Environmental *Change* Institute

Landscape Connectedness Under Climate Change in Oxfordshire

Implications of the Bioclimatic Ecosystem Resilience Index

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1. Introduction

Projected climate futures force us to rethink the way we approach nature. The concept of conservation breaks down as we are forced to consider a changing ecology, with new assemblages of species, and a shift from a relatively steady state to dynamic, continuous change. Our goal becomes the preservation of functioning natural systems, supporting the survival of species rather than the preservation of particular ecosystem types.

The magnitude and rate of climate change is an important consideration, since natural systems are already subject to continuous variation in climate, on short timescales with flood and drought, and on longer timescales with glaciation cycles. Projections of climate change over the next half century, however, potentially require rapid shifts in the locations of species. For long lived tree species, we can expect individuals to be living in unsuitable climatic conditions by the end of their lives. The directional aspect of the expected change is also important. Even with the more optimistic carbon mitigation projections, we can expect the climate to be around 2°C warmer for the foreseeable future, so that natural systems will have to adapt, rather than simply endure these new conditions.

To what extent does this really change the way we manage nature in and around Oxfordshire? Humans have extensively modified the countryside, and crops, improved pastures and urban development have fragmented the landscape. In order to improve outcomes for nature, we have only a few simple options. We can protect existing areas which are relatively natural. We can make our more modified systems more supportive of nature. And we can increase the degree of connectivity between more natural areas. In this way, we can increase the effective size of ecological populations, and of metapopulations (i.e. networks of connected populations). In a highly modified, co-evolved landscape such as the South East of England, it is useful to move to a continuous view of naturalness. Our species live not only in remnant bits of woodland or on patches of ancient (modified) meadows, but are also found in backyards, rubbish tips, wasteland, parkland, under crops, on pasture and in our canals, ponds and rivers. Whilst some of these areas are not as ecologically diverse as more natural systems, they still perform a vital role in the preservation of species. Increasing the connectedness of metapopulations, therefore, involves connecting all these systems, not just good condition to good condition. A caveat to this statement is that we want to optimise connection between like systems, so there are still advantages to connecting woodland to woodland, grassland to grassland and pond to pond. However, if we bring climate change into the picture, we can take a more nuanced perspective. Woodlands exist in environmental conditions for woodlands, flood meadows in conditions for flood meadows. We can therefore consider what we are already doing as connecting similar environmental conditions to similar environmental conditions. Putting a climate change lens on the problem, we can track the movement of these conditions, and potentially connect current woodlands to the place where conditions will be suitable for woodlands in the future.

These are the principles on which BERI, the Bioclimatic Ecosystem Resilience Index (Ferrier et al 2019, Harwood et al 2022) is built. BERI is a Component Indicator for Target 8 of the UN Convention on Biodiversity Global Biodiversity Framework 2022.

Target 8 Minimize the Impacts of Climate Change on Biodiversity and Build Resilience. Minimize the impact of climate change and ocean acidification on biodiversity and increase its resilience through mitigation, adaptation, and disaster risk reduction actions, including

through nature-based solution and/or ecosystem-based approaches, while minimizing negative and fostering positive impacts of climate action on biodiversity.

BERI is designed to quantify the extent to which the configuration of the landscape supports the movement of species to track shifting bioclimatic envelopes as they move with a changing climate. Over the next few decades, Britain will experience increased temperatures and shifts in rainfall patterns. These changes are likely to be of sufficient magnitude that many species will find themselves in environmental conditions that are sub-optimal. Such species will have several pathways to survival. Some may have sufficient flexibility in their existing makeup to endure the sub-optimal conditions in the absence of stronger competitors. Some may have the genetic capacity to adapt to the new conditions. Some may have to migrate in order to track the movement of their optimal climatic envelope.The directional nature of the climatic shift means that migration may be forced upon most species as time passes and temperature rises.

2. Methods

2.1 The BERI Index

The BERI Index is described in detail in Harwood et al 2022. The index builds upon Generalised Dissimilarity Models which synthesise biological observation data and environmental data to describe the change in composition of species between locations or over time. This is combined with a continuous surface of Habitat Condition which is used to both describe the extent to which each pixel can support native biodiversity and the permeability of the landscape (on the assumption that more natural landscapes are easier to traverse, When applied in a climate change context as in the BERI index, the system can be used to measure the extent to which the current landscape configuration allows each location to be connected to similar future ecological environments which are in good condition.

