Boosting Ecological Restoration for a Wilder Europe

Making the Green Deal Work for Nature

Rewilding Europe

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Martin-Luther-Universität Halle-Wittenberg

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Authors
Néstor Fernández, Aurora Torres, Florian Wolf, Laura Quintero and Henrique M. Pereira.
German Centre for Integrative Biodiversity Research (iDiv) and Martin-Luther-Universität Halle-Wittenberg

Contributors
Frans Schepers, Rob Stoneman and Wouter Helmer (Rewilding Europe), Ariel Brunner, Barbara Herrero and Jeremy Herry (BirdLife Europe & Central Asia), Sabien Leemans and Andreas Baumueller (WWF European Policy Office), Sergiy Moroz and Patrick Ten Brink (European Environmental Bureau), Teresa Goicolea and María Cruz Mateo (Universidad Politécnica de Madrid), Christoph Plutzar and Karlheinz Erb (Universität für Bodenkultur Wien).

Contact
nestor.fernandez@idiv.de

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Markus Varesvuo / Wild Wonders of Europe

Photographers
Staffan Widstrand, Juan Carlos Muñoz Robredo, Jari Peltomäki, Frans Schepers, Mark Hamblin, European Parliament, Getty Images/iStockphoto, Bruno D'Amicis, Elio della Ferrera, Solvin Zankl

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UNIVERSITÄT
HALLE-WITTENBERG

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Shaping the EU restoration agenda

This document is one of the outputs of a wider project called 'Promoting and shaping the EU ecological restoration agenda, through mobilisation of rewilding principles to create a coherent Ecological Network in Europe' (2017–2020). This is a joint project of Rewilding Europe, WWF (European Policy Office), BirdLife Europe & Central Asia, the European Environmental Bureau and the German Centre for Integrative Biodiversity Research (iDiv) and Martin-Luther-Universität Halle-Wittenberg.

Over the last three years, the project focused on providing solutions for the recovery of Europe's nature, and promoting rewilding principles to be accepted in the political debate. As a logical consequence, the introduction of rewilding principles would support the development of a European Green Infrastructure network. With this overall aim, the project has sought to (a) make the policy case for an EU-level ecological restoration strategy; (b) create the governance and financial framework for making investments in large-scale restoration; and (c) develop advice on priority areas and regions for such investments.

Providing solutions to both the climate and biodiversity crises, large-scale restoration and the adoption of rewilding principles will help the EU meet its biodiversity and climate targets, while benefitting every European citizen. Two main outputs of this project are an Ecological Integrity Indicator for assessing the state of European terrestrial landscapes and a first version of a priority map for planning European Green Infrastructure, as presented and explained in this document. These provide practical tools for supporting large-scale ecological restoration and to ensure the recovery of nature at landscape-scale across Europe.

Nature providing solutions

The influence of the human activity on biodiversity and ecosystems is virtually ubiquitous in Europe, shaping all aspects of nature and the benefits it provides[1]. Unsustainable development, that destroys rather than enhances biodiversity, has significantly degraded the ecosystem services that humans depend upon. Biodiversity loss and ecosystem degradation, for example, reduces carbon sequestration and increases emissions of carbon from degraded soils accelerating climate change; reduces regulation of pests; reduces pollination and dispersal of seeds; and causes a deterioration in people's health whilst magnifying natural disasters such as fires and floods.

Solutions to the biodiversity crisis involve measures which are complementary and synergistic with climate change mitigation and adaptation, particularly the restoration of functional and self-sustained ecosystems. Nature-based solutions are significant. For example, forest restoration could sequester up to two thirds of accumulated emissions of CO_2 in the atmosphere[2], contributing decisively to limit global warming to below 1.5°C, but these efforts will only be effective if directed towards restoring natural, biologically complex and self-sustaining forests[3]. Likewise, restoring ecological functions in many other natural ecosystems, such as scrub, grasslands, wetlands and peatlands, is equally important to adapt to global changes; examples include:

- Peatlands are a natural sink of CO_2 which is captured from the atmosphere and retained in the soil when the peatlands are in a healthy ecological condition but conversely, when they are degraded by drainage, peat extraction, plantation forestry or burning, they act as a source of carbon.
- Landscape planners are reconnecting rivers to natural floodplains to mitigate increased incidents of flooding.
- Similarly, upland landscapes (e.g. mires, heaths, woodland and grasslands) create hydrologically 'rougher' surfaces that reduce the flow of stormwater, mitigating flood peaks in downstream towns and cities and make urbanised floodplains far safer places.
- Green spaces counteract heat islands in cities[4]

