Imperial College London

HITACHI
Inspire the Next

Biodiversity and Ecosystem Function:

A global analysis of trends

E R Moffett, J H Gayford,
G Woodward, W D Pearse

IMPERIAL
POLICY
FORUM

What are ecosystem functions and how do they relate to biodiversity?

Ecosystem functions are the biological, geochemical, and physical processes that take place within an ecosystem. The terminology around them is complex - when an ecosystem function provides a benefit to humans it may be termed an 'ecosystem service', and when a function solves a societal challenge it may be termed a 'nature-based solution' - but ultimately ecosystem functions support human life and contribute to ecosystems' health, stability, and resilience. The absorption of carbon dioxide by forests, the control of rodent populations by birds of prey, and the filtering and storing of water by wetlands are all examples of ecosystem functions that are also nature-based solutions, and they operate across all habitat types (Figure 1).

High levels of biodiversity are vital to preserving ecosystem functioning. Species play different roles in ecosystems, such as pollination, decomposition, and carbon capture[1–4], and maintaining diversity is essential for all these roles to be fulfilled. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) found that most ecosystem services are in decline[5]. Decreases in biodiversity have a negative impact not only on our ability to maintain fully functioning ecosystems, but also harm our economy both directly and indirectly. For example, each year invertebrate pests (which can proliferate due to reduced biodiversity) cost the UK economy over £1.7 billion[6]. Biodiversity is in some ways similar to capital goods, which may depreciate with overexploitation, but unlike other capital goods ecosystems are often irreplaceable and may collapse at unknown tipping points[7].

Why does this research matter?

Humans have significantly reduced biodiversity through various activities, including habitat destruction, overexploitation, introduction of invasive species, climate change, and pollution[8]. In the United Kingdom, monitored freshwater and terrestrial biodiversity has reduced by 19% between 1970 and 2021[9]. In 2022, Governments from across the world agreed on the creation of the Kunming-Montreal Global Biodiversity Framework at COP15, with a mission to halt and reverse the loss of nature by 2030 and achieve recovery by 2050. This agreement was historic in that it linked biodiversity loss and climate change at the international level for the first time. Reversing declines in biodiversity is key to preserving the ecosystem functions that ultimately underpin human wellbeing. If we are to implement our 2030 and 2050 goals we must develop a better understanding of the relationship between biodiversity and ecosystem function.

This research was conducted over the last year as part of the *Hitachi-Imperial Centre for Decarbonisation and Natural Climate Solutions*, with the aim of better understanding biodiversity and ecosystem function relationships. While we know that biodiversity often improves ecosystem functioning and so the provision of nature-based solutions, our goal was to synthesise disparate studies to build a complete, quantitative picture of how different kinds of ecosystem functions respond to biodiversity, since the shape of the relationship will be key for designing future interventions.

What did we find?

We have produced what we believe to be the world's largest database of how changes in biodiversity affect ecosystem function, containing >220,000 direct measurements. We found a huge variety in how ecosystem functions respond to biodiversity, with functions such as carbon sequestration and productivity responding the most strongly (Figure 2). This drives home the importance of biodiverse and healthy ecosystems in providing the nature-based solutions that humanity depends upon.

Recommendations for policymakers:
grow diverse ecosystems, don't just plant trees

1.
DIVERSE ECOSYSTEMS CAPTURE MORE CARBON

Tree-planting is an increasingly important weapon in the fight against climate change[10], but carbon sequestration from forests will be much more effective when those forests are biodiverse. This makes the protection of intact biodiversity critical, as its loss threatens the environment's ability to sequester carbon, and makes the planting of diverse, native forests a priority in tree-planting initiatives. This need for explicit consideration of (native) biodiversity is also true for other conservation and restoration projects that don't involve trees, including marine and freshwater carbon sequestration (so-called 'blue carbon')[11].

