Genetic diversity is key to a nature-positive future

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Abstract

1. Nature-positive describes the concept of halting and then reversing the loss of biodiversity in a manner that is equitable to all, particularly indigenous peoples and local communities.
2. Genetic diversity is the foundational component of biodiversity, underpinning species and ecosystem diversity. Genetic diversity is vital to resilience and ecosystem services. While genetic diversity was included in early definitions of nature-positive, it has been omitted from some more recent framings. Here we discuss why this omission may jeopardise the very ecosystems which the concept aims to protect.
3. The limitations around data and methods for assessing genetic diversity are rapidly disappearing. Thus we argue genetic diversity should be used for measuring nature-positive outcomes. With advances in genetic and genomic technologies, this approach can even be more affordable than assessing species or ecosystems. If DNA-based data are not available, indicators are available for inferring the status of genetic diversity with proxy data.
4. *Policy implications*: It is both possible and beneficial to incorporate genetic diversity in biodiversity assessments for nature-positive. It should be used in co-developing management plans at local and national levels. Including genetic diversity in steps to build a nature-positive future is thus essential if the concept is to achieve its aims.

Keywords

Metrics, bending the curve, biodiversity loss, resilience, just transition, science-policy, genetic diversity.

Introduction

Nature and people are inextricably linked. The relationship between them ranges from nature as a resource, to people being part of nature (Pereira et al., 2020). The sizeable loss of biodiversity since the industrial revolution (Dìaz et al., 2019) is reducing the ability of nature to provide life-sustaining contributions to people. Nature-positive has emerged as a concept that builds on, and seeks to go beyond, previous strategic approaches to halt and reverse biodiversity loss (zu Ermgassen et al., 2022).

Genetic diversity is the foundational component of biodiversity and underpins species and ecosystem diversity. Genetic diversity is historically under-recognised in policy and reporting (Hoban et al., 2021), is poorly protected (Schmidt et al., 2024), and is being lost at a rate outside of safe Planetary Boundaries for humanity (Richardson et al., 2023).

A nature-positive future requires halting and reversing nature loss by 2030, followed by restoration leading to full recovery by 2050, frequently referred to as “bending the curve” (Locke et al., 2021). Such a future would be equitable and carbon neutral. It is therefore well-aligned with the concept of a just transition (Booth et al., 2024). Originally, nature-positive envisaged a holistic biodiversity focus, including genetic diversity, species diversity, ecosystem diversity, and ecological and global processes (Locke et al., 2021; Nature Positive Initiative, 2022). While Locke et al. (2021) recognised the intrinsic value of within species genetic diversity, both in its own right and as one of Nature’s Contributions to People, more recent interpretations of nature-positive omit genetic diversity (e.g. IUCN, 2023; Baggaley et al., 2023). Here we argue that omitting genetic diversity from nature-positive will limit its potential and jeopardise the very ecosystems which the concept aims to protect.

At the heart of the link between genetic diversity and nature positive, is its link with resilience. The term ‘ecological resilience’ is used in a range of ways (see review by Meerbeek et al, 2021), broadly encompassing the ability of populations to recover after perturbation (Pimm, 1984). Ecological resilience is key to stable nature derived goods and services (i.e. ecosystems services or Nature’s Contributions to People). Genetic diversity is vital for ecological resilience because it underpins variation in response, natural selection and adaptation, and the maintenance of long term fitness (Standish & Parkhurst, 2024).

The role of genetic diversity in a nature-positive future

European ash *Fraxinus excelsior* provides an example of the importance of genetic diversity for provisioning services. Ash is important for timber production and other ecosystem services, as well as supporting a very large number of other taxa. It is severely affected by ash dieback *Hymenoscyphus fraxineus*. Coker et al (2019) found maximum recorded mortalities of 85% in plantations established before the epidemic arrived, compared with 70% in natural woodlands. The reason for lower mortality in natural woodlands is not clear, but may relate to higher genetic diversity, better local site adaptation, or greater microbial diversity, which might provide protection against *H. fraxineus*. The latter two reasons may also be linked to host genetic diversity. Semizer-Cuming et al (2019) showed that trees with lower susceptibility contributed more to the next generation. Provided regeneration is able to occur, ash populations should thus be able to adapt to this threat.

Similarly, seagrasses (*Zostera* spp) provide a wide range of regulating services including carbon capture and acting as nurseries for a wide array of species, including commercially important fish and shellfish. Seagrass is the focus of conservation interventions throughout its range. Heat resilience in seagrasses is strongly correlated with genetic diversity and, as a result, genetic considerations have played a key part in restoration efforts (Pazzaglia et al, 2021).

