to be achieved through five-yearly Environmental Improvement Plans, although the policy guidance and instruments on these are currently unclear.

While we wait to see how the policy framework fully unfolds in England, the *Nature Recovery Green Paper* raised a series of concerns that may result in a diminution of environmental protection and a failure to realise the benefits restored nature delivers for society. These concerns include a lack of detail, with potentially weakened protections for certain species and sites, and a loss of coherence and effectiveness.[13] The green paper also suggests that the Defra secretary of state be given sole power for designating protected sites – essentially being able to overrule the evidence-based process used by Natural England, where the power to designate sites of special scientific interest currently resides. What is more, local authorities may be ill-equipped to manage the planning regime to ensure effective restoration of high-quality habitat.[14]

While inevitably trailing somewhat behind the science of restoration ecology, there has been a clear evolution of nature policies to underpin the conservation of biodiversity and the ecosystems it supports. However, as global change intensifies, it is increasingly unrealistic that future environmental conditions will reflect those of the past. Such a stark outlook begs the question: to what extent should we be conserving our currently in situ biodiversity rather than securing the functionality and global biodiversity of future nature to meet the societal needs of tomorrow? In this regard, there is still much to do. ES

Ben McCarthy is an ecologist working as Head of Nature Conservation & Restoration Ecology at the National Trust. This role involves realising the Trust's ambition for nature and nature-based climate solutions, contributing towards building the evidence and Trust's reputation as a leading UK nature conservation organisation.

Professor Jim Harris is a systems ecologist interested in system complexity, function and emergent properties – particularly resilience and how the principles learned from ecology can be applied to the Five Capitals of our socio-ecological system. He principally works in soil microbiology, restoration ecology and ecosystem service research in relation to ecosystem processes.

REFERENCES

1. United Nations General Assembly (2019) *United Nations Decade on Ecosystem Restoration (2021–2030).* Resolution A/RES/73/284. Available at: https://digitallibrary.un.org/record/3794317?ln=en (Accessed: 6 August 2022).
2. Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES) (2019) *Global Assessment Report on Biodiversity and Ecosystem Services,* in E. Brondizio, S. Diaz, J. Settele and H.T. Ngo (eds). https://doi.org/10.5281/zenodo.3831673 (Accessed: 29 July 2022).
3. United Nations (no date) *Rio Conventions.* https://www.unccd.int/convention/partners/rio-conventions (Accessed: 11 August 2022).
4. Bonn Challenge (no date) Home page. https://www.bonnchallenge.org/ (Accessed: 11 August 2022).
5. Sewell, A., van der Esch, S. and Löwenhardt, H. (2020) *Goals and Commitments for the Restoration Decade: A Global Overview of Countries' Restoration Commitments under the Rio Conventions and Other Pledges.* The Hague: PBL Netherlands Environmental Assessment Agency. https://www.pbl.nl/sites/default/files/downloads/pbl-2020-goals-and-commitments-for-the-restoration-decade-3906.pdf (Accessed: 7 August 2022).
6. European Commission. Directorate-General for Environment (2022) *Proposal for a nature restoration law.* https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en (Accessed: 16 August 2022).
7. Gann, G.D., McDonald, T., Walder, B., Aronson, J., Nelson, C.R., Johnson, J., Hallet, J.G., Eisenberg, C., Guariguata, M.R., Liu, J., Hua, F., Echeverria, C., Gonzalez, E., Shaw, N., Decleer, K. and Dixon, K.W. (2019) International principles and standards for the practice of ecological restoration. *Restoration Ecology,* 27 (S1), pp. S1–S46. https://onlinelibrary.wiley.com/doi/10.1111/rec.13035 (Accessed: 7 August 2022).
8. Higgs, E., Harris, J., Murphy, S., Bowers, K., Hobbs, R., Jenkins, W., Kidwell, J., Lopoukhine, N., Sollereder, B., Suding, K., Thompson, A. and Whisenant, S. (2018) On principles and standards in ecological restoration. *Restoration Ecology,* 26 (3), pp. 399–403. Doi: 10.1111/rec.12691.
9. Convention on Biological Diversity (2016) *Text of the convention.* https://www.cbd.int/convention/text/ (Accessed: 16 August 2022).
10. Dasgupta, P. (2021) *The Economics of Biodiversity: The Dasgupta Review.* London: Her Majesty's Treasury. https://www.gov.uk/government/publications/final-report-the-economics-ofbiodiversity-the-dasgupta-review (Accessed: 29 July 2022).
11. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31992L0043&qid=1660158066475 (Accessed: 10 August 2022).
12. Department for Environment, Food and Rural Affairs (2018) *A Green Future: Our 25 Year Plan to Improve the Environment.* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf (Accessed: 6 August 2022).
13. British Ecological Society (2022) *Nature recovery green paper: protected sites and species.* https://www.britishecologicalsociety.org/nature-recovery-green-paper-protected-sites-and-species/ (Accessed: 7 August 2022).
14. Snell, L. and Oxford, M. (2021) *Survey of Local Planning Authorities and their Ability to Deliver Biodiversity Net Gain in England.* Report prepared for the Association of Local Government Ecologists. https://www.alge.org.uk/wp-content/uploads/sites/15/2022/06/ALGE-ADEPT-Report-on-LPAs-and-BNG-2022.pdf (Accessed: 7 August 2022).

Supporting climate resilience for nature in our network of protected sites

© drhfoto | Adobe Stock

ANALYSIS

Simon Duffield, **Humphrey Crick**, **Mike Morecroft** and **Kim Owen** look at the role of protected sites in tackling climate change.

Since the days of King Canute in the 11th century, we have known that there is no way to stop the rising tide. In the same way, it has become increasingly apparent even if all greenhouse gas emissions were to stop today, the inertia in the system means that the climate will continue to change for some time to come and that responding to climate change will require action that considers how to manage that inevitable change.[1]

SITES OF SPECIAL SCIENTIFIC INTEREST

Protected areas have been central to efforts to protect biodiversity since the advent of modern conservation. In the UK, the suite of sites of special scientific interest (SSSIs) has played this role since their establishment through the National Parks and Access to the Countryside Act in 1949. Such sites include the Wash at over 63,000 ha, down to others that are no more than a few square metres in size.

SSSIs protect a representative sample of species and habitats across the country. However, in the face of rapid climate change, an approach that seeks to protect a small number of sites in fixed locations, assessed against the presence of species and habitats that were present at the time of designation, is unlikely to be optimal.

For this reason, and to help inform a wider review of protected areas, Natural England is assessing the current impact of climate change on the condition of each SSSI, reviewing the ability of the existing legal framework to respond to current and projected future impacts, and asking questions such as: if starting from scratch, would this site be designated? What should it be designated for? How will success be determined, and progress monitored?

Early results from reviewing around 150 units in 66 SSSIs (a unit being a discrete part of a SSSI) suggest that climate change is already a contributory factor in the poor condition of over three-quarters of these and a major factor in close to a third. Looking ahead, it suggests that climate change will be a major threat to the condition of over 90 per cent of the units covered in this preliminary survey. While these units are expected to remain important places for conservation, the species and habitats present are likely to be different from those present when the site was first designated.

When considering whether the impact of climate change on the condition of a SSSI can be addressed within the existing legal framework or if a new approach is required, several key issues need to be considered.

WIDER FUNCTIONAL NETWORKS

For an individual SSSI, some of the species it supports are likely to increase, others will decrease, some will disappear altogether, and others still will move in. This increasing dynamism is problematic under a system that uses a historic baseline of species presence and abundance to determine whether a site is in 'favourable' condition. From a conservation perspective, this becomes less of an issue when the entire range of a species is considered – so long as it is viable in other parts of the protected site network, it may be considered adequately protected.

Thus, one conclusion would be to consider individual sites as components of a wider functional network.[2] Species targets could be assessed across the entire network and species range rather than considering sites individually on a one-by-one basis. Management objectives could then be set at the network scale and linked to wider targets. Indeed, SSSIs are now being considered as a key part of a national Nature Recovery Network for England and such considerations will inform the development of this network.[3]

For example, a major review carried out by Professor Sir John Lawton and a team of experts in 2010 called Making Space for Nature concluded that the current network of protected sites was neither resilient nor coherent.[4] The report highlighted the need to make sites better, bigger, with more of them and joining them up to improve the functional connectivity of the network and therefore its resilience. Connectivity is important within landscapes so that localised populations can support each other through movement between sites, and action to promote this has been the goal of much activity since the report's publication. But to help species adapt to long-term climate change, we increasingly need to consider directional connectivity to promote long-distance movement across landscapes, thus enabling species to track climate change. Such consideration may prioritise different locations to those needed to promote within-landscape movement, and these would be a novel addition to the current set of criteria used when identifying potential additions to the SSSI network.

A FOCUS ON EXISTING SPECIES RANGE

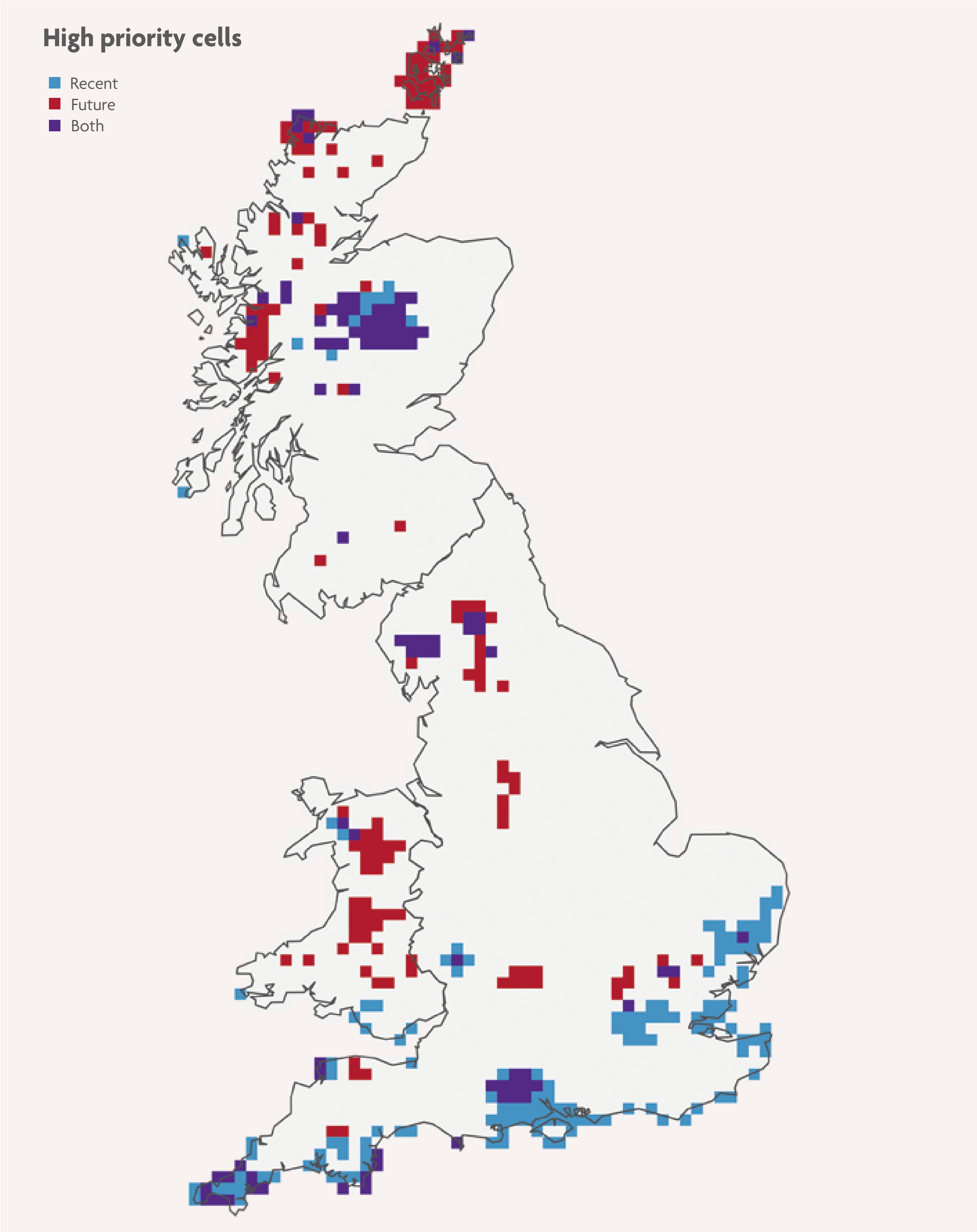
On the flipside to action that encourages the movement of species to track climate change is action to encourage the persistence of species within their existing range. One way of doing this is to identify and protect parts of the landscape where the rate of climate change is at its slowest. Such areas have the potential to act as climate change refugia. These can occur where a range of factors reduce the amount of warming – such as proximity to the coast, inland water bodies and cool air flows – or in areas that experience cooler microclimates – such as north-facing slopes or mountains. Evidence suggests that climate refugia do exist in England now, with lower extinction rates than in other areas of the country that have warmed more rapidly.[5,6]

In terms of our response, action is required at both site and network levels. At the site level, one of the simplest approaches to help the SSSI network become more climate-ready would be the judicious and evidence-led adjustment of targets for sites as conditions change: taking account of when new species of conservation interest arrive, or when climate-driven changes in distribution mean that species are lost. However, due to the current fixed nature of how a SSSI is designated – i.e. in terms of its features (species or habitats) – renotification would be required, which is a lengthy and difficult process. However, many SSSIs are also defined by the presence of iconic species or habitats, the loss of which is likely to have an impact that is broader than a solely ecological one – for example, a SSSI may be important for local tourism. It is therefore important that wider society is fully engaged with decisions on how sites are designated, managed and assessed.