UK policy needs to shift from its current focus on counts of, or areas covered by, trees, to increasing the area of diverse forest. The Environmental Improvement Plan (2023)[12] sets a commitment to increasing canopy cover to 16.5% of land-cover by 2050; our findings suggest that setting diversity commitments within those forests would make the delivery of nature-based solutions more effective, and would likely increase tree survival and so increase efficiency of restoration. The current proposals for the UK's Biodiversity Net Gain[13] framework place heavy emphasis on habitat area and tree size, but less on biodiversity and its quality or composition. Quantifying the change in biodiversity before/after interventions and in restorations is possible and will ensure more effective delivery of nature-based solutions.

2.
DIVERSE ECOSYSTEMS SUPPORT PRIORITY SPECIES

While the majority of ecosystem functions are more efficiently and effectively provided by more diverse ecosystems, our research suggests that the provision of a small number of functions is not necessarily enhanced by greater biodiversity. Crucially, this does not mean ecosystems are not providing these functions - they must be because those benefits have been measured in our database - but rather that improving the biodiversity within an ecosystem doesn't enhance their provision. For example, our data suggests that high biodiversity is not an essential component of the regulation of hazards and extreme events (Figure 2). Sand dunes, for example, are often stabilised by one or two key shrub species which allow sand dunes to build up and provide protection from extreme events by creating a natural barrier, reducing flooding and coastal erosion[14]. It is these few functionally important 'ecosystem engineers' that are disproportionately important. Even these species, however, cannot exist in isolation and are themselves supported and sustained by the wider ecosystem. More biodiverse ecosystems are more resilient to environmental change[15], and so investing in biodiversity now will yield a greater, and more efficient, return on investment.

Influential reports such as the Dasgupta Review on the Economics of Biodiversity have broadly accepted that biodiverse ecosystems are more resilient, but metrics that inform UK policy need to be updated to accommodate this. For example, Defra's 2023 Environment Improvement Plan commits to using nature to reduce flood and coastal erosion risk, but contains no specifics about the metrics by which to assess the ecosystems providing these solutions. These plans, and any plans involving specific nature-based solutions, should not only incorporate specific, named species to be prioritised but also highlight that these species must themselves be supported and maintained by a diverse, healthy ecosystem.

3.
GROW URBAN ECOSYSTEMS

Many ecosystem functions spill over to their surroundings, providing potential solutions to humans in nearby regions. For example, planting diverse forests provides many benefits in addition to carbon sequestration, such as providing natural spaces, improving public health, and improving water quality and quantity. While we still need to understand precisely how far those benefits ripple out to the wider landscape, more needs to be done to both publicise and make use of those benefits. In many cases humans benefit from natural areas that are distant from cities (such as the flood protection and water quality that wetlands provide), and in other cases from biodiversity embedded nearby, as within urban ecosystems (such as the cooling and wellbeing benefits of trees).

Maximising the return on investment of the UK's biodiversity net-gain policies will mean engaging carefully with urban development. Biodiversity credit systems, where local losses are compensated elsewhere, have the potential to lead to nature-based solutions going untapped because the biodiversity providing them is separated from humans. Equally, tree- and area-counting approaches could lead to individual units of biodiversity being so separated that they cannot form ecosystems. Net-gain metrics and accounting should be designed to reward connected, resilient, self-sustaining ecosystems rather than gardens that showcase individual trees and plants but require costly maintenance and struggle to provide broader benefits.