Genetic diversity also underspins cultural services. Tuatara (*Sphenodon punctatus*) is the sole remaining representative of a once widespread reptile order, endemic to New Zealand. Tuatara are considered a *taonga* species (special treasure) and are viewed as the *kaitiaki* (guardian) of knowledge and the messengers of Whiro, the god of death and disaster.

Conservation efforts, such as translocation, have fully incorporated genetic diversity to reduce the risk of issues such as inbreeding depression and to provide a reservoir of adaptive potential (Cree, 2014). These efforts also highlight the importance of co-development of conservation strategies with indigenous and local communities to ensure equitability (Cree, 2014; Minter et al., 2021), a key tenet of nature-positive.

The concept of equitability in sharing the benefit sharing forms of Digital Sequence Information (DSI) has been central to negotiations at the Convention on Biological Diversity (CBD), and is highly relevant to the nature-positive debate. DSI refers to information derived from genetic sequence data typically held in a database. DSI is already being used for nature conservation and to provide economic benefit, for example in the development of medicine. However, the financial benefits are frequently not realised by the local communities whence the original genetic samples were taken (Halewood et al. 2023). A nature-positive lens will help ensure more equitable benefit-sharing with indigenous peoples who have often been responsible for the safeguarding of genetic diversity.

Climate change is amplifying the biodiversity crisis, and Global South countries are expected to be disproportionately affected (Almulhim et al. 2024). In the largest wetland in the world, the Brazilian Pantanal, fires and drought have increased due to climate change. This is so severe that up to 30% of the biome suffered from human-made fires in 2020 alone (Leal Filho et al., 2021). The Pantanal holds the second largest population of Jaguars which are known to be vulnerable to genetic diversity loss when populations are fragmented (Haag et al., 2020; De Barros et al., 2022). These climate-change mediated disturbances will likely impact the genetic diversity and resilience of many species like jaguars, increasing their extinction or extirpation risk. Loss of genetic diversity in species will likely also exacerbate climate change’s effects further. Widespread coral bleaching and mortality are increasing in response to ocean warming. Genetic variants linked to increased thermal tolerance can exist in some species. It is vital these are preserved to maximise the probability of adaptation to higher temperatures occurring to support species persistence (van Woesik et al., 2022).

Genetic diversity and economic systems

Whilst biodiversity conservation action has traditionally been financed and led by governments and specialist Non Government Organisations, the private sector is becoming increasingly important. During the 2022 United Nations Biodiversity Conference (COP15) in Montreal, over 1,400 businesses called for action on biodiversity, demonstrating commitment to implementing international agreements (Burgess et al., 2024). The drivers for engagement for safeguarding biodiversity vary between sectors and individual companies, but often centre on developing new business opportunities or risk mitigation, whether that be from loss or degradation of ecosystems services, reputational damage, or other causes (World Economic Forum, 2020). While there has been an uptake of the concept of nature-positive by some companies, there is also a high risk of green-washing (Maron et al., 2024).

Halting the biodiversity crisis will be only successful if a mitigation strategy is developed to address the economic drivers of biodiversity loss (see e.g. Mair et al., 2024). Reporting on the status of biodiversity by business needs to be formalised and aligned with that required for economic and financial trends. Notably, the Kunming-Montreal Global Biodiversity Framework (KMGBF) has an action-oriented target (Target 15) in which businesses are encouraged to identify and disclose their dependencies and impacts on biodiversity (Convention on Biological Diversity, 2024). However, current guidance for business disclosures such as the Taskforce on Nature-related Financial Disclosures (TNFD) and Science Based Targets Network (SBTN) generally lack explicit metrics for monitoring genetic diversity. At best, TNFD’s additional sector guidance recognises “genetic material” within ecosystem services in guidance for food and agriculture, aquaculture, chemicals, and metals and mining; the biotechnology and pharmaceuticals guidance mentions that degradation of genetic diversity might impact raw material quality and availability; while only the oil and gas guidance explicitly mentions Target 4 and genetic diversity restoration (TNFD, 2024) . The neglect of genetic diversity must be rectified to ensure nature positive reaches its full potential.