2.1.1 Generalised Dissimilarity Model

For the Oxfordshire region, a Generalised Dissimiliarity Model for the Temperate Broadleaved and Mixed Leaved Forests biome (Olson *et al* 2001) for the whole of the Palearctic Realm was used. This is assembled from 1km resolution data covering ecological environments across the whole Realm, covering a range of environmental conditions. This biome covers most of Britain. The model used here is for all Vascular Plants across the Palearctic. The resultant GDM model can be used to calculate the ecological similarity between any grid cell and all surrounding grid cells. The advantage of GDM models is that they can be used to estimate ecological similarity across time as well, so a cell can be compared with its future self or other cells in the future in the same way that it can be compared with other cells in the present.

2.2.2 Habitat Condition

The Habitat Condition surface used for the global 1km BERI analyses was generated by first downscaling the 12 Land Use Harmonisation 2 data products (Hurtt et al, 2020) using the approach of Hoskins et al (2016) to provide the proportion of each class in each square kilometre. These proportions are then converted to a measure of habitat condition using a weighted average of species-area based coefficients derived from the PREDICTS database. (Hudson et al 2017). The result is a map showing, for each 1km resolution grid cell, an average habitat condition, scaled 0 to 1 as an areal equivalent, such that two cells of condition 0.5 are functionally equivalent to 1 cell of condition 1 in terms of their ability to support native biodiversity. The resultant map can be seen in Figure 4a.

2.2.3 The BERI calculation

BERI is designed to measure, for each cell, how well the contents of that cell are connected to similar ecological environments of the future. The calculation is in essence a cost-benefit measure, where the benefit of being connected to another location is the ecological similarity (0-1) multiplied by the habitat condition (0-1). This benefit is calculated using current habitat condition and a range of future climate scenarios for each cell, as described in Harwood et al 2022. The cost of getting to the location is calculated by assuming that permeability of the landscape is a function of condition, and by calculating a least cost path across the landscape to get to each other location. This is calculated on a radial grid as shown in Figure 1 below, using the least cost path to each target segment, and the benefit as the sum of similarity times condition for that segment. The final index is an aggregation of

the results from multiple futures. The index is calculated for all cells relative to their neighbourhood. Whilst the index is calculated out to 500km, the radial grid structure ensures that local effects in the immediate neighbourhood are fully considered, and these tend to dominate the index, since a cell in a poorly connected area cannot become well connected.