▲ **Mudflat forming on former flood plain grazing marsh. Horsey Island, Devon. (© Simon Duffield, Natural England)**

▲ **Scrub on grassland providing microrefugia and shading. South Dorset Coast site of special scientific interest, Dorset. (© Simon Duffield, Natural England)**

ANALYSIS



▲ **Figure 1. Systematic conservation planning, showing the top 10 per cent of priority areas for 4,447 species from 18 different taxonomic groups (from bryophytes to birds) under the present climate conditions and under a future scenario of 4°C global warming.[8]**

ANALYSIS

BROADER ECOSYSTEM FUNCTION

At the other end of the spectrum, an approach to designation based on broader ecosystem function could address the issues of species and place. For example, a site could be designated on the basis of soils that are not impacted by nutrient inputs or pesticides, allowing a range of species of conservation concern to flourish, regardless of the exact species composition. At the network scale, locations can be identified based on their increasing potential to support priority species for conservation due to changing species distributions or the role they could play in encouraging persistence or connectivity. This could include locations that are currently degraded or under different land uses altogether that have the potential for ecosystems and habitats to be restored or created.

SYSTEMIC CONSERVATION PLANNING

The multiple drivers and amount of underpinning data, plus the complex interactions with societal values and choices, mean that our approach to the identification of prospective sites will also need to change. One approach that is being trialled in England is systematic conservation planning,[7] which seeks to identify those sites that will support a comprehensive, adequate and resilient Nature Recovery Network (see **Figure 1**). Such a network would cover all the biodiversity areas of importance and would be adequate in terms of providing enough resource to support populations in the long term. The beauty of systematic conservation planning is that it allows other factors to be included, so that competing interests of, say, agriculture and recreation can be included without losing biodiversity interest. It is a transparent process that involves significant inputs at all stages so that stakeholders feel they have ownership of the results.

The programme to review the SSSI system is currently in its early stages and the issues highlighted will need to be considered as part of wider reform. However, the challenge of climate change is only going to increase, and the evidence suggests that a new approach is a necessity to support the resilience of the natural environment in the face of increasing dynamism and transformative change. **ES**

Dr Simon Duffield is a Senior Climate Change specialist at Natural England. With a focus on climate change adaptation, he works to ensure that the threat posed by climate change is reflected in policy and delivery through an understanding of its impact on the natural environment and the effectiveness of our responses.

Dr Humphrey Crick is Principal Specialist in Conservation Ecology in the Chief Scientist's Directorate of Natural England. He is working on the development of nature networks and the use of systematic conservation planning and led on the production of Natural England's Nature Networks Evidence Handbook.[2]

Dr Mike Morecroft is an ecologist and Principal Specialist in Climate Change at Natural England, where he leads on the development of science and evidence to support climate change adaptation and mitigation in the natural environment. He is a Coordinating Lead Author on ecosystems for the Intergovernmental Panel on Climate Change.

Dr Kim Owen is an ecologist and manages the SSSI Future Reforms project for Natural England. The project is investigating whether the legal framework for SSSIs has enough flexibility to support the natural world's adaptation to climate change.

REFERENCES

1. Natural England (2020) *Climate Change Adaptation Manual (NE751).* http://publications.naturalengland.org.uk/publication/5679197848862720 (Accessed 10 August 2022).
2. Natural England (2020) *Nature Networks Evidence Handbook (NERR081).* http://publications.naturalengland.org.uk/publication/6105140258144256 (Accessed: 11 August 2022).
3. Department for Environment, Food and Rural Affairs (2018) *A Green Future: Our 25 Year Plan to Improve the Environment.* https://www.gov.uk/government/publications/25-year-environment-plan (Accessed: 16 August 2022).
4. Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J. and Wynne, G.R. (2010) *Making Space for Nature: A Review of England's Wildlife Sites and Ecological Network.* Technical Report to Defra. https://www.researchgate.net/publication/268279426_Making_Space_for_Nature_A_Review_of_England%27s_Wildlife_Sites_and_Ecological_Network (Accessed: 1 August 2022).
5. Suggitt, A.J., Wilson, R.J., August, T.A., Beale, C.M., Bennie, J.J., Dordolo, A., Fox, R., Hopkins, J.J., Isaac, N.J.B., Jorieux, P., Macgregor, N.A., Marcetteau, J., Massimino, D., Morecroft, M.D., Pearce-Higgins, J.W., Walker, K. and Maclean, I.M.D. (2014) *Climate Change Refugia for the Flora and Fauna of England.* Sheffield: Natural England. https://nora.nerc.ac.uk/id/eprint/509452/ (Accessed: 1 August 2022).
6. Maclean, I.M.D., Hopkins, J.J., Bennie, J., Lawson, C.R. and Wilson, R.J. (2015) Microclimates buffer the responses of plant communities to climate change. *Global Ecology and Biogeography*, 24 (11), pp. 1340–1350. https://doi.org/10.1111/geb.12359 (Accessed: 1 August 2022).
7. Margules, C.R. and Pressey, R.L. (2000) Systematic conservation planning. *Nature*, 405, pp. 243–253. https://doi.org/10.1038/35012251 (Accessed: 17 August 2022).
8. Critchlow, R., Cunningham, C.A., Crick, H.Q.P., Macgregor, N.A., Morecroft, M.D., Pearce-Higgins, J.W., Oliver, T.H., Carroll, M.J. and Beale, C.M. (2022) Multi-taxa spatial conservation planning reveals similar priorities between taxa and improved protected area representation with climate change. *Biodiversity and Conservation,* 31, pp. 683–702.

New members and re-grades

Fellow

is for esteemed individuals in environmental science and sustainability who are held in high regard by their peers.

Craig Love – Associate Director, Climate Impact Assessment & Reporting

Member

is for those individuals who have substantial academic and work experience within environmental science.

Zadie Astill – Principal Air Quality Scientist
Emmanuel Awulu – Student
Lucy Baker – Environmental Consultant
Kieran Barry – Environmental Scientist
William Bennett – Senior Geo-environmental Consultant
Simon Clarke – Head of Catchment Management & Water Quality
Simon Collin – Geo-environmental Engineer
David Copeland – Co-Director & Sustainable Business Development
Adam Dawson – Senior Consultant
Kerry Dinsmore – Principal Scientific Advisor
Thomas Evans – Project Manager
Lee Faulkner – Associate Director - Acoustics
Katherine Fawcett – Consultant
Emily Foster – Senior Environmental Consultant
James Gooding – Senior Consulting Engineer
Lisa Gordon – Senior Environmental Consultant
Siddharth Grover – Noise, Vibration & Air Quality Lead
Ibrahim Haruna – Intermediate Environmental Consultant
James Hayward – Project Manager
Valerie Heffernan – Environmental Scientist
Rima Isaifan – Researcher & Joint Faculty Associate Professor
Meenu Jain – Process Engineer
Natalie Jones – Senior Consultant
Hiu Yau Lam – Consultant
Hannah Leggatt – Senior Environment Manager
Craig MacGarvie – Environmental Manager
Isabella Marshall – Project Manager & Senior Geo-environmental Engineer
Kirsty McKenzie – Environmental Health Officer
Abdulla Moussa – Consultant, Air Quality & Permitting
Shaik Muneer Ul Rahman – Environmental Manager
Roger Newman – Environmental Protection Officer
Joe Nightingale – Senior Consultant
Aine O'Brien – Environmental Pollution Control Office
Uchenna Onyeizu – Logistics manager
Emma Painter – Senior Geo-environmental Consultant
Ben Parkes – Research Fellow
Lucy Price – Environmental Scientist
Jeanette Rotchell – Professor of Aquatic Toxicology
Nicola Sellars – Senior Geo-environmental Consultant
Emma Thomas – Sustainability & Climate Change Manager
Carl Todd – Multi-Skilled Operator
Craig Tyrrell – Assistant Geo-environmental Consultant
Timothy Wallis – Forensic Scientist
James Tsz Fung Wong – Environmental Protection Officer
Nantanella Yerushalmi – Senior Environmental Consultant

Associate

is for individuals beginning their environmental career or those working on the periphery of environmental science.

Athanasios Antonopoulos – Health, Safety & Environmental Engineer
Liam Bryan – Acoustics Consultant
Leticia Campello – Air Quality Consultant
Alexander Child – Assistant Head Environmental Protection
Matthew Clegg – Environmental Scientist
Zoe Cullerne – Graduate Geo-environmental Consultant
Tshepo Dibonwa – Graduate
Andrew Dobbs – Director
Levent Dogan – Director
Bethany Elliott – Geo-environmental Engineer
Lucia Grimm – Graduate Environmental Scientist
Ann Gwyther – Senior Consultant
Shauna Lackenby – Student
Hannah Lillis – Graduate Air Quality Consultant
Magnus MacFarlane – Graduate Environmental Consultant
Brendan McCormack – Undergraduate Air Quality Consultant
Katie Neary – Environmental Consultant
Racheal Nowakowski – Technical Director (Hairdresser)
Georgia Piggott – Environmental Consultant
Maria Sol Quintero Rodriguez – Operations & Safety Consultant
Amina Reeb – Graduate Consultant
Jack Stapeley – C2 Environmental Consultant
Rachael Stiles – Senior Air Quality Consultant
Ellena Thomson – Senior Environmental Consultant
Max Tuzinkiewicz – Graduate Environmental Consultant
Emma Tyson – Environmental Scientist
Jennifer Webb – Senior Environmental Consultant
Joshua Willoughby – Graduate Air Quality Consultant
William Wrench – Assistant Consultant

Affiliate

is for individuals with an interest in environmental issues but who don't work in the field, or for students on non-accredited programmes.

Christian Anisiobi – Student
Alexander Britten – Manufacturing Projects Engineer
Megan Hatwell – Student
Christian Hendriksen – CEO
Alex Huntley – Student
Claire Ling – Community Project Officer
Megan Walsh – Student
Yi Zhang – Summer Placement Environment

Not a member?

Whatever stage of your career you are at, the IES has membership services that will help you gain recognition and progress to the next level. Members come from all areas of the environmental sector, wherever their work is underpinned by science.

Time for a re-grade?

If your career has progressed recently it could be time for a re-grade to reflect your success.

Re-grading can take place at any time of the year. Re-grading from Associate to Full Member means that you can apply for Chartership. There's never been a better time to take the next step in your career.

Eligible for chartership?

If you have been building your career for four years or more, now could be the right time to become Chartered.

Chartered status is a benchmark of professionalism and achieving this will see you join the ranks of the best environmental scientists in the sector. The IES awards two Charterships: Chartered Scientist and Chartered Environmentalist. We also offer the REnvTech register.

Contact Us

To find out more about membership or chartership, get in touch.

info@the-ies.org
+44 (0)20 3862 7484
www.the-ies.org
@IES_UK

Will biodiversity net gain lead to ecosystem restoration?

Christopher Nichols, **Rebecca Pullinger**, **Ben McCarthy**, **Neil Riddle**, **Sam Lattaway** and **Nick White** examine the complexity of biodiversity net gain policies in ecosystem restoration.

As environmental scientists, few of us will argue with the need to act rapidly to halt and reverse the loss of biodiversity. The threats are well-known: habitat loss, habitat fragmentation and invasive non-native species, to name but a few, all of which can be associated with land use change and development such as roads, railways and housing. Across the world, planners, politicians and environmental scientists are investigating how to reconcile the impact development has on our natural world with the need not only to protect what we have left but to also support its recovery.

RECONCILING NATURE RECOVERY AND DEVELOPMENT

Biodiversity net gain is an approach to development that aims to leave biodiversity in a better state than it was in before development took place. Building on examples of biodiversity offsetting from across the globe, the UK Government, through the Environment Act 2021, has introduced a mandatory requirement for a minimum 10 per cent biodiversity net gain for most future developments in England, expected to come into force in late 2023. (Exempted development, such as permitted developments, in England will not have to meet this requirement.) But how will this admirable ambition work in practice?

An assessment of whether a biodiversity net gain will be achieved is made at the planning application stage, or as part of the Development Consent Order process for large infrastructure projects. While this is essential to ensure a baseline is set, there is also a need to predict future ecological outcomes. The assessment process relies on pre-application habitat surveys of the project site that are then used to produce an overall biodiversity unit score using the government's biodiversity metric calculator.[1] The calculation is then repeated based on the habitat that will be retained and enhanced, as well as any newly created habitats that will form part of the wider impact of the development, both onsite or offsite. The existing baseline biodiversity units at the site will

ANALYSIS

© yanikap | Adobe Stock

then be compared with the predicted post-development units to determine whether the required minimum biodiversity net gain will be met. The planning authority will then consider this alongside all other planning requirements for the proposed scheme when determining whether to grant planning consent.

RESTORATION AND ECOLOGICAL COMPLEXITY

Biodiversity net gain is one tool at our disposal to help nature recovery at a landscape scale. The Making Space for Nature principles of *bigger*, *better*, *more and joined up* are often cited as a blueprint for tackling the biodiversity crisis.[2] We need to improve the quality of current wildlife sites, increase current site size, enhance connections between them, create new sites and reduce the pressures on wildlife by improving the environment at a landscape scale. Arguably, the most important of these principles is aiming for *better* habitats. But what makes a high-quality habitat for wildlife?