Protection of natural areas in Europe through the European Union Habitats Directive and national and regional legislation, have been instrumental in preventing further loss of biodiversity and functional ecosystems[5]. A new Green Deal should now tackle even more ambitious goals and give more space to nature. The most recent global assessments by the IPCC on climate[6] and by IPBES on the state of biodiversity and ecosystems[7] both agree that implementing far-reaching ecosystem restoration policies is critical to achieve the international agreements to combat the climate and the biodiversity crises. However, not all proposed approaches to ecosystem restoration are equally suitable to contribute effectively to these goals. For example, active afforestation through plantation forestry of just one or a few rapid growing species often exacerbates rather than resolves environmental problems, may result in impoverished biodiversity, and does not guarantee self-sustained and resilient ecosystem functions in time[8].

Rewilding principles

Rewilding is a form of ecological restoration that promotes self-sustained ecosystems able to provide important services to nature and people while requiring minimum human management in the long term.

The restoration and maintenance of biologically diverse and functional ecosystems is of the utmost importance to achieve the objectives of the European Birds and Habitats Directives and of a new EU Green Deal. The EU's Biodiversity Strategy to 2020 aimed to "restore at least 15% of degraded ecosystems". The mid-term evaluation of the EU Biodiversity Strategy made it clear that progress on this target has been largely insuffi-

Rewilding is a form of ecological restoration that promotes self-sustained ecosystems able to provide important services to nature and people while requiring minimum human management in the long term.

1. Fischer, M. The regional assessment report on biodiversity and ecosystem services for Europe and Central Asia: summary for policymakers. (2018).
2. Bastin, J.-F. et al. The global tree restoration potential. Science 365, 76–79 (2019).
3. Lewis, S. L., Wheeler, C. E., Mitchard, E. T. A. & Koch, A. Restoring natural forests is the best way to remove atmospheric carbon. Nature 568, 25–28 (2019).
4. European Commission & Directorate-General for Research and Innovation. Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities: final report of the Horizon 2020 expert group on 'Nature-based solutions and re-naturing cities' : (full version). (Publications Office of the European Union, 2015).
5. European Commission. Fitness check of the EU Nature Legislation (Birds and Habitats Directives). https://ec.europa.eu/environment/nature/legislation/fitness _ check/index _ en.htm (2016).
6. IPBES. IPBES Global Assessment Summary for Policy Makers. https://ipbes.net/sites/default/files/inline/files/ipbes _ global _ assessment _ report _ summary _ for _ policymakers.pdf (2019).
7. IPCC. Summary for Policymakers. Global Warming of 1.5°C. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15 _ SPM _ version _ report _ LR.pdf (2018).
8. Suding, K. et al. Committing to ecological restoration. Science 348, 638–640 (2015).

cient. Likewise, the fitness check of the EU Nature Directives (op. cit.) pointed to the lack of connectivity of the Natura 2000 network as one of the main implementation gaps.

Rewilding pursues effective large-scale restoration of self-sustained and functional ecosystems through recovering natural ecological processes and the functions and services of wildlife. Critical components of rewilding include restoring the ecological functions of wild species and their interactions, enhancing connectivity within and among habitats and promoting natural ecosystem dynamics and vegetation succession[9]. When the synergies among these three components are improved, ecological restoration actions result in increased ecosystem resilience and higher biodiversity value. Thus, ecological restoration in line with rewilding principles can enhance, across many ecosystems, the provision of a wide range of services to people, such as carbon sequestration by naturally functioning vegetation, reduction of fire risk through the browsing and grazing activity of large herbivores[10] and free movement across

Biodiversity and climate policies should acknowledge that reducing the human control on ecosystems is often a cost-effective approach to address restoration targets.

connected habitats of pollinator species and seed dispersers, among other benefits.

Biodiversity and climate policies should acknowledge that reducing the human control on ecosystems is often a cost-effective approach to address restoration targets. For instance, rewilding spontaneously occurs in areas of Europe where wildlife is able to recover as a result of reduced persecution and where the amount of shrublands and forests have increased as some agricultural areas became uneconomic for farming[11]. These areas can provide new opportunities for restoring nature and contribute to the green economy in a manner that deliver a suite of ecosystem services of benefit to people and the environment in lands that are otherwise economically unproductive.

9. Perino, A. et al. Rewilding complex ecosystems. Science 364, eaav5570 (2019).
10. Johnson, C. N. et al. Can trophic rewilding reduce the impact of fire in a more flammable world? Phil. Trans. R. Soc. B 373, 20170443 (2018).
11. Kaplan, J. O., Krumhardt, K. M. & Zimmermann, N. The prehistoric and preindustrial deforestation of Europe. Quaternary Science Reviews 