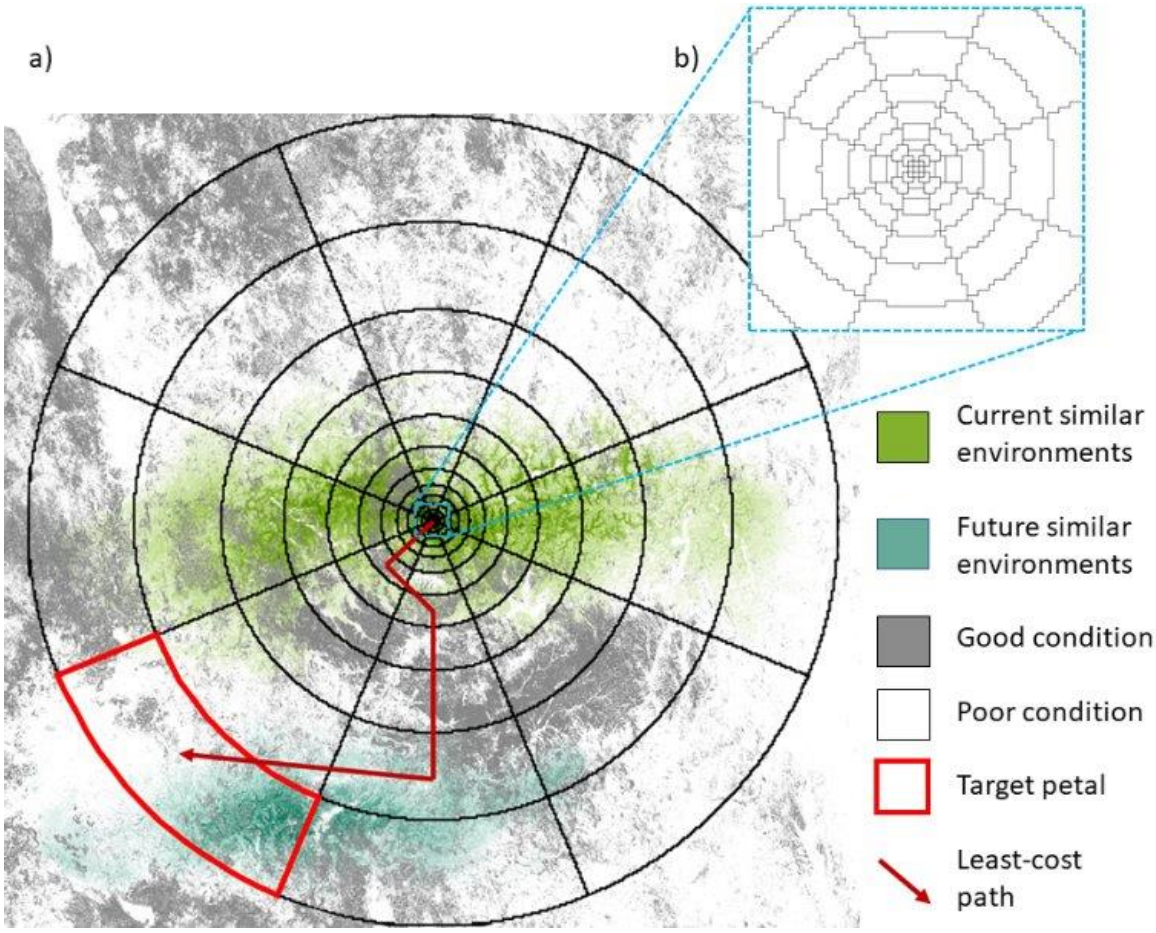

Figure 1: Calculating least cost paths to future ecological environments for the BERI index. A) shows the calculation for a single target segment from the central test cell, with the segment and least cost path shown in reds. The calculation is repeated for all segments relative to the test cell. This calculation is repeated for all cells in the grid. Figure from Harwood et al 2022.

2.2 Disappearing and Novel Environments

To help provide some context for the character of climate change in the region, some GDM analyses of disappearing and novel environments are presented. The Disappearing environment measure is defined as the dissimilarity of the most similar future cell with a 50km radius of each cell..i.e. how different is the most similar future cell. For situations where it is possible to find exactly the same environment in a future scenario, the result will be 0. For those which have no future analogue, the index would be 1. For Oxfordshire in 2050, the values range up to 0.3, which is different, but not too dramatic. The Novel index is calculated by looking back to the present from the future state of each cell, and saying whether there are any similar cells in the present to the future state of each cell. Areas which are disappearing will have their species struggling to find suitable locations in the

future, Areas which will have very novel environments have future states which are difficult to predict. We can expect an influx of native and non-native migrants, and entirely new configurations of species.

3. Results

Before examining the BERI index, the nature of climate change in the region can be examined in terms of the disappearance of current environments and the emergence of new ones (Figures 2 and 3).