Despite an increase in interest in landscape restoration and overall increase in the UK's tree canopy cover throughout the 20th century, woodland wildlife continues to decline.[3] What is wrong with all these newly restored ecosystems? An assessment of woodland ecological condition in Great Britain by Forest Research indicated that just 7 per cent of native woods were in favourable ecological condition, a measure of habitat quality.[4]

Ecological condition is the state of an ecological system and its suitability for supporting biodiversity. Factors that influence the ecological condition of woodland include, for instance, the diversity of tree species present and how varied their physical structure is – in other words, how complex the environment is on a three-dimensional level: are there abundant opportunities for wildlife to thrive and niches for diverse species to live naturally? Is there deadwood left for fungi and invertebrates to flourish on? Do veteran and ancient trees exist with all their cracks and crevices to serve as nests for bats and birds?

However, our thinking on what makes better, higher-quality habitats is progressing, and we are looking beyond observable ecosystem traits to examine how they function and how resilient they are. Are natural processes playing out as they should – for example, nutrient cycling and pollination? How well does the ecosystem respond to change? This broader way of thinking about habitat quality and condition comes down to how complex the habitats within a landscape are. The definition of ecological complexity need not be complex itself. Simply defining it as the number of components in a system, their physical arrangement and the number of connections among them allows *components* to encompass species, structural diversity of vegetation, functional groups etc., and *connections* to include species interactions and connectivity between habitat patches.[5]

WILL BIODIVERSITY NET GAIN POLICIES WORK?

The biodiversity metric used to calculate biodiversity units includes a range of variables to assign scores to different habitats. Each habitat patch within a proposed development is surveyed, and data such as habitat condition and distinctiveness are inputted along with the habitat size and location. The resultant biodiversity units incorporate risk variables arising from the development and give an estimate of the value of habitats now and in the future, once development has taken place. While some of the factors used to calculate the biodiversity metric may result in habitat restoration or creation in a strategic location that is beneficial to producing functioning ecosystems, the metric is not designed to fully measure the potential complexity of ecological processes that will eventually be delivered.

This approach can lead to trade-offs: perhaps a reduction in the total habitat area, but with the promise of higher-quality habitat in the future. Indeed, analysis of early adoption of local net gain policies in England showed a 34 per cent reduction in the area of non-urban habitats, generally compensated by commitments to deliver smaller areas of higher-quality habitat years later.[6]

MARRYING RESTORATION COMPLEXITY AND NET GAIN

The first step to achieving successful net gain is to follow the mitigation hierarchy, which puts emphasis on the protection of important habitats and ecological networks in the first place. The metric does this by assigning a value to all habitats found within the proposed development footprint based on their relative distinctiveness – a measure of the quality and value of a habitat. There is recognition that there are irreplaceable habitats where the ecological complexity and time it takes to develop a functioning ecosystem mean that biodiversity net gain cannot be achieved where these habitats are damaged by development; ancient woodland, blanket bog and lowland fen for example, are exempt from biodiversity net gain calculations. But for these irreplaceable habitats, it is acknowledged that the biodiversity metric should be treated as a supporting tool rather than the sole basis for agreeing compensation requirements.

Spatial mapping tools will be essential if biodiversity net gain is to both avoid harm to these important, irreplaceable habitats and ensure nature is in a better state than before development. In addition, the new Local Nature Recovery Strategies in England will be an important tool to target the location and prioritisation of habitat creation and restoration at the landscape scale.

If implemented alongside the mitigation hierarchy, biodiversity net gain policies can benefit wildlife, and indeed have been shown to support landscape-scale restoration. In the Midlands National Forest, for instance,

ANALYSIS

© yanikap | Adobe Stock

22 per cent of all the forest created to date has come through the planning system. This example highlights a key factor when it comes to the ability of biodiversity net gain policies to enhance landscape restoration. The National Forest has been created by an organisation whose aim is to implement, manage and fund landscape restoration in the Midlands. A development policy of leaving the land in better condition than before is only likely to be successful if there is sufficient capacity factored in for future management and care – as is the case in the National Forest.

Landscape restoration is not merely the moment of planting a tree, or the decision not to mow a road verge; it is a long-term commitment to the upkeep and protection of that habitat long into the future. Habitat management is one of the most important factors for ensuring ecosystems show resilience and are on the trajectory to being in good ecological condition. Decisions on when and how to intervene will be instrumental for the ecological outcomes at new or existing sites in developers' crosshairs. Biodiversity net gain supports this by requiring that gains are managed and maintained for a minimum of 30 years, with those delivered offsite secured through a legal agreement and entered into a national register.

Mandatory biodiversity net gain will also require developers or landowners to undertake and submit regular management reports to the consenting body, or oversee the process, to demonstrate how the habitat is being managed and maintained in order to achieve what was initially predicted.

"Landscape restoration is not merely the moment of planting a tree, [...] it is a long-term commitment to the upkeep and protection of that habitat long into the future."

What happens to habitats after the minimum 30 years of management and maintenance stipulated by biodiversity net gain expires? For many habitats, such as woodland creation projects, trees will only just be reaching maturity; they will not yet have formed fully functioning, complex ecosystems. Vertical and horizontal three-dimensional complexity in the canopy and understory will likely still be in its infancy after 30 years. Complex woodland soil communities take many decades of continuity and lack of disturbance to form. The clue to the value of old-growth features such as veteran trees is in the name. Deadwood does not adhere to arbitrary deadlines. Thirty years is young when it comes to such landscape restoration initiatives. If they are to deliver nature recovery into the future, natural processes must be encouraged and maintained in the long term through management choices. Ecological restoration should aim for dynamism, turnover and change, not a static endpoint.

Long-term habitat management is a key determinant of ecological complexity. Ecosystems in the UK are under a barrage of increasing and compounding threats – from pests and diseases to overgrazing and pollution.[4] Enhancing ecological complexity via management choices, including minimum intervention where appropriate, will increase resilience to such threats, but only up to a point. Without a long-term commitment to habitat management and monitoring, there can be no assurances that a net gain in biodiversity will be realised or sustainable. **ES**

Dr Christopher Nichols is Conservation Evidence Manager at the Woodland Trust and is responsible for ensuring the Trust's work is underpinned by evidence. Chris oversees the Woodland Trust's Conservation Research Programme and Monitoring, Evaluation & Learning Framework.

Rebecca Pullinger MRTPI is Lead Policy Advocate for planning at the Woodland Trust. In this role she advocates for improving the protection of woodlands and trees, in particular ancient woodland and ancient and veteran trees, improved access to woods and trees and the recovery of nature through the planning system.

Ben McCarthy is an ecologist working as Head of Nature Conservation & Restoration Ecology at the National Trust. This role involves realising the Trust's ambition for nature and nature-based climate solutions, contributing towards building the evidence and Trust's reputation as a leading UK nature conservation organisation.

Neil Riddle is the Forestry Commission's National Head of Natural Environment specialising in woodland ecology and providing policy advice and evidence on habitats and wildlife to Government and other agencies. He is a chartered forester, woodland owner and a member of the British Ecological Society.

Sam Lattaway is the National Forest Company's Head of Landscape, Biodiversity & Research. In addition to leading on biodiversity, he also manages strategic aspects of the creation of the National Forest, including the use of the planning system to create woodlands and associated habitats.

Nick White is Principal Advisor, Net Gain for Natural England. Nick works across national and local government, and with developers, NGOs and academia to advance policy, practice and standards around net gain, focusing on biodiversity net gain legislation, the biodiversity metric and biodiversity net gain standards and guidance.

Acknowledgements

The authors would like to thank Sophus Zu Ermgassen, Kirsty Park, Kevin Watts and Jim Harris for their comments and support in writing this article.

REFERENCES

1. Natural England (2021) *Access to evidence: the biodiversity metric 3.1* (JP039). http://publications.naturalengland.org.uk/publication/6049804846366720 (Accessed: 1 August 2022).
2. Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J. and Wynne, G.R. (2010) *Making Space for Nature: A Review of England's Wildlife Sites and Ecological Network.* Technical Report to Defra. https://www.researchgate.net/publication/268279426_Making_Space_for_Nature_A_Review_of_England%27s_Wildlife_Sites_and_Ecological_Network (Accessed: 1 August 2022).
3. Reid, C., Hornigold, K., McHenry, E., Nichols, C., Townsend, M., Lewthwaite, K., Elliot, M., Pullinger, R., Hotchkiss, A., Gilmartin, E., White, I., Chesshire, H., Whittle, L., Garforth, J., Gosling, R., Reed, T. and Hugi, M. (2021) *State of the UK's Woods and Trees 2021.* Woodland Trust. https://www.woodlandtrust.org.uk/media/49731/state-of-the-uks-woods-and-trees-2021-the-woodland-trust.pdf (Accessed: 12 August 2022).
4. Forestry Commission (2020) *NFI Woodland Ecological Condition in Great Britain: Methodology.* Edinburgh: Forestry Commission. https://frwordpressmedia.blob.core.windows.net/staging/2022/02/fr_nfi_condition_scoring_methodology_dj8ftgq.pdf (Accessed: 1 August 2022).
5. Bullock, J.M., Fuentes-Montemayor, E., McCarthy, B., Park, K., Hails, R.S., Woodcock, B.A., Watts, K., Cornstanje, R. and Harris, J. (2021) Future restoration should enhance ecological complexity and emergent properties at multiple scales. *Ecography*, 2022 (e05780). doi: 10.1111/ecog.05780.
6. zu Ermgassen, S.O.S.E., Marsh, S., Ryland, K., Church, E., Marsh, R. and Bull, J.W. (2021) Exploring the ecological outcomes of mandatory biodiversity net gain using evidence from early-adopter jurisdictions in England. *Conservation Letters*, 14 (6). https://doi.org/10.1111/conl.12820 (Accessed: 1 August 2022).

FEATURE

Restoration and resilience: soils, climate and nature

Clive Mitchell examines how changing our use of soils and nature can lead to a more balanced climate.

OUR BROKEN CARBON CYCLE

Our global carbon cycle is broken. The climate–nature crisis is the result of a short-circuiting of the carbon cycle through the burning of fossil fuels (about 70 per cent) and land use change (about 30 per cent).

SOIL, NATURE AND THE CLIMATE EMERGENCY NOW

Our economy is directly based on fossil fuel extraction and use (see **Figure 1a**). Peatlands are drained and degraded, deer suppress the restoration of peatlands and woodlands, woodlands are mostly commercial plantations, grasslands for livestock are mostly fed by synthetic fertilisers, our monoculture lowlands are managed by heavy machinery with most trees and hedges removed, flood plains are prevented from flooding, urban areas have little greenspace, especially in poorer areas, coastal habitats such as salt marsh, seagrass and kelp have been diminished, and the seabed is widely disturbed. Overall, our landscapes are simple.

Carbon that would normally be stored for hundreds and thousands of years (in soils and sediments) or millions of years (in fossil fuels) is now being returned to the atmosphere in a matter of years. For the climate such releases are catastrophic.

Land-based emissions result from a progressive simplification from more biodiverse to less biodiverse systems, including monocultures and the drainage of wet, carbon-rich soils in particular, leading to systematic ecosystem degradation.

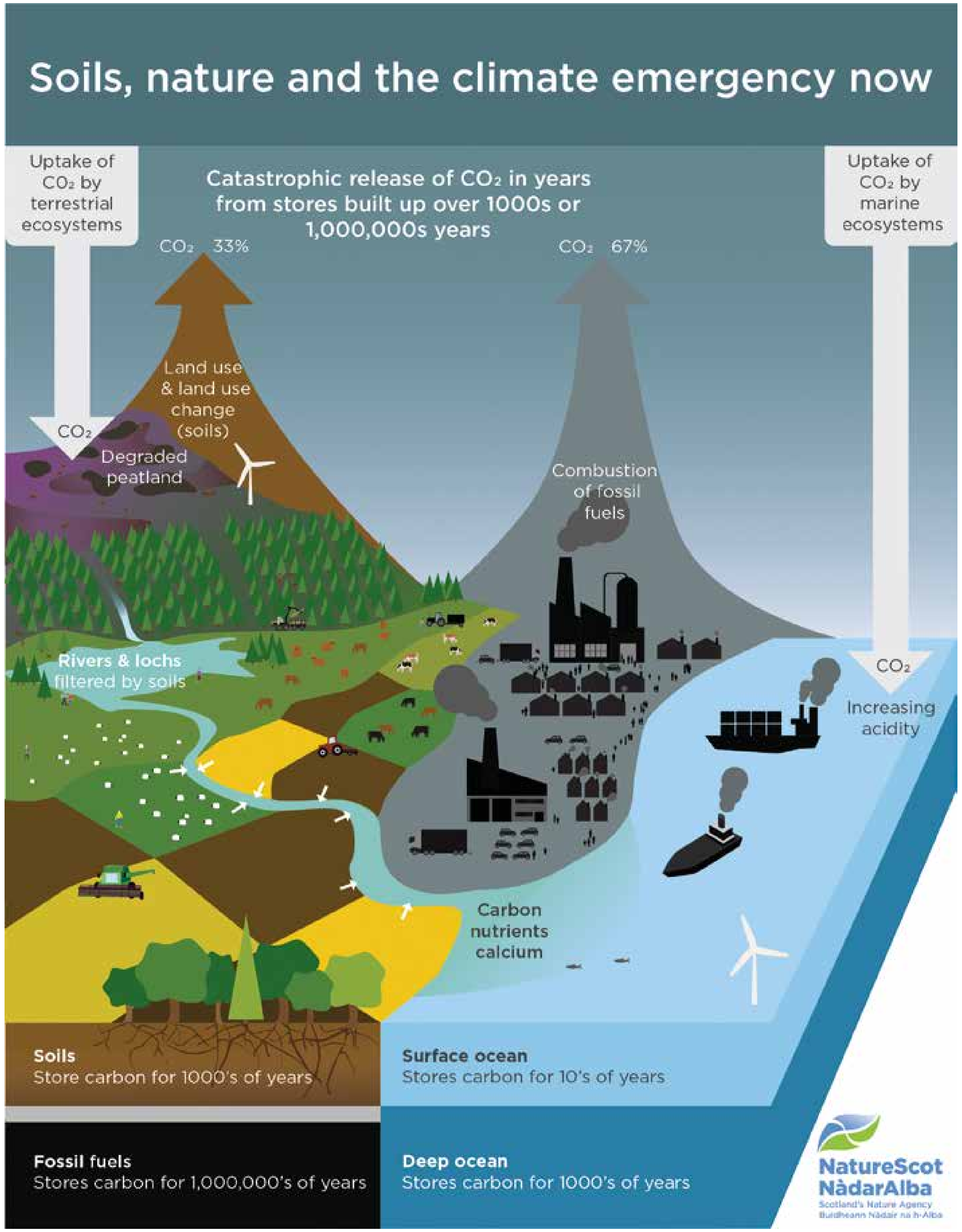
All life on Earth is carbon based, and soils, along with the oceans, perform a pivotal role in this global carbon cycle. Our modern carbon and water cycles came into being with the evolution of the leaf – and thus modern soils – about 400 million years ago. Soils regulate the 'fast' and 'slow' parts of the carbon cycle – with fast processes ranging from hours to thousands of years mainly through flows across the atmosphere, land and sea, including life, and slow processes taking millions of years primarily through geological reservoirs. Soils also regulate other key biogeochemical cycles necessary for life, including nitrogen and other nutrients.