Genetic diversity in wild and domesticated species supports human wellbeing

The relationship between the health, wellbeing, and resilience of ecosystems is recognised in the interlinked triple planetary crisis (climate change, biodiversity loss, and pollution; World Economic Forum, 2024). Access, proximity and exposure to biodiversity and nature is associated with long-term and population-level improved physical, mental and social wellbeing (e.g. Kardan et al., 2015; Robinson et al., 2021; Geary et al., 2023). The artificial boundary between health and ecology continues to be dismantled, revealing linkages between our environment and human health at the microbial level. For example, diversity of land-use and soils is related to microbial diversity, and to human immune systems (von Hertzen et al., 2011; Roslund et al., 2022). Host plant genetic diversity has been shown to be a key driver of microbial community (Van Geel et al., 2021), demonstrating an underappreciated interaction that impacts human health.

Coherent, resilient and thriving ecosystems also create greater opportunities for people to interact with nature. This promotes direct health and wellbeing benefits over the long-term, as well as fostering connectedness with nature, that is integral to pro-ecological behaviours, addressing the key indirect drivers associated with the loss of biodiversity (IPBES, 2019). However, as already demonstrated, nature needs genetic diversity in order to be resilient and provide these benefits.

Measuring and managing genetic diversity

Genetic diversity may be excluded from nature-positive definitions because of the view that it is too complex to assess or manage (Baggaley et al., 2023). However, genomic advances mean that genetic diversity can be measured and monitored easily, and at a greatly reduced cost relative to historical averages. Thus, conservation of genetic diversity can and should be implemented in practical management plans and programmes. Governments and businesses can begin by implementing genetic diversity monitoring programmes, and setting targets for its protection that reflect global policy agreements. This would allow improved measurement of loss of genetic diversity, and identification of regions undergoing harmful loss or target regions for protection (Hollingsworth et al., 2020; O’Brien et al., 2022; Hoban et al., 2024a,b).

Genetic diversity can be monitored using DNA-based genetic data and with simpler and affordable proxies or indicators. DNA-based data is more affordable than formerly and can be used for measuring nature-positive outcomes at a local level for at least hundreds and possibly thousands of species. Datasets covering global diversity are publicly available (e.g. Schmidt et al, 2024), and with advances in technology, this may be more affordable than assessing species or ecosystems. If DNA-based data are not available, nature-positive outcomes can be measured with proxy data, such as effective population size or number of populations (Mastretta-Yanes et al., 2024). Countries and sub-national governments already use a range of approaches including DNA-based data, proxies or a combination of both. For example a genetic scorecard, as used by Scotland for reporting to the CBD in 2020 and further developed subsequently (O’Brien et al., 2022), and indicators of within- and among-population genetic diversity are being deployed for CBD reporting (Hoban et al., 2024a). Both approaches are scalable and can be included in nature-positive assessments, and there is guidance on species selection (Hvilsom et al., 2022).

It is important to consider loss of allelic variation from a species as an extinction-like event, as it will take hundreds of generations to re-arise through mutation (if at all). Though nature-positive may imply a recovery from current depleted levels of biodiversity in the future, this may not be possible if genetic diversity is irreversibly lost. Rapidly developing genomic methods now allow integration of large-scale genetic diversity data into management actions supporting legislation, policy and financial incentives (Hogg, 2024). Countries and regions can use this information to implement restoration actions for small populations through breeding programmes to encourage population growth, and translocations to restore genetic diversity (Hollingsworth et al. 2020; Minter et al., 2021). Furthermore, genetic diversity can be incorporated into area-based conservation, by protecting areas key for population connectivity or regions of high genetic diversity, reducing the risk of irreversible loss through habitat fragmentation and population isolation (e.g. Hoban et al., 2024b; Nielson et al., 2023; Paz-Vinas et al., 2018).

Conclusion

If the nature-positive concept is to be translated into actions for effective measures to halt and reverse biodiversity loss by 2030, it must consider and incorporate genetic diversity to ensure that its long-term recovery and adaptation goals are successful. Genetic diversity is the third and equally important component of biodiversity along with species and ecosystems (United Nations, 1992). Limitations around data and methods for monitoring genetic diversity are disappearing, and feasible indicators (Hoban et al., 2021; O'Brien et al., 2022) are ready for many species (Hollingsworth et al., 2020; Mastretta-Yanes et al., 2024). Therefore, genetic diversity is a vital component in any nature-positive future, and its incorporation in nature-positive metrics must be a priority.

Figure 1.