3.1 Disappearing and Novel Ecological Environments

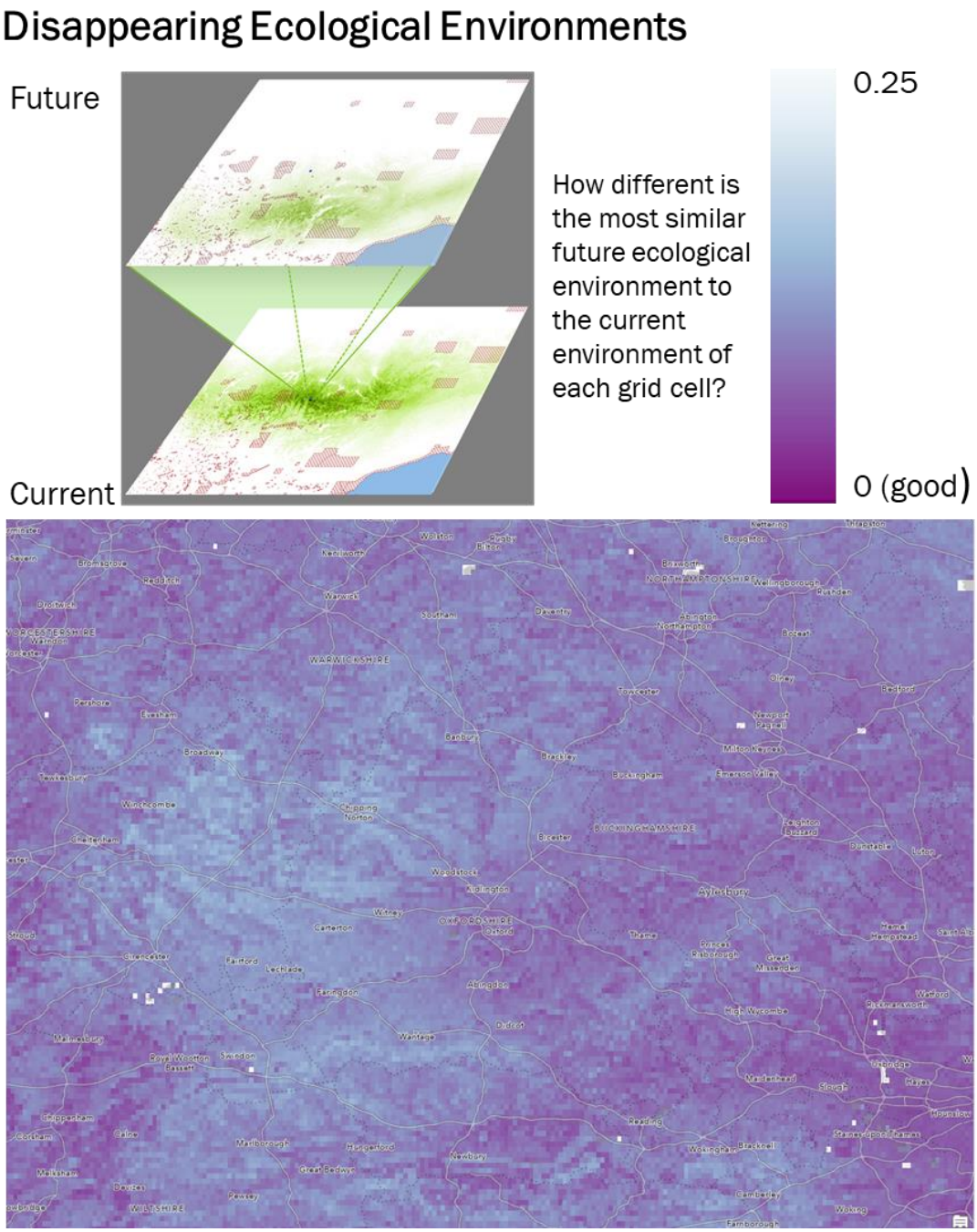

Figure 2: Disappearing Ecological Environments in Oxfordshire. Paler areas show higher levels of regional climate change.