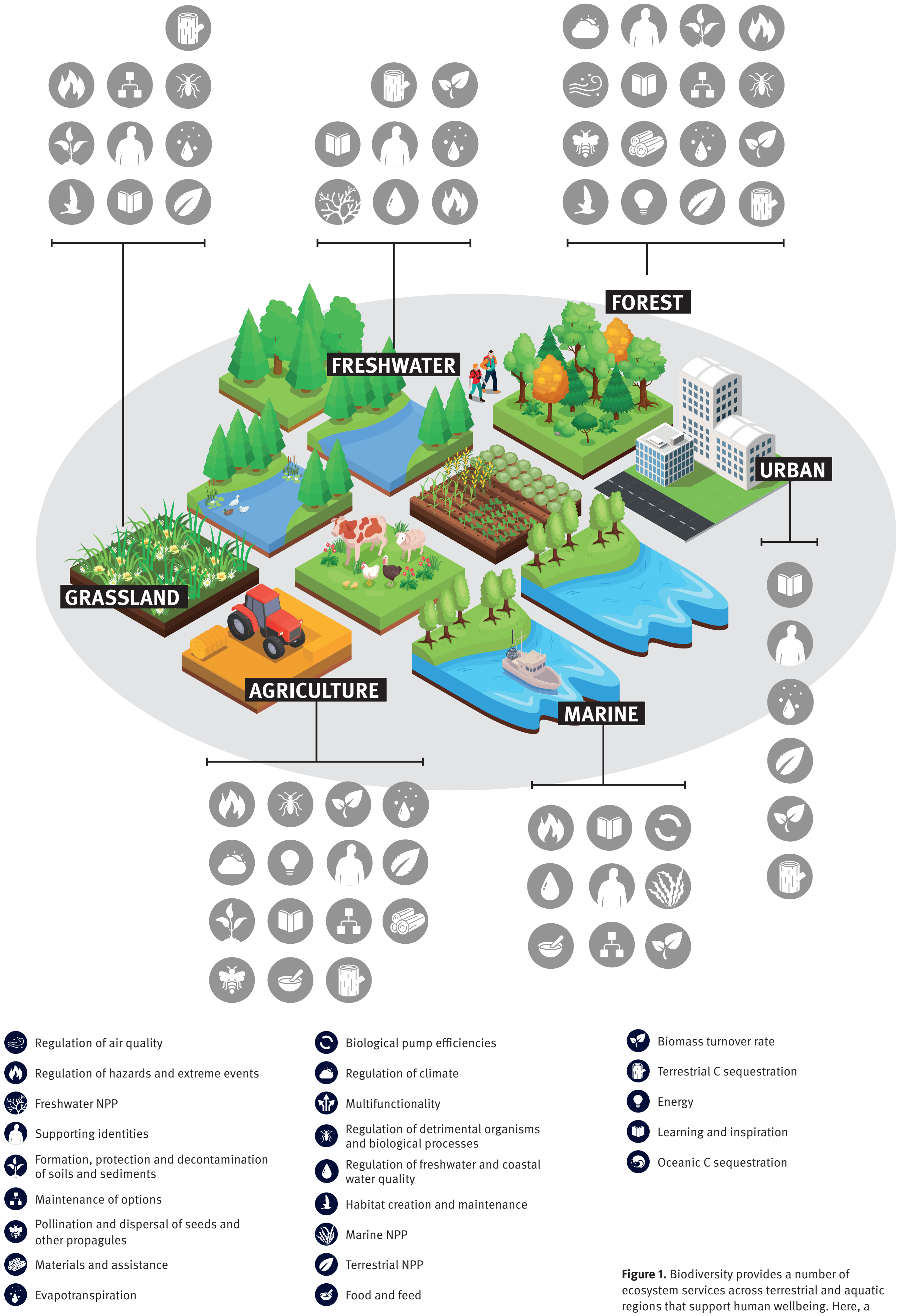

Figure 1. Biodiversity provides a number of ecosystem services across terrestrial and aquatic regions that support human wellbeing. Here, a selection of those services are shown across a variety of habitats. NPP stands for Net Primary Production.

Figure 2. A comparison of how each ecosystem function responds to increases in biodiversity. These are 'effect sizes' (Fishers Z-score; Zr) where higher values indicate a greater increase in function in comparison with other functions. We emphasise that all of these functions are provided by ecosystems: here we are measuring how that provision increases with biodiversity. NPP stands for Net Primary Production.

Methodology

Literature survey

We used a meta-analysis approach to determine the effect of biodiversity on ecosystem functions. Because there has been a significant amount of research done on this topic, we used a stratified meta-analysis to select an initial 4,875 publications to check for relevant data. Our stratified approach ensured selected literature covered all biomes, eco-regions and the most commonly studied ecosystem function categories. We used the ecosystem function categories set out by IPBES from global indicators of rates of ecosystem function and nature's contributions to people (Diaz *et al*. 2019; IPBES, 2021). Each publication was checked for data by reading through the publication's abstract and checking its keywords. If a publication was relevant and data were available, we added it to our database.