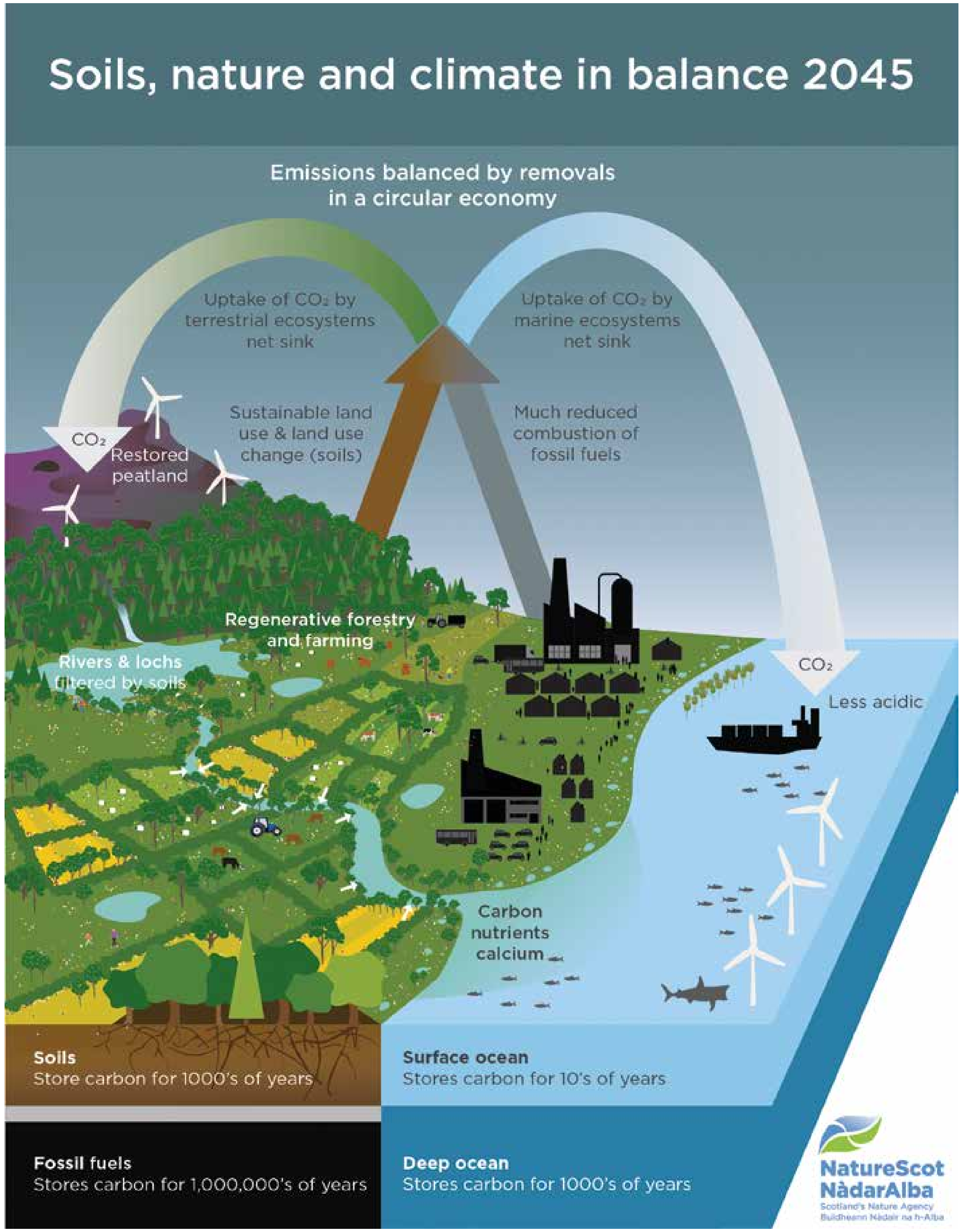
It is therefore strange that soils have been so neglected in all forms of land use, including approaches to conservation where they are a co-benefit rather than a direct focus for action.

The role of soils and marine sediments. Healthy soils and marine sediments – diverse and functioning effectively – are essential to a healthy climate–nature system. The stronger our disruption to these cycles, the greater the problems for nature and people.

To reach and maintain net zero carbon we must fix the biological parts (land and sea) of the carbon cycle, represented by the blue and green arrows (see **Figure 1b**). Focusing only on fossil fuels (represented in black) is vital, but only gets us two-thirds of the way to net zero. No amount of heat pumps or electric vehicles alone will fix the biological elements: we must transform the way we use all land and sea for farming, fisheries and forestry.

FEATURE





▲ Figure 1a (left page) and 1b (right page). Relationships between soils, nature and climate now (on the left) and in 2045 (on the right). The upward arrows (now) represent the net accumulation of greenhouse gases arising from fossil fuels (in grey) and land use and land use change, especially from degraded soils (in brown), based on cumulative emissions. On the right (2045), soil health is at the centre of a circular economy in which the burning of fossil fuels has been markedly reduced so that the net anthropogenic contributions to the atmosphere from both fossil fuels and land use are matched by uptake in terrestrial and marine ecosystems to reach and maintain net zero. (Source: NatureScot)

FEATURE

SOILS, NATURE AND CLIMATE IN BALANCE

Looking ahead to 2045 and a circular economy embedded in nature with greater balance for soils, nature and our climate, peatlands are re-wetted and restored. Commercial and conservation woodlands are diversified (see **Figure 1b**).[1] Agroforestry is the norm, and hedges are more plentiful, as are more numerous and smaller fields. Intercropping is widely practised for better pest control, and most farms mix crops and graze livestock extensively. Soils are less disturbed, and soil health is key. Most riverbanks are wooded, and flood plains allowed to flood making them seasonally wet. There is more green space in towns and cities to manage surface water, enhancing local nature and sequestering carbon. More extensive and diverse marine habitats and less disturbance of the seabed ensure both productive fisheries and more resilience in marine biodiversity undergoing a long recovery from acidification. Sea levels continue to rise and both coasts and rivers are recognised and managed as largely unrestricted, dynamic systems. Landscapes are more complex.

Of course, there are already such pockets of this future, demonstrating that the potential exists for the more radical transformation that is required. The reasons why they are not more widespread are numerous – and beyond the scope of this article – but stem from the underlying drivers of biodiversity loss[2] including market failure and externalised costs, the distribution of costs and benefits, vested interests, and governance and power relations, including participation in decision-making.[3,4]

In a circular net zero economy, production systems for food and fibre will need to be transformed.[5] For food, they will reflect more closely the productivity of natural systems, with more emphasis on lower trophic levels (plants and plankton), and they will be geared towards nutritious food, a healthy planet and growing population.[6,7] Patterns of consumption for food, fibre and timber will need to align with production: consuming less and differently and reducing waste.[3]

But not only must our use of the land and sea contribute to and maintain net zero, it must also be resilient to inevitable changes. Even the most aggressive emissions reduction scenarios involve global temperatures above 1.5°C around the 2050s before stabilising to 1.5°C by 2100. These consequences include an increased frequency and intensity of floods, fires, drought, pests, disease and pandemics. The more simplified and degraded nature is, the more severe the impacts of a changing climate on nature itself and its associated services.[8]

Early action to fix the land and sea elements of the carbon cycle through soil health and more diverse nature – including soil biodiversity – would not only build resilience but would also reduce the likelihood of changes occurring by correcting disruptions to biogeochemical cycles.[9]

The infographics can be used to evaluate whether choices in how we use land and sea reinforce the 'now' scenario (see **Figure 1a)** or lead us to where we could be by 2045 (see **Figure 1b**). Although an anathema to administrators, complexity at a range of scales – from field to landscape – is key to greater resilience to the impacts of a changing climate, enabling different people to do different things in different places, depending on the local context and situation.[10]

Nature has a vital role to play in fixing the biological aspects of a circular economy, but the approaches must be for multiple benefits, be locally appropriate and involve local communities.[9,11] In most cases, this will mean carbon savings are a co-benefit rather than the principal reason for the intervention. In all cases, the benefits should be for all life – noting that ecosystems and their benefits to people change over time – and include carbon in both vegetation and soils on land, and include carbon in coastal sediments for marine systems.

All uses of land and sea must sit within this framework, *simultaneously* mitigating for 1.5°C while building diversity and resilience for higher orders of climate change and enhancing the state of nature. This means diversity at all scales.

Land and sea use will change. If we continue with the current paradigm mainly for single benefits (i.e. as we do now) and so choose a world warmer by 2+°C (and it is a choice), the changes are largely out of our control, driven increasingly by the impacts of a changing climate with its inherent and increasing chaos and imposing escalating loss and damage costs to people and planet.

But the closer we aim for a 1.5°C world (i.e. the 2045 scenario), the more changes there are within our control. This no-regrets pathway is by far and away the least costly to people and planet. In a system that has co-evolved for the last 4 billion years, purported trade-offs between climate and nature should be viewed with suspicion. **ES**

Clive Mitchell is a Strategic Resource Manager for NatureScot's work on nature and climate change. He also works for the Open University teaching modules on Earth system sciences and the environment. He is an Honorary Fellow of the Royal Scottish Geographical Society.

© Rob | Adobe Stock

REFERENCES

1. Dasgupta, P. (2021) *The Economics of Biodiversity: The Dasgupta Review.* London: Her Majesty's Treasury. https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review (Accessed: 29 July 2022).
2. Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES) (2019) *Global Assessment Report on Biodiversity and Ecosystem Services.* Brondizio, E., Diaz, S., Settele, J. and Ngo, H.T. (eds). https://doi.org/10.5281/zenodo.3831673 (Accessed: 29 July 2022).
3. Benton, T.G. and Harwatt, H. (2022) *Sustainable Agriculture and Food Systems: Comparing, Contrasting and Contested Versions.* Chatham House Research Paper, Environment and Society Programme. https://www.chathamhouse.org/sites/default/files/2022-05/2022-05-24-sustainable-agriculture-benton-harwatt_4.pdf (Accessed: 29 July 2022).
4. Oliver, T.H., Boyd, E., Balcombe, K., Benton, T.G., Bullock, J.M., Donovan, D., Feola, G., Heard, M., Mace, G.M., Mortimer, S.R., Nunes, R.J., Pywell, R.F. and Zaum, D. (2018) Overcoming undesirable resilience in the global food system. *Global Sustainability*, 1 (e9). https://doi.org/10.1017/sus.2018.9 (Accessed: 29 July 2022).
5. Zurek, M., Hebinck, A. and Selomane, O. (2022) Climate change and the urgency to transform food systems. *Science*, 376 (6600), pp. 1416–1421. https://pubmed.ncbi.nlm.nih.gov/35737771 (Accessed: 29 July 2022).
6. Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., *et al.* (2019) Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *Lancet*, 393 (10170), pp. 447–92. https://doi.org/10.1016/S0140-6736(18)31788-4 (Accessed: 29 July 2022).
7. Intergovernmental Panel on Climate Change (2019) *Special Report: Climate Change and Land.* https://www.ipcc.ch/srccl (Accessed: 29 July 2022).
8. Intergovernmental Panel on Climate Change (2022) *Climate Change 2022: Mitigation of Climate Change. Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf (Accessed: 29 July 2022).
9. Seddon, N. (2022) Harnessing the potential of nature-based solutions for mitigating and adapting to climate change. *Science*, 376 (6600), pp. 1410–1416. https://www.science.org/doi/abs/10.1126/science.abn9668?af=R (Accessed: 29 July 2022).
10. Moore, J.W. and Schindler, D.E. (2022) Getting ahead of climate change for ecological adaptation and resilience. *Science*, 376 (6600), pp. 1421–1426. https://pubmed.ncbi.nlm.nih.gov/35737793 (Accessed: 10 August 2022).
11. United Nations Environment Programme (2022) *Nature-based solutions for supporting sustainable development. Resolution adopted by the United Nations Environment Assembly. United Nations Environment Assembly of the United Nations Environment Programme, fifth session, Nairobi, 22–23 February 2021 and 28 February–2 March 2022.* https://wedocs.unep.org/bitstream/handle/20.500.11822/39752/K2200677%20-%20UNEP-EA.5-Res.5%20-%20Advance.pdf?sequence=1&isAllowed=y (Accessed: 9 August 2022).