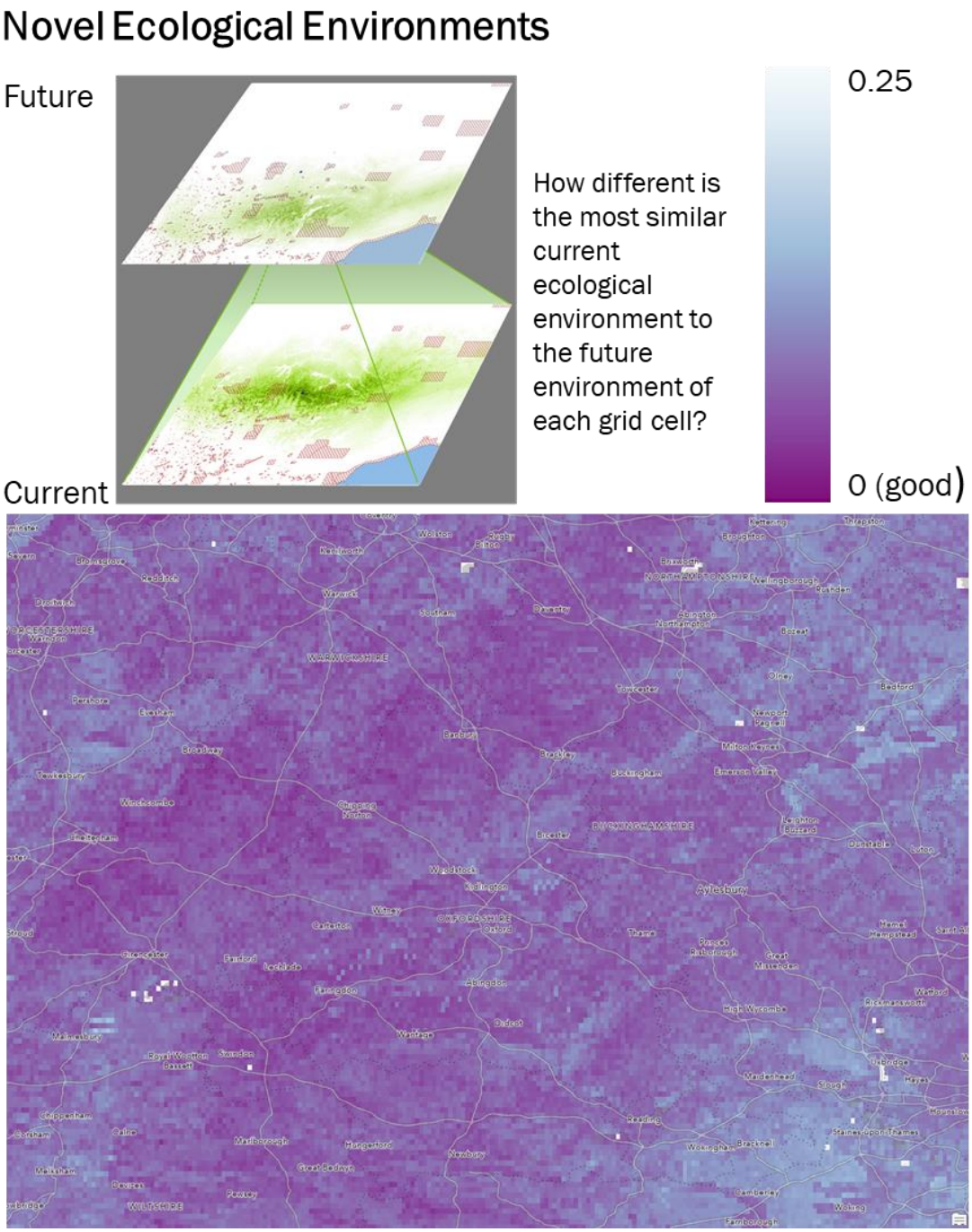

Figure 3: Novel Ecological Environments in Oxfordshire. Paler areas show higher rates of regional climate change

The results show a relatively simple pattern, with areas to the north and west leaning towards their current environments disappearing, but being replaced by future environments with a good analogue in the present. These areas will likely see a turnover of species as local migrants gradually outcompete the current complement of species. Given that the overall difference remains low (Bray-Curtis dissimilarity<0.3), and persistence and adaptation will play some role, this is likely to be a small proportion of total species in the area. The species in the south and east are able to find good analogues in the future, so

their ecological climates are not disappearing. However these locations will become environmentally unique by current standards, and the long term ecological outcomes are difficult to predict. These measures assume that species can get where they need to get, and do not account for the connectivity of the landscape, so we need the BERI index to get a more holistic view.