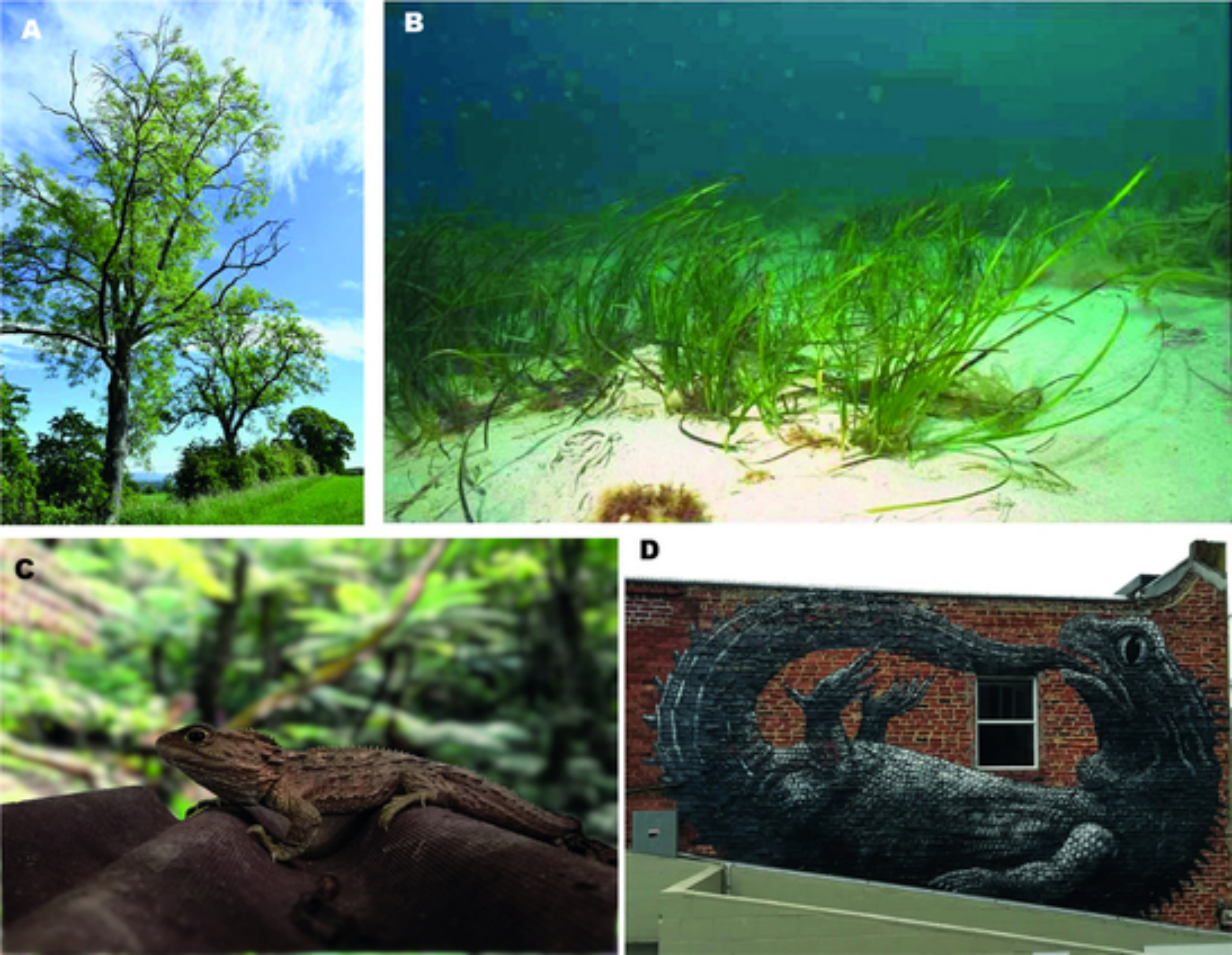
1.a European ash (*Fraxineus excelsior*) provides valuable timber as well as other ecosystems services, but is threatened by novel pests and pathogens. Genetic diversity is central to resistance to the pathogen *Hymenoscyphus fraxineus*.

1.b Seagrasses (*Zostera spp*) capture carbon and act as nurseries for marine species but are vulnerable to extreme heat. Resilience to heat has a genetic base and genetic diversity has been a key consideration in restoration projects.

1.c and 1.d The tuatara (*Sphenodon punctatus*) is a species of spiritual and wider cultural importance in New Zealand. The success of conservation and reintroduction programmes has been underpinned by genetics.

Author contributions

David O'Brien: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Conceptualisation;
Sean Hoban - Writing -original draft, Conceptualisation
All: Writing – review & editing, Writing –original draft, Investigation.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Conflict of interest statement

The authors declare no conflicts of interest.

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