CASE STUDY

Broom East Wildlife Conservation Site

Enrique Moran Montero outlines an example of a collaborative and dynamic approach to ensuring resilient ecosystem restoration.

Mineral extraction is a temporary use of land that often takes place over long periods of time. It can only take place once the operator has obtained planning permission and any other required permits and approvals. Following mineral extraction, land should be restored to a suitable after-use agreed as part of the planning process.

FROM QUARRY TO CONSERVATION SITE

Broom Quarry is a former sand and gravel quarry located to the north of Broom village, approximately 1.5 km west of Biggleswade in Bedfordshire (see **Figure 1**). Mineral extraction began at the main site in 1997 and was followed by progressive restoration to a mix of agriculture, wetlands, woodland blocks and lakes.

▲ **Lowland meadow restored at Broom East Wildlife Conservation Site. (© Tarmac Limited)**

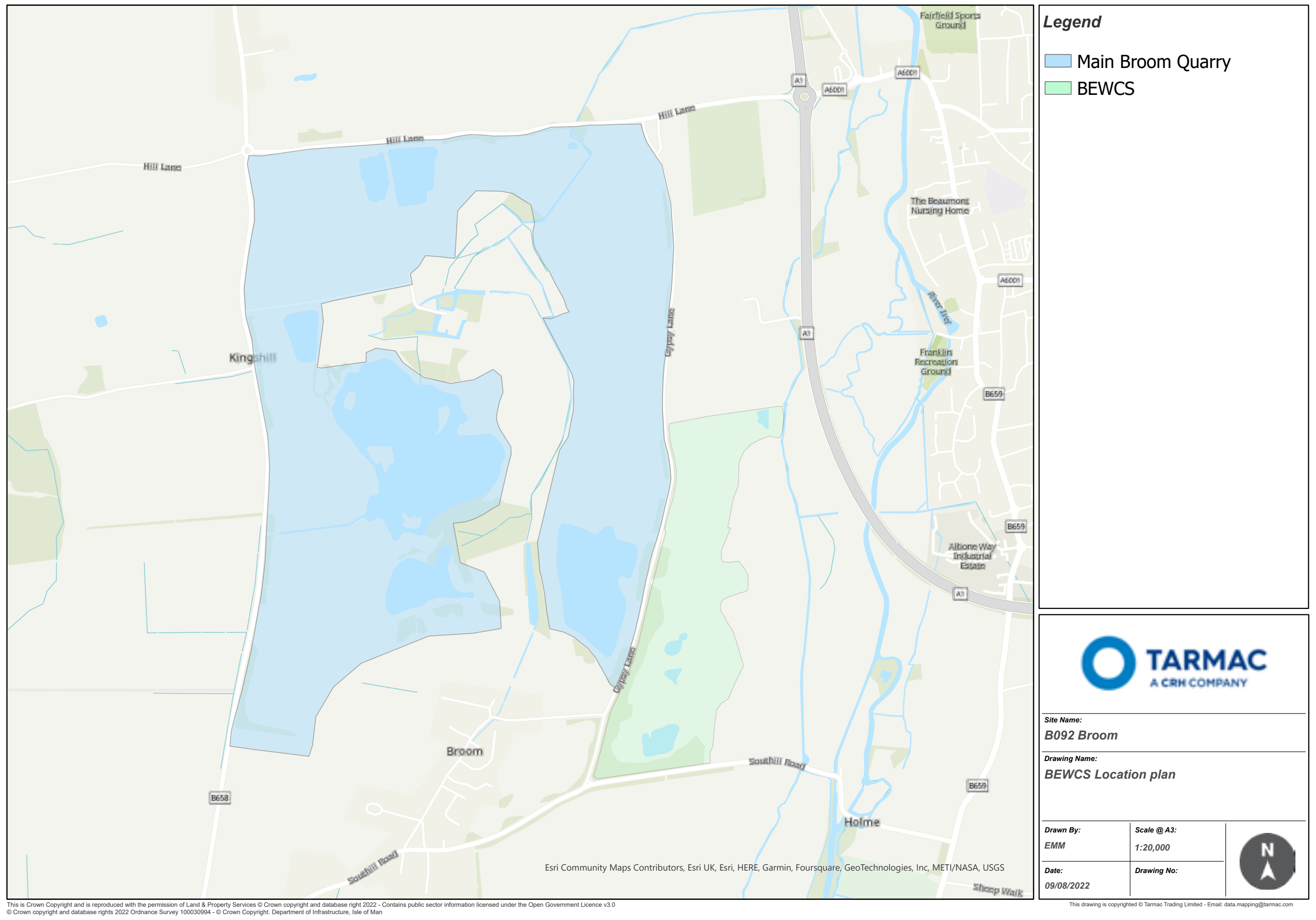


Figure 1. Broom East Wildlife Conservation Site (BEWCS), also known as Broom East, and the main quarry site. (© Tarmac Limited)

Planning permission for a 32 ha extension located to the east of the main site (known as Broom East) was granted in 2006. Mineral extraction in Broom East began in October 2007 and the site was due to be restored to a mix of meadows and ponds to promote white-clawed crayfish (*Austropotamobius pallipes*). However, since extraction commenced in 2007, the native population in the county became extinct and no suitable donor population could be found in the region. Alongside the progressive restoration process, it was realised that the site's landform and hydrological regime gave it qualities of high value for important bird species and that a change of objective could deliver other valuable biodiversity gains.

As a result, and following discussions with the Mineral Planning Authority, landowners and local conservation groups, the type and layout of habitats created in the southern part of the site are different to those originally envisioned. Now, there is an extensive seasonal wetland on the valley floor, with areas of reed beds, wet woodland and gravelly islands, as well as woodlands and wildflower meadows on the slopes. The restoration of this part of the site was completed in 2016 and this area, now known as Broom East Wildlife Conservation Site (BEWCS), was designated a county wildlife site in 2017 (see **Figure 2** and **Figure 3**).

BEWCS is especially significant for birds, with 117 different species recorded on site, including little ringed plover, lapwing, redshank and grey partridge. In addition, the restored meadows show a rich flora with 48 different species recorded. This diversity will be enhanced further in the following years thanks to grazing by local Dexter cattle.

PARTNERSHIP AND COLLABORATION

Collaboration with local groups and the community is key at BEWCS. Tarmac manages the wildlife conservation site working closely with Shuttleworth Estate and the Bedfordshire Bird Club, which also carries out bird monitoring. Annual review meetings to monitor progress are also held involving staff from Tarmac, the Royal Society for the Protection of Birds (RSPB), Bedfordshire Bird Club, Central Bedfordshire Council, and the Wildlife Trust for

Figure 2. Final landform created at the northern part of the site for the lowland meadow establishment. (© Tarmac Limited)

Figure 3. Northern lowland meadow two years after seeding. (© Tarmac Limited)

Bedfordshire, Cambridgeshire and Northamptonshire. A 20-year management plan[1] was prepared by Tarmac, Shuttleworth Estate and Bedfordshire Bird Club in 2017, ensuring that the habitats created remain in favourable condition.

The standard of restoration achieved at Broom Quarry was recognised at the Mineral Products Association's 2019 Restoration & Biodiversity Awards, when the site was named joint winner of the prestigious Cooper–Heyman Cup for outstanding restoration. The independent judges referred to Broom as a 'massive transformation of what was originally typical, uninteresting, agricultural land – this is of great value to both the local community and to wildlife'.[2]

KEY LEARNINGS

On many occasions, the implementation of the restoration scheme commences after a considerable lapse of time from its design. We live in a changing world and restoration priorities and species distribution may have changed by the time of implementation. This is one of the key learnings of this restoration: it is fundamental to have an open view to be able to identify opportunities that may come along. In this case, such flexibility led to the creation of a rare habitat in Bedfordshire (see **Figure 4**).

Another key learning from the Broom East restoration project is the importance of working with the local community and establishing partnerships with different organisations that can bring new ideas and fresh views. In this case, the Bedfordshire Bird Club flagged up the opportunity to change the restoration scheme, and the restored meadows are managed through grazing by a local farmer with his herd of Dexter cattle (see **Figure 5**). The establishment of connections with local communities and organisations was facilitated through liaison meetings and was made possible through the Tarmac team's openness to being approached with new ideas.

The site is also under a 20-year management plan. As such, it is monitored every year by an ecologist, and annual meetings are held involving Tarmac, the RSPB, Bedfordshire Bird Club, Central Bedfordshire Council,

▲ **Figure 4. Seasonal wetlands restored within the southern part of the site. (© Tarmac Limited)**

▲ **Figure 5. Dexter cattle grazing at Broom East Wildlife Conservation Site. (© Tarmac Limited)**

and the Wildlife Trust for Bedfordshire, Cambridgeshire and Northamptonshire as well as representatives of the landowners. Management actions are discussed and agreed as part of those annual meetings. This ensures that informed decisions are taken, and the management priorities of the site evolve as the site matures (see **Box 1** for an overview of the key elements necessary to deliver resilient ecosystem restoration).

BOX 1. RESILIENT ECOSYSTEM RESTORATION

- At scheme design level, working with restoration experts, ecologists and landscape architects ensures that the schemes designed and submitted for planning consent aim to deliver functional ecosystems in the future.
- At site level, the long-term management plans of some of our restored sites involve annual monitoring and review by experts and management groups. In this way, the management approach for a particular site can change as the restored habitats evolve over time.
- Working with trade organisations like the Mineral Products Association allows us to share and learn best practice.
- Working with research institutions such as Cranfield University and the University of Stirling involves learning how to improve and adapt our restoration and habitat management works and be part of research projects that can bring new findings to the wider scientific community.

Overall, the restoration scheme is a great example of how mineral operators, landowners, conservation organisations and planning authorities can work together to deliver positive outcomes for nature. Habitat restoration and management should be dynamic and adapt to the opportunities that may come along in the process. ES

Enrique Moran Montero is National Restoration Manager for Tarmac, heading the team that provides support to the company with quarry restoration and biodiversity management. He has a background in agronomy and forestry and has an MSc in Land Reclamation and Restoration. He is a Chartered Environmentalist and a Full Member of the IES.

REFERENCES

1. Andrews Ecology on behalf of Tarmac (2017) *Biodiversity Management Plan for Land East of Gypsy Lane at Broom Quarry, Biggleswade, Bedfordshire.* https://app.box.com/embed/preview/apv690m70s14fltyyz2m8s8jfzdtrojn?direction=ASC&theme=dark (Accessed: 15 August 2022).
2. Mineral Products Association (2019) MPA Restoration & Biodiversity Awards '19. *Mineral Products Today*, 20, pp. 6–10.

CASE STUDY

East Chevington nature reserve

Mark Carey and **Duncan Hutt** look at the successes, challenges and future of a restored opencast mining site.

EAST CHEVINGTON TODAY

East Chevington nature reserve lies immediately adjacent to Druridge Bay in Northumberland, north-east England, at the northern end of the coalfield coast and just south of Amble. Today, the nature reserve is considered one of the best bird-watching sites in the country. It comprises a mixture of reedbeds and watercourses, woodland and hedges as well as agricultural land. It is home to a diverse array of species including reed buntings, reed warblers, marsh harriers and bearded tits that breed on site, and overwintering bitterns. Barn and short-eared owls, red squirrels, water shrews, great crested newts and common lizards have all been recorded as have five species of orchid and 21 species of butterfly among a total of 438 different species identified on the reserve. In 2003, harvest mice were first introduced, then augmented with further releases in 2021.

▲ The meadow area containing lesser butterfly orchids. (© Sophie Webster)

▲ Figure 1. One of the metal hides and the north pool in 2006. (© Duncan Hutt)

A BRIEF HISTORY OF THE SITE

Yet just 30 years ago, this was an opencast mining site extending to 210 ha, with 4 million tonnes of coal removed between 1982 and 1993. Prior to being mined, the site was occupied by the derelict mining village of East Chevington, whose remaining residents had been rehoused in the nearby village of Hadston. Much of this low-lying area included poor-quality agricultural land, spoil tips and a refuse site, so the land was already considerably damaged prior to mining.

The site is located within the centre of one of the most geographically concentrated areas of opencast coal mining activities spanning many decades and, as such, it was subject to significant ecological devastation. It is surrounded by relatively new recovering opencast restoration on three sides and the North Sea to the east.

RESTORING THE SITE

With British Coal's expertise in restoration following opencast mining and Northumberland County Council's desire to promote the countryside, a master plan was developed to establish a series of nature reserves along the bay. From this early concept, proposals were developed further with the assistance of the Northumberland Wildlife Trust (NWT), which recognised the importance of establishing wetland habitats for migrating birds along the coast. The Druridge Bay Partnership – formed between the Wildlife Trust, British Coal Opencast and Alcan Farms – was launched by Bill Oddie in 1988.

Having already developed nature reserves following mining nearby at Hauxley, Druridge Pools and Cresswell, the last and largest reserve to be restored was East Chevington. Here, reedbeds were planted with a mixture of stock taken from undisturbed areas on the site, Hauxley nature reserve – to where some of the reeds had originally been translocated – and cultivated material.