3.2 BERI

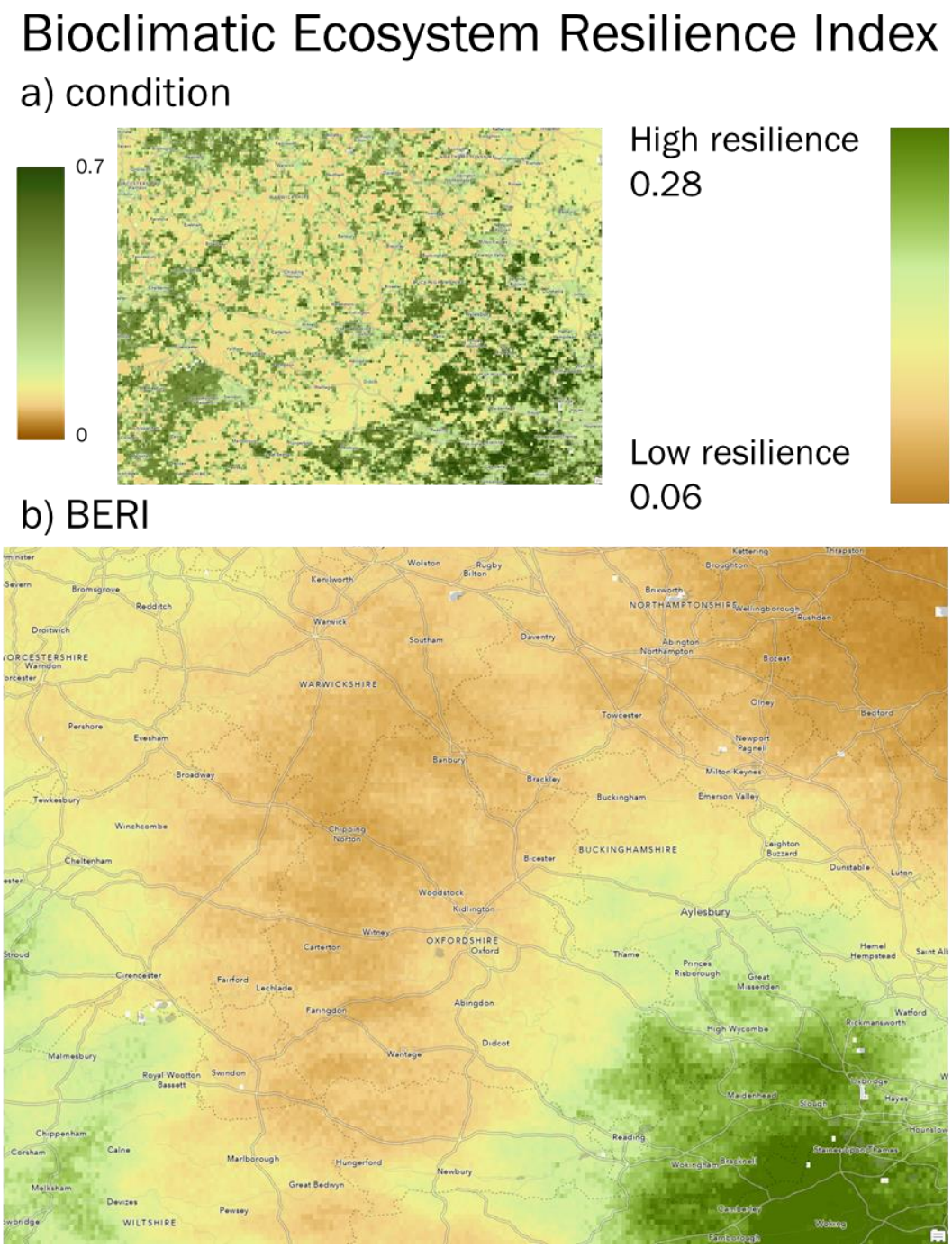

Figure 4: BERI index for Oxfordshire. A) shows the underlying condition surface, and b) shows the BERI index scaled between 0.05 and 0.28

Moving to the BERI index for 2020, which can be downloaded from Harwood et al 2022 (https://doi.org/10.25919/437m-8b91), we see a strong effect of the current habitat condition as we would expect. Less natural areas do not support adaptive migration as well as more intact areas. Superimposed over this is the effect of climate change. The flatter areas of Oxfordshire, which will experience less climatic buffering (i.e. the species can't go uphill to keep cool) are also the more modified regions. The range of values are fairly typical for more developed areas and countries, especially in Europe. East Anglia has lower BERI scores, but the West coast, Wales and Scotland have higher scores due to both lower rates of change and more intact landscapes facilitating movement.

4. Discussion

The BERI index is a measure of state and impact, and is not a priority index. It highlights areas which would benefit from increased connectivity under climate change, but does not show which locations should be restored in order to support that increase in connectivity. If the species of an area need to migrate to the north, then the priority restoration area would be somewhere north of the area, but if the species need to move westward, restoration in the west would be beneficial. However, these areas may already be in good condition, and increased on connectedness in other directions might support an overall improvement in effective metapopulation size. Calculating a priority index requires the BERI index as just one input, and is particularly complex under multiple climate futures.