We split data from publications into unique datasets where a study included multiple measurements of biodiversity, ecosystem function, location, or taxon. Within each dataset, we filtered out data with less than six data points for either ecosystem function or biodiversity measurement. After filtering, our database includes data from 424 unique publications, 1962 unique datasets, and 223,056 data points. Data were standardised to control for different measurement units across studies.

Effect size calculation

To determine differences in biodiversity effects among ecosystem functions, we calculated effect size as the response of ecosystem functions to increasing biodiversity on each dataset. To calculate effect size we used simple correlation coefficients (*r*) between biodiversity and ecosystem function, which were normalized using Fisher's z-transformation (*Zr*) as;

Zr = 0.5 ln1+ r(1-r)

We use *Zr* as an independent variable to compare the strength of biodiversity and ecosystem function relationships among ecosystem function categories.

References:

1. Tilman, Isbell & Cowles (2014). *Annual Review of Ecology, Evolution, and Systematics*, 45 471–493. DOI: 10.1146/annurev-ecolsys-120213-091917.

2. Brose & Hillebrand (2016). *Philosophical Transactions of the Royal Society B* 371: 20150267. DOI: 10.1098/rstb.2015.0267.

3. Schwartz *et al.* (2000). *Oecologia* 122: 297-305. DOI: 10.1007/s004420050035.

4. Jax (2005). *Oikos* 111: 641-648. DOI: 10.1111/j.1600-0706.2005.13851.x.

5. Williams *et al.* (2010) "The Economic Cost of Invasive Non-Native Species on Great Britain". CABI Proj No. VM10066: 1-199.

6. IPBES. *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (2019).

7. Dasgupta (2021). T*he economics of biodiversity: the Dasgupta review.* London HM Treasury.

8. Turvey & Crees (2019) *Current Biology* 29: R982-R986. DOI: 10.1016/j.cub.2019.07.040.

9. State of Nature Partnership, State of Nature. TP25999, 1-108 (2023).

10. Mo *et al.* (2023) Nature 624: 91-101. DOI: 10.1038/s41586-023-06723-z.

11. Reynard *et al.* (2020) Grantham Institute, Imperial College London. DOI: 10.25561/84458

12. Defra (2023). Environmental Improvement Plan. Available at https://www.gov.uk/government/publications/environmental-improvement-plan. Last accessed: 8th February 2024.

13. Defra (2023). Guidance: Calculate biodiversity value using the biodiversity metric. Available at: https://www.gov.uk/guidance/biodiversity-metric-calculate-the-biodiversity-net-gain-of-a-project-or-development. Last accessed: 8th February 2024.

14. Arkema *et al.* (2013) *Nature Climate Change* 3(10): 913-918. DOI: 10.1038/nclimate1944.

15. Craven *et al.* (2018) *Nature Ecology & Evolution* 2(10): 1579-1587. DOI: 10.1038/s41559-018-0647-7.

This Briefing Note has been generated via the *Hitachi-Imperial Centre for Decarbonisation and Natural Climate Solutions*, a 5-year initiative between Hitachi Ltd, Hitachi Europe and Imperial College London which commenced in August 2022 with the goal of aiding the transition to net zero pollution. Taking a multidisciplinary approach, we work together on a set of joint research projects, co-created and co-supervised, with a focus on decarbonisation and climate repair. Our activities are based on three research pillars: Carbon Management and Decarbonisation, CO_2 Removal (Technology and Nature-based Solutions), and Socioeconomic and Policy work. The Centre brings together researchers at Imperial from the Faculties of Engineering, Natural Sciences and the Business School and in partnership with the Global Challenge Institutes for Energy and Climate.

For more information visit:
www.imperial.ac.uk/hitachi-centre