This site is also an example of where restoration has involved imagining what could be rather than trying to reinstate what we think was previously there. The ambition to develop any resilient ecosystem has one key starting point and that is below ground, in the soil: an often neglected but critical restoration resource in mining and other disruptive activities on land.

WORKING IN PARTNERSHIP

Initial restoration of the site, including much of the access infrastructure, and aftercare were done by The Coal Authority, which ceased site management activities in 2000; NWT took over aftercare and management following acquisition of the site in 2003. NWT's role included construction of bird-watching hides, originally constructed of wood. However, one hide was soon destroyed by fire, after which metal hides were installed (see **Figure 1**). While they are practical and robust, they are not as pleasant to use as the more traditional wooden structures.

For many years following the transfer to NWT the Trust managed the site largely using income from letting the agricultural fields. In that time, grazing was introduced in some of the smaller paddock areas to help diversify the grass cover and maintain some areas of short vegetation. Some additional access was provided to help create more routes on the site and enable access to view the reedbed areas. A small amount of additional tree planting was undertaken to help link habitat across the site and two new small ponds were created that have proved valuable for dragonflies and amphibians.

▲ Figure 2. Aerial view of the southern reedbed and pool. (© Andrew Bryson Photography)

SUCCESSES AND CHALLENGES

The site is quite remarkable and an example of how such dramatic ecological recovery can be achieved without compromising agricultural systems on adjacent land when working with the prevailing physical and climatic constraints, the correct management techniques and an understanding of landscape function.

One of the initial major successes was the arrival of the first marsh harriers to the reedbed to the south of the site. The arrival of this bird, followed by the first

▲ **Figure 3. A view over the north pool and reedbeds. (© Sophie Webster)**

▲ **The young plantations in 2005. Some of the pines on the left blew over in Storm Arwen in 2021. (© Duncan Hutt)**

breeding success in 2009, was a major milestone for the reserve, proving that the creation of what was then Northumberland's largest reedbed could attract some of these iconic species to the county's coast.

In 2019, NWT was successful in securing funding from the National Lottery Heritage Fund for the Catch My Drift (CmD) project. This was the first major funding brought in on a site-wide basis to make habitat improvements as well as link local residents more effectively with the reserve. This project was also the first time NWT was able to have a dedicated member of staff working solely to improve the nature reserve.

One of the major challenges that NWT faced was controlling water levels. The original sluices were functional but altering water levels was challenging, as it was extremely difficult to remove the drop-board sleepers once they became wet. In addition, the channel leading to the sluice in the northern pool had become blocked, so control of levels in this pool had become impossible. The CmD project enabled NWT to clear the northern channel and install new sluices at both lakes. These gate sluices are much easier to manipulate and thus enable site staff to control water levels. Now that water control to the reedbed has been established, particularly in the south of the site, managing this habitat is crucial (see **Figure 2**). For the northern pool, this control should enable the reedbeds to spread further, as was originally planned (see **Figure 3**).

Some of the farmland originally let for grazing has since been taken back. Since 2020, a total of 20 ha has been sown with a Northumbrian meadow seed mix that has been partially successful in establishing a more diverse sward, and this is expected to improve over time. In some sections of the site, NWT has added more ponds, largely for the great crested newt population, but these do, of course, have far wider benefits to nature on the reserve.

The establishment of trees on the site following restoration was extremely successful to the point where NWT is now involved in thinning and in some cases planting understory species. Two factors have led to a loss of trees: the first is ash dieback, which has severely affected the area and resulted in patches of dead trees; the second was Storm Arwen in autumn 2021, which saw swathes of trees flattened, mostly pine. These areas will be left to regenerate naturally, as the fallen stems are a good way of protecting seedling trees from damage by deer and hares.

Another CmD output has been the engagement of local communities and working with those who had a link to the old village of Chevington Drift. Community links to the site will be of increasing importance into the future as NWT works to enable local residents to have more involvement and say in the management of nature reserves, both here and elsewhere in the county.

FUTURE PLANS

Upcoming work on the site includes making major changes to the hides to make them robust yet pleasant for visitors – both the bird-watching community as well as those new to enjoying nature. Beyond that, we envisage taking more land back to enable more effective habitat linking and to recreate habitat that is all but lost locally.

Wilding is the word of the moment and means different things to different people. The future of East Chevington is likely to be even wilder than it already is, where natural processes start to govern the changes taking place on site. However, some management to maintain the locally important habitats and species will always be needed. The future is looking positive, building firmly on the foundations that were laid down during the restoration and aftercare of the reserve. ES

Mark Carey is a Fellow of the Royal Institution of Chartered Surveyors. He is a rural practice surveyor and was part of the team that conceived the East Chevington project. Now, with over 35 years' experience in restoration and aftercare he works for The Coal Authority within the Water and Abandoned Metals Mines Programme, a partnership with the Environment Agency and Defra.

Duncan Hutt is Director of Conservation with Northumberland Wildlife Trust. Duncan has worked for the Trust for 25 years. Prior to this he was a volunteer at the Trust, during which time one of his tasks involved planting reeds at East Chevington. His role today involves oversight of the land management and conservation functions of the Trust including the recent acquisition of more previously opencast land at nearby West Chevington.

CASE STUDY

Creating tomorrow's woodlands for nature recovery

Vanessa Burton outlines and applies the principles of woodland creation to the expansion of Pepper Wood.

Woodland creation is central to the Woodland Trust's vision of a UK rich in native woods and trees, for both people and wildlife. The relatively sparse cover of woods and trees that remains in the UK today is the result of a wide-ranging combination of impacts including agricultural intensification, infrastructure development, growing deer populations, increasing numbers of invasive species and more. The Trust's approach to woodland creation seeks to initiate nature recovery across landscapes. The aim is not to restore the land to some historic condition but to support a recovery from historic loss, fragmentation and degradation. As recovery progresses and natural processes become re-established, landscapes will become more ecologically resilient with the capacity to adapt to future change.

The Woodland Trust's *Woodland Creation Guide*[1] builds upon the UK Forestry Standard to provide a framework for native woodland creation at the site scale, developed around the role of a competent adviser. From articulating a vision for a future woodland to careful selection of objectives, the guide encourages users to develop a clear rationale for woodland development. It goes on to support thorough, scalable site assessment and creative design, ensuring creation is carried out in the appropriate place in a way that will meet the site's objectives. It advocates for mixed methods in initiating creation and takes a long-term view, outlining evidence-based interventions during establishment that will enable the development of diverse and naturally functioning woodland ecosystems that contribute to nature recovery and more.

© Helen Davies | Adobe Stock

Throughout this framework, there are a number of principles for nature recovery that inform woodland-creation design, initiation and ongoing establishment. Derived from reviews of scientific evidence and over 25 years of collective experience across the Trust, these principles guide the Trust's approach to ecosystem restoration and the role of woodland creation within this.

NATURE RECOVERY PRINCIPLES

There are six key recovery principles the Trust follows.

1. **Use predominantly native trees.** Rich and complex associations between our native trees and wildlife have developed over thousands of years, making native trees best suited for assisting nature recovery. Even tiny populations of tree species in native woodland fragments show a surprising range of genetic diversity, and we must enable the space and opportunity for these populations to reproduce and adapt to rapidly changing environmental conditions. The *Tree Species Handbook*[2] provides guidance on a range of native trees and shrubs.

2. **Enable habitat mosaics and structural complexity.** Structural complexity is a useful and simple proxy for habitat quality.[3,4] It enhances the conservation value of woods and trees by providing a diversity of microclimates and a range of resources for wildlife. Woodlands with a varied horizontal structure of dense groves, open glades and transitional open-wooded habitats create a range of environmental conditions that support a variety of specialist species. These woodland elements should be combined with open habitats, scrub and hedgerows to create mosaic landscapes (see **Figure 1**).

3. **Restore and enhance existing landscape features.** The restoration or enhancement of existing habitat features will make an important contribution to the creation of quality woodland. Grassland, wetland and heathland habitats will support an assemblage of specialist species of their own and provide resources that are important to many woodland specialist species. Woodland-creation designs should not negatively impact areas of existing priority habitat.

4. **Re-establish natural processes.** How the woodland ecosystem functions will influence its contribution to nature recovery as trees establish and mature. Although these processes may take time to develop, designs can create the conditions and initiate the processes that will lead to the establishment of healthy, naturally functioning woodland ecosystems. Processes such as natural colonisation and regeneration, decomposition and wood decay, competition for space, light, water and nutrients, and disturbance – herbivory and predation – are all essential processes in a functioning woodland ecosystem with a diversity of habitat niches.

5. **Address the needs of indicator and target species.** Applying these principles to create habitats with complex structures and restoring semi-natural features and natural processes will go a long way towards ensuring that rich and abundant wildlife is supported. Depending on the site and nature recovery objectives defined, it may also be important to consider the habitat and resource requirements of specific wildlife species, communities or assemblages.

6. **Create nature recovery networks and connectivity.** Species populations experience natural cycles of colonisation, expansion, decline and localised extinction as suitable habitats emerge and decline within landscapes.[5] To survive, wildlife needs to be able to disperse and move across sites and landscapes to occupy suitable habitats. To support nature recovery, woodland-creation designs need to look beyond the site boundaries and consider how the project can contribute to habitat networks at a landscape scale.[6]

▲ **Figure 1. A structurally complex woodland mosaic, comprising dense groves (far left), glades (centre) and open-wooded habitats (far right) with broad transitional zones in between. (© The Woodland Trust, Alistair Hotchkiss)**

The following case study illustrates how these principles can be enacted within a woodland-creation design.

PUTTING PRINCIPLES INTO PRACTICE

A project is currently underway to expand woodland northwards from Pepper Wood, an ancient woodland and site of special scientific interest in central England. The Woodland Trust has owned and managed the existing 60 ha Pepper Wood with its important botanical features since the 1980s. The project involves the following steps:

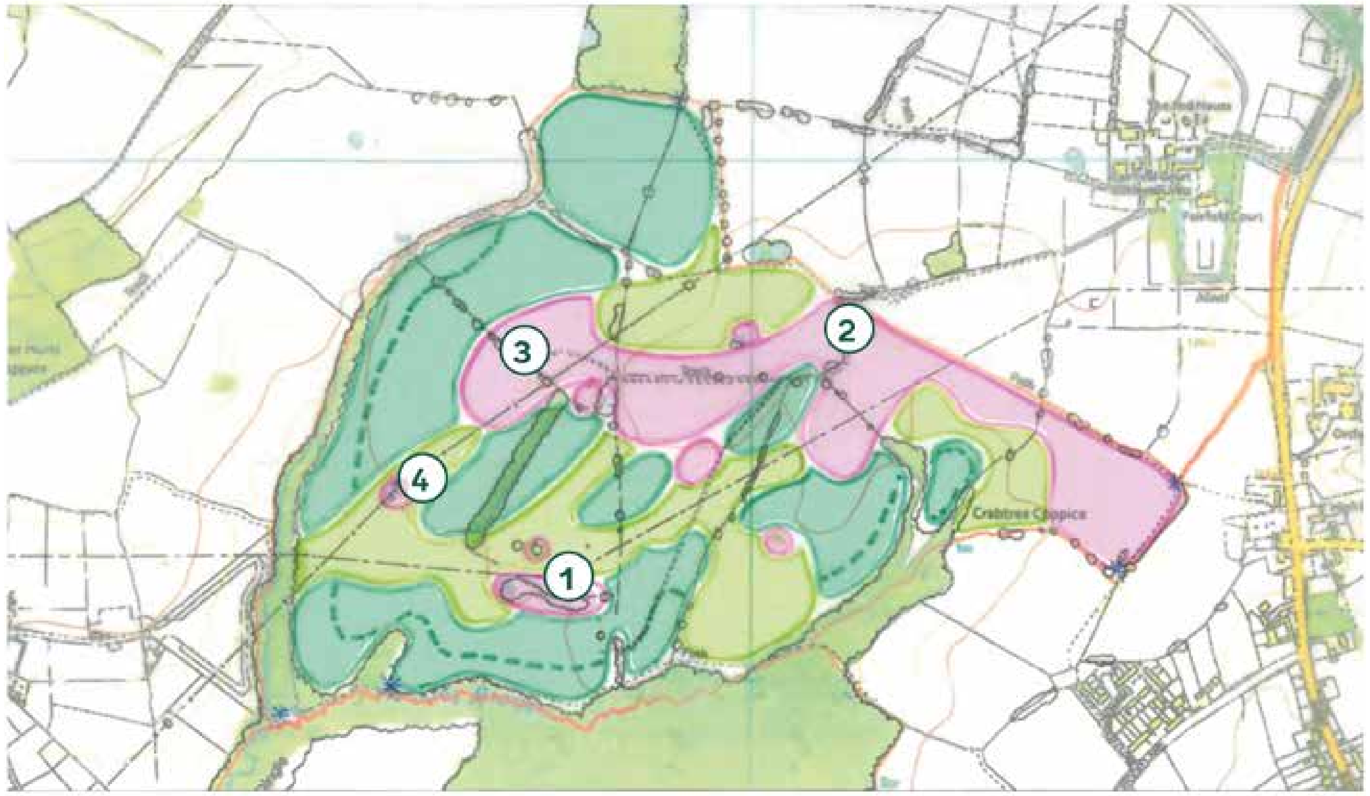
Vision: a clear rationale and objectives. Using the structural components of groves, open-wooded habitats and glades and by blending different establishment methods, a rich mosaic of woodland habitat will be created to extend and buffer the existing Pepper Wood ancient woodland by a further 50 ha.