For Oxfordshire, the BERI index shows that Oxfordshire suffers from a relatively average combined impact of land use and climate change over the next couple of decades. The low lying, modified areas in the central west of the county are under the most pressure. The hills to the south provide an important climatic buffering service, and connecting landscapes to these will make a lot of sense. To the north east, as one approaches East Anglia., there is extensive modification of relatively flat land, and these areas have a low BERI score. There is perhaps less value in connecting to these areas than in the other directions.

Overall, however, the most important take home message is that we cannot plan for conservation of species without considering the projected rates of future climate change. Learning to factor this consideration into our planning may take a little time. We are required to change our world view from the conservation of the ecological communities with which we are familiar to the conservation of the species that comprise those systems, embracing new combinations of species that support thriving wildlife. As the effects of climate change begin to play out across the landscape, we can move away from steady-state objectives and help adaptive migrations both in and out of Oxfordshire. This will involve cooperation with our neighbouring counties after building a shared understanding of the challenges we face.

5. Conclusion

Oxfordshire’s biodiversity will, like the rest of the world, be impacted by climate change and as a modified landscape, adaptive movement of species will be limited. In a global context, the amount of biologically scaled climate change is on the lower side, but the highly fragmented landscape still lowers the overall capacity of species to adapt.

6. References

S Ferrier, T Harwood, C Ware, A Hoskins (2020) A globally applicable indicator of the capacity of terrestrial ecosystems to retain biological diversity under climate change: The bioclimatic ecosystem resilience index. *Ecological Indicators* 117, 106554 doi: 10.1016/J.ECOLIND.2020.106554

TD Harwood, RJ Donohue, KJ Williams, S Ferrier, TR McVicar, G Newell, M White (2016), Habitat Condition Assessment System: a new way to assess the condition of natural habitats for terrestrial biodiversity across whole regions using remote sensing data. *Methods Ecol Evol.,* 7: 1050–1059. doi:10.1111/2041-210X.12579

T Harwood, J Love, M Dreilsma, C Brandon, S Ferrier (2022) Staying connected: assessing the capacity of landscapes to retain biodiversity in a changing climate. *Landscape Ecology*. 37:3123 doi: 10.1007/s10980-022-01534-5

T Harwood, C Ware, A Hoskins, S Ferrier, A Bush, M Golebiewski, S Hill, N Ota, J Perry, A Purvis, K Williams (2022) BERI v2: Bioclimatic Ecosystem Resilience Index: 30s global time series. v1. CSIRO. Data Collection. https://doi.org/10.25919/437m-8b91

A Hoskins, A Bush, J Gilmore, T Harwood, L Hudson, C Ware, KJ Williams, S Ferrier (2016). Downscaling land-use data to provide global 30″ estimates of five land-use classes *Ecology and Evolution 6: 3040–3055.*: doi: 10.1002/ece3.2104

AJ Hoskins, TD Harwood, C Ware, KJ Williams, JJ Perry, N Ota, JR Croft, DK Yeates, W Jetz, M Golebiewski, A Purvis, S Ferrier (2020) Supporting global biodiversity assessment through high-resolution macroecological modelling: Methodological underpinnings of the BILBI framework. *Environmental Modelling and Software* doi: 10.1016/J.ENVSOFT.2020.104806

LN Hudson, T Newbold, S Contu, SLL Hill, I Lysenko et al (2017), The database of the PREDICTS (Projecting Responses of Ecological Diversity In Changing Terrestrial Systems) project. Ecology and Evolution, 7: 145–188. doi: 10.1002/ece3.2579

GC Hurtt, L Chini, R Sahajpal, S Frolking, BL Bodirsky, K Calvin, et al (2020) Harmonization of global land use change and management for the period 850–2100 (LUH2) for CMIP6, Geosci. Model Dev., 13, 5425–5464, https://doi.org/10.5194/gmd-13-5425-2020, 2020.

M Di Marco, T Harwood, AJ Hoskins, C Ware, SLL Hill, S Ferrier (2019) Projecting impacts of global climate and land-use scenarios on plant biodiversity using compositional-turnover modelling. *Global Change Biology* doi: 10.1111/gcb.14663

DM Olson, E Dinerstein, ED Wikramanayake,ND Burgess, GVN Powell et al (2001) Terrestrial Ecoregions of the World: A New Map of Life on Earth: A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity, *BioScience,* 51: 11, 933–938, doi: 10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2

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