Assess: characteristics, features and constraints. A site assessment was undertaken to identify the location of service lines, such as a gas pipeline and overhead power cables. Existing features, including hedgerows, veteran trees, groves, ponds and viewpoints, were recorded and mapped. Checks with the local council ensured there were no negative impacts of woodland creation on archaeological features and landscape character. Ecological surveys were conducted to record existing habitat value and the presence of any species that would need special consideration.

Design: synthesis and creativity. An independent landscape designer led the design process to ensure rigour and objectivity. The resulting design includes denser woodland on lower ground and more open-wooded habitats on higher ground, preserving long-range views to the Malvern Hills.

The design has been through a consultation process with local residents and stakeholders. On-site walks were conducted to explain the design concept, and opinions were invited through these walks and an online questionnaire (see **Figure 2**). Statutory organisations such as the Forestry Commission and Natural England as well as local bodies, including Worcester Wildlife Trust and Worcester County Council, were also consulted. The final sympathetic and ecologically based design has been strongly supported by all those consulted (see **Figure 3**).

Initiate: species choice and creation methods. A proportion of the woodland habitat will be initiated via natural colonisation, making full use of the seed



▲ **Figure 2. An initial concept design for the new woodland. Dark green areas indicate dense woodland groves, paler green areas open-wooded habitats and pink areas open glades. Specific features include: (1) buffering and extending existing ancient woodland; (2) responding to local landform and retaining open ground on the ridgeline; (3) reflecting the pattern of enclosure by building on the existing network of hedgerows, boundary trees and copses; and (4) integrating infrastructure constraints (power line and gas main corridors). (© Gareth Price, GIDE Associates)**

▲ **Figure 3. The final woodland-creation design showing: (1) planted areas using variable density patterns; (2) blended planted and naturally colonising areas; (3) natural colonisation as the principal method of establishment within 50 m of the ancient woodland edge; (4) interlocking areas of tree cover and open ground to reduce the corridor effect of infrastructure constraints; (5) open glades to retain expansive views out from the site; (6) ponds, hedgerows and hedgerow trees integrated as existing features; (7) open-wooded habitat to include cattle grazing; (8) two large deer-fenced areas; (9) access; (10) path network; and (11) Second World War track and buildings maintained for cultural interest. (© Gareth Price, GIDE Associates)**

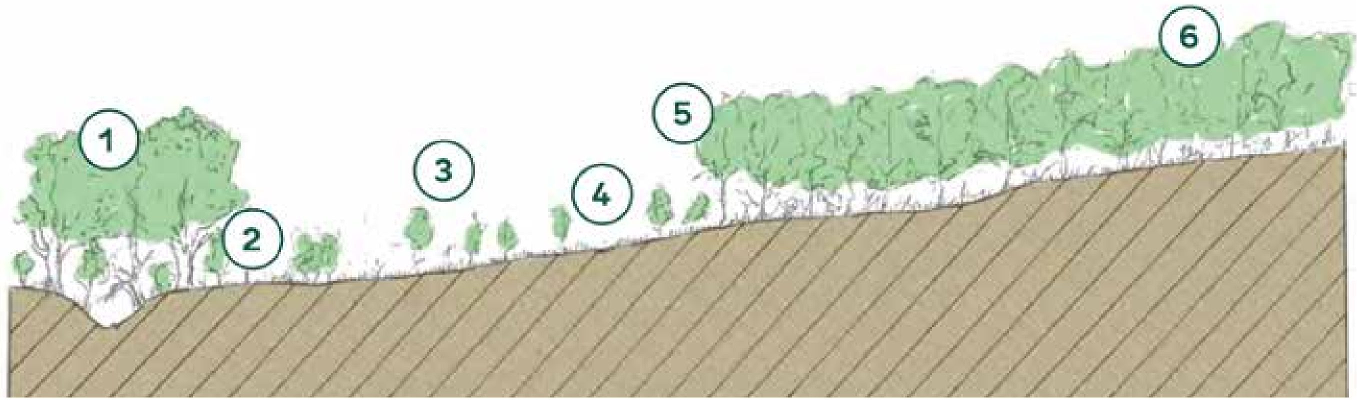
source from Pepper Wood and existing seed trees present on site. The interface between open ground and woodland habitat will be soft – achieved through a variable naturalistic tree-planting matrix and developing scrub (see **Figure 4**). There will be a substantial amount of woodland edge habitat, which will conserve existing hedgerows and groves. Deer and rabbit fencing will be installed to reduce browsing pressure and help establish the young trees for the first 5–10 years.

Establish: a naturally functioning ecosystem. The establishment of woods and trees over around 20 years should support the development of naturally functioning woodland ecosystems. This can include aftercare, promoting establishment by controlling herbivory, establishing richer communities of flora, fungi and fauna, thinning to promote structural complexity or managing for future veteran trees. Monitoring throughout this stage should inform management decisions.

The Pepper Wood expansion is currently at the initiate stage, with work underway to erect a deer fence prior to planting in the north-west corner of the site. Plans are also in progress to monitor the efficacy of different methods of ground preparation for natural colonisation in areas throughout the site using fixed plots and fixed-point photography.

ES

Vanessa Burton is a landscape ecologist working as Conservation Adviser for woodland creation at the Woodland Trust. In this role, Vanessa develops advice, guidance and training to support evidence-based decision-making in conservation practice and policy.



▲ **Figure 4. A cross-section of the final design showing: (1) ancient semi-natural woodland along the stream; (2) a field boundary fence; (3) area of natural colonisation; (4) informal path; (5) varied planting spacing to create a blended edge; and (6) variable density planting to promote structural complexity. (© Gareth Price, GIDE Associates)**

REFERENCES

1. Herbert, S., Hotchkiss, A., Reid, C. and Hornigold, K. (2022) *Woodland Creation Guide.* Grantham: The Woodland Trust. https://www.woodlandtrust.org.uk/media/50673/woodland-trust-woodland-creation-guide.pdf (Accessed: 28 August 2022).
2. Hotchkiss, A. and Herbert, S. (2022) *Tree Species Handbook.* Grantham: The Woodland Trust. https://www.woodlandtrust.org.uk/media/50812/tree-species-handbook-woodland-creation-guide.pdf (Accessed: 28 August 2022).
3. Ferris, R. and Humphrey, J.W. (1999) A review of potential biodiversity indicators for application in British forests. *Forestry*, 72 (4), pp. 313–328. https://doi.org/10.1093/forestry/72.4.313 (Accessed: 28 August 2022).
4. Zellweger, F., Braunisch, V., Baltensweiler, A. and Bollmann, K. (2013) Remotely sensed forest structural complexity predicts multi species occurrence at the landscape scale. *Forest Ecology and Management*, 307, pp. 303–312. DOI:10.1016/j.foreco.2013.07.023.
5. Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J. and Wynne, G.R. (2010) *Making Space for Nature: A Review of England's Wildlife Sites and Ecological Network.* Technical Report to Defra. https://www.researchgate.net/publication/268279426_Making_Space_for_Nature_A_Review_of_England%27s_Wildlife_Sites_and_Ecological_Network (Accessed: 1 August 2022).
6. Fuentes-Montemayor, E., Goulson, D., Cavin, L., Wallace, J.M. and Park, K.J. (2012) Factors influencing moth assemblages in woodland fragments on farmland: implications for woodland management and creation schemes. *Biological Conservation*, 153, pp. 265–275. dx.doi.org/10.1016/j. biocon.2012.04.019.

▲ Old omega sign at Wicken Fen nature reserve, Cambridgeshire. (© National Trust Images/Rob Coleman)

CASE STUDY

The National Trust's Wicken Fen nature reserve

Rosie Hails and **Ben McCarthy** examine how the National Trust's vision and strategy have led to the restoration of Wicken Fen.

The National Trust Act of 1907 locks nature conservation into the very essence of the National Trust's charitable purpose, defining it as '..the permanent preservation for the benefit of the nation of lands … of beauty or historic interest and as regards lands for the preservation … of their natural aspect features and animal and plant life'.

Although we talk less of preservation per se at the Trust nowadays, this statutory underpinning for the active conservation of the Trust's 250,000 ha estate across England, Wales and Northern Ireland puts great significance on our active conservation of the land for the nation to enjoy and benefit from; the Trust's recent focus on fungi is one such conservation programme.[1]

The strategy Playing Our Part[2] articulates the Trust's long-standing commitment to make space for nature by adopting Professor Sir John Lawton's recommendations of 'better, bigger and more joined up' sites for wildlife.[3] This includes achieving good condition on nearly half the estate for biodiversity and geodiversity, which is of national importance. This strategic ambition was further cemented when we announced on our 125th birthday our ambition to be net zero by 2030, with clear implications for the land use and management employed across our estate.

Nature-based solutions, working towards resolving both the nature and climate crises, are where we have identified the sweet spot in both building our carbon stocks and delivering benefits to nature through, for example, establishing 20,000 ha of new woodlands and restoring our 25,000 ha of peatlands.

As we start developing our new strategy from 2025, our approach to restoring nature comes into ever-sharper focus, recognising that climate, social and economic changes are impacting on all aspects of the Trust's business: from weather so hot that valuable works of art are damaged, to farm tenants vulnerable to the loss of government basic payment schemes that prop up so many farm businesses, and a responsibility for conserving the biodiversity that occurs across some of the most important nature sites in the country.

DEVELOPING OUR APPROACH

Although the Trust has long been involved in active research, it was not until we achieved independent research organisation status in 2019 that we have been able to develop a more comprehensive and active research approach to our nature conservation work and build on the many years of experience the organisation has had in delivering solutions for nature.

A range of approaches has been adopted across the organisation, from autecological research into individual threatened species to interventions to effect landscape processes. One example of this is the Trust's work at Wicken Fen nature reserve.

WICKEN FEN NATURE RESERVE

The National Trust's work to restore Wicken Fen first started with the initial site acquisition in 1899; the site is the Trust's (and one of Britain's) oldest nature reserve. As a major landowner of the 250 ha site, Wicken Fen nature reserve represents one of our most important nature sites. It comprises extensive areas of alkaline fen, marsh, swamp and lowland farmland, supports over 9,000 species and is recognised as an internationally important wetland.

For years, the site was intensively and conventionally managed to conserve the existing high-value biodiversity, with conservation actions typical for such wetlands such as rotational cutting and removal of fen vegetation and efforts to maintain water levels. However, this approach started to shift in 1999 with the adoption of a 100-year vision that seeks a landscape-scale habitat restoration over 5,300 ha of this part of England's Fenlands.

Because of the intensive and prolonged period of drainage and intensive arable cultivation, it was not feasible (technically or economically) to restore the site to the extensive wetland of yesteryear – the area has been under direct human influence for centuries. Instead, a more open-ended approach has been adopted to restore the wetlands. Rather than set targets comprising specified species expected in a 'reference habitat', the main goal is to allow or establish ecological processes over a large scale. The result of this approach has seen a habitat mosaic of shallow water bodies, reedbeds, wet and dry grasslands, and scrub develop. The extensive research

▲ **Konik ponies on Baker's Fen at Wicken Fen nature reserve, Cambridgeshire. (© National Trust Images/Mike Selby)**

▲ **Morning mist rises over the reed and sedge landscape at Wicken Fen nature reserve, Cambridgeshire. (© National Trust Images/Rob Coleman)**

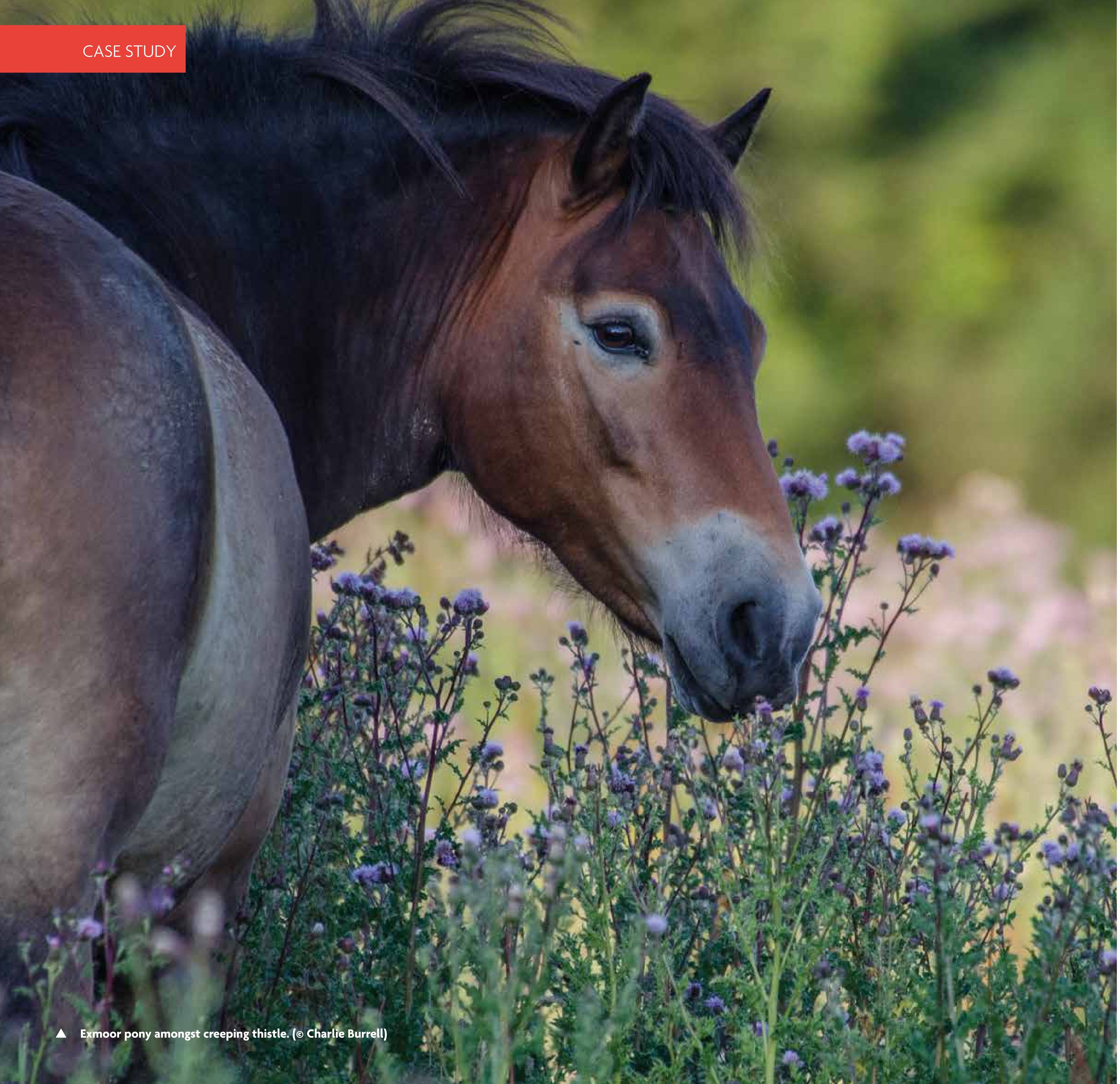
across the Wicken Fen vision area yields insights into the success and consequences of this approach, and the future trajectory of the site continues to be driven by biotic and abiotic factors. ES

Professor Rosie Hails MBE is an ecologist and Nature and Science Director at the National Trust, holding honorary chairs at Exeter and Cranfield universities. Her role is to develop the Trust's nature strategy and research portfolio and advise on science evidence relevant to Trust decision-making. She is a member of Defra's Science Advisory Council, chairing the Biodiversity Targets Advisory Group, and a member of Defra's Bovine Tuberculosis Partnership. Formerly, she was the Science Director for Biodiversity & Ecosystem Science at the UK Centre for Ecology & Hydrology. She was awarded an MBE for services to environmental research in 2000.

Ben McCarthy is an ecologist working as Head of Nature Conservation & Restoration Ecology at the National Trust. This role involves realising the Trust's ambition for nature and nature-based climate solutions, contributing towards building the evidence and Trust's reputation as a leading UK nature conservation organisation.

REFERENCES

1. National Trust (no date) *Fabulous fungi.* https://www.nationaltrust.org.uk/features/fabulous-fungi (Accessed: 5 September 2022).
2. National Trust (2015) *Playing Our Part.* https://nt.global.ssl.fastly.net/documents/national-trust-playing-our-part.pdf (Accessed: 5 September 2022).
3. Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J. and Wynne, G.R. (2010) *Making Space for Nature: A Review of England's Wildlife Sites and Ecological Network.* Technical Report to Defra. https://www.researchgate.net/publication/268279426_Making_Space_for_Nature_A_Review_of_England%27s_Wildlife_Sites_and_Ecological_Network (Accessed: 1 August 2022).



▲ Exmoor pony amongst creeping thistle. (© Charlie Burrell)

CASE STUDY

Rewilding Knepp Castle estate

Isabella Tree looks at how the Knepp rewilding project differs from conventional ecosystem restoration efforts.

A BRIEF HISTORY OF LAND MANAGEMENT AT KNEPP

The land on the 3,500-acre Knepp Castle estate in West Sussex is comprised of notoriously heavy clay with traditional small fields marked out by hedges and ditches. It has never been ideal for intensive farming. However, in the 1940s, as Britain began to 'Dig for Victory', every inch of the land – including ancient water meadows – was ploughed up for arable use, right up to the front door. The Green Revolution of the 1970s heralded pesticides, fertilisers, new crop varieties and bigger machinery – and yet, still, more often than not, we failed to turn a profit.

And so, 22 years ago, we embarked on a rewilding project. We began to look for an alternative way to manage the land, starting with the restoration of Repton Park around the house and gradually, over the course of six years, took out all the remaining land from agricultural use.

Twenty-two years on, the wildest and woolliest part of the estate – known as the Southern Block – has taken on an African look, with wild scrub crisscrossed by meandering animal trails. Among numerous species returns the Southern Block has become a breeding hotspot for some of the UK's rarest migrant birds. This year we counted 50 singing nightingales – a Red List bird making a comeback (see **Figure 1**). We heard our first turtle dove here 15 years ago and last summer we believe we had at least 20 male territories – a quarter of Sussex's population in just 1,000 acres (see **Figure 2**). Cuckoos, too – now conspicuous by their absence in much of the rest of the country – are plentiful here once again.

CASE STUDY

▲ Figure 1. A nightingale photographed at Knepp. Nightingales are one of the most remarkable and surprising successes of the rewilding project. (© David Oldham)

WHAT MAKES KNEPP DIFFERENT

The question is: why Knepp? What is happening here that is not happening elsewhere? Can lessons learnt at Knepp change existing conservation practices for the better? These questions go to the very heart of rewilding, what it means as a concept and its implications as a practice that could be rolled out nationwide.

"[...] it is here, in the shifting margins between grassland, scrub and trees, the crumbling banks of rivers, muddy scrapes and evaporating puddles, where most of life thrives."

The key to Knepp's success is that it is process-led. In contrast to conventional conservation practices that often target a particular species, like the lapwing or bittern, or aim to preserve a particular habitat, like woodland or heath, Knepp is concerned with natural processes, allowing nature its head. This involves, in a sense, sitting back and simply seeing what happens. It is a lesson in how to relinquish control. Inspired by Frans Vera's groundbreaking treatise *Grazing Ecology and Forest History*[1] we took on board the theory that grazing animals are key drivers of habitat generation and biodiversity and introduced red deer, fallow deer, longhorn cattle, Exmoor ponies and Tamworth pigs (see **Figure 3**). Roaming freely in natural herds with minimal human interference, they are allowed to graze, browse, root around, puddle and trample as they like. Each species, through its different actions, stimulates vegetation in a variety of ways, thus encouraging species biodiversity across the spectrum.

We have intentionally excluded sheep. In effect, the ungulates (hooved animals) we have introduced are proxies of some of the key species of megafauna – like the auroch, elk, tarpan and wild boar – that would have been present in our landscape after the last ice age, and with which our ecology has evolved. The only managerial role we take as the apex predator – in the absence of the wolf, lynx, wild boar and bear – is to control stocking levels. Too few animals and the

▲ Figure 2. The Knepp estate is a stronghold for the turtle dove in Britain. The species has seen a steep decline in numbers nationally and across Europe over the past half-century. (© Ben Green)

CASE STUDY

▲ **Figure 3. Free-roaming Tamworth pigs and longhorn cattle at Knepp. (© Charlie Burrell)**

land will revert to species-poor closed-canopy woods; too many and it will revert to species-poor open grassland. But the right density of grazers stimulates a dynamic mosaic of habitats, and it is here, in the shifting margins between grassland, scrub and trees, the crumbling banks of rivers, muddy scrapes and evaporating puddles, where most of life thrives.

Because the project is not goal-driven, we have learnt to take a back seat in all other managerial respects. For example, in the early days when large areas of grassland were overtaken by pioneering creeping thistle, it took a great deal of willpower to resist spraying it. Had we done as our old farming instincts urged us, we would have missed the miraculous sight of tens of thousands of migrating painted lady butterflies swarming on the flowering thistle heads. And only by sitting on our hands did we discover one fine day that the thistle had gone of its own accord – overtaken by some natural pathogen or by a perfect storm of events that eradicated the lot.

REMARKABLE LESSONS LEARNT

It is this simple wait-and-see policy that has led to some of Knepp's most unexpected returns and discoveries that are beginning to rewrite the scientific textbooks. The demise of coppicing in the UK over the last 20 years has meant that nightingales have abandoned woodlands and shifted to areas of scrub. Unfortunately, there is very little scrubland left in the UK and this is presumably one of the main contributing factors to their decline.

At Knepp, however, we have plenty of emerging scrub – notably, miles of unruly, expanding hedgerows. This is where nightingales have established their territories. What they are selecting specifically, according to studies undertaken by Imperial College in 2013,[2] are old hedges comprised of at least 60 per cent blackthorn where the base has grown out to 8 m wide. This is where the dense, thorny, complex, cathedral-like structure provides them with maximum protective cover from the ground up, and plenty of foraging potential inside with a cornucopia of insects in the leaf litter on the ground. In these areas we have male nightingales, sometimes only yards apart, singing their hearts out to overflying females – an extraordinary density of territories. Had we been solely concerned with re-establishing nightingales we would probably have discovered none of this. We would likely have followed the prescriptions for the

▲ **Figure 4. First observed at Knepp in 2010, the estate is now home to the UK's largest colony of purple emperor butterflies. (© Neil Hulme)**

nightingale as a woodland species and been surprised when our attempts met with few, if any, colonising birds.

The same goes for the astonishing appearance of purple emperor butterflies at Knepp – now one of the biggest breeding hotspots in the UK (see **Figure 4**). Previously considered an exclusively woodland species, we see them thriving on Knepp's emerging sallow where they lay their eggs. You are just as likely to see them chasing each other around the scrub here in summer as displaying in the oaks canopies nearby.

The problem is that the UK landscape is so changed and so manicured that many species, if they survive at all, are living at their absolute edge of viability, forced to take up inappropriate or excessively challenging habitats. Because we only ever see them in such habitats, though, we assume these are their natural preference and we try to mimic these impoverished landscapes in our conservation efforts.

We almost certainly underestimate the ecosystems that most successfully support an individual species, too. The decline of the turtle dove in the UK is attributed primarily to the loss of weed species – such as fumitory with its tiny seeds – thanks to intensive farming practices. There are certainly plenty of small seed-carrying plants at Knepp, along with tracks and open ground where the dove likes to feed. But who is to know if there aren't many more factors involved in its return here?

The reappearance of scrub at Knepp, and the astonishing resurgence of wildlife it has encouraged in such a short space of time, has the potential to re-educate our sensibilities. It shows how we might improve biodiversity on marginal land likely to fall out of agriculture in the post-Brexit shakeup of farming subsidies; it points to a way of providing the webbing that can connect existing conservation sites, to bring about Professor Sir John Lawton's vision of 'bigger, better and more joined up' nature in Britain.[3] It shows how land can be used for other forms of provision vital for the public good – ecosystem services like carbon sequestration, soil restoration, flood mitigation, water storage, air purification, human health and recreation. It even demonstrates an alternative, low-cost, natural way of re-establishing woodland, without the need for carbon-intensive polypropylene cylinders, tanalised wooden stakes and high-maintenance planting by human hand. The Knepp project is, ultimately, a signal reminder of our need to embrace messy, exuberant scrubland once again and to allow it space in the landscape – and in our hearts. ES

Isabella Tree writes for publications such as *National Geographic*, *Granta*, the *Sunday Times* and *The Observer*. Her articles have been selected for the Best American Travel Writing and *Reader's Digest*, and she is an Overall Winner of the Travelex Travel Writer Awards. She published her first book *The Bird Man – a Biography of John Gould*[4] when she was 25. Her latest book *Wilding – the Return of Nature to a British Farm*[5] charts the story of the pioneering rewilding project in West Sussex.

REFERENCES

1. Vera, F. (2000) *Grazing Ecology and Forest History*. Wallingford: CABI Publishing.
2. Hicks, O., Burrell, C. and Lord, A.M. (no date) *Benefits of Extensive Agriculture for the Nightingale, Luscinia Megarhynchos*. https://static1.squarespace.com/static/595ca91bebbd1a1d0aaab285/t/5a538a56ec212d62e320eb25/1515424344364/Hicks+Burrell+and+Lord+_Conservation_Biology_manuscript.pdf (Accessed: 22 August 2022).
3. Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J. and Wynne, G.R. (2010) *Making Space for Nature: A Review of England's Wildlife Sites and Ecological Network*. Report to Defra. https://webarchive.nationalarchives.gov.uk/ukgwa/20130402170324mp_/http://archive.defra.gov.uk/environment/biodiversity/documents/201009space-for-nature.pdf (Accessed: 5 August 2022).
4. Tree, I. (1991) *The Bird Man – a Biography of John Gould*. London: Barrie & Jenkins.
5. Tree, I. (2019) *Wilding – the Return of Nature to a British Farm*. London: Picador.

Editor	Danielle Kopecky
Guest editor	Professor Jim Harris
Subeditor	Christina Petrides www.lastglance.net
Designer	Kate Saker katesaker.com
Printer	Lavenham Press Ltd
Published by	Institution of Environmental Sciences 1st Floor 6–8 Great Eastern Street London EC2A 3NT
Tel	+44 (0)20 3862 7484
Email	info@the-ies.org
Web	www.the-ies.org
Twitter	@IES_UK

This journal is printed on Forest Stewardship Council certified paper. The CO_2 emissions generated by the production, storage and distribution of the paper are captured through the Woodland Trust's Carbon Capture scheme.

There are many reasons why

we're one of the UK's

fastest growing

professional bodies.

Find out why you should join us.

Professionalism

Sound science

Quality assurance

Responsibility

Equality

Equity

Integrity

www.the-ies.org

The Institution of Environmental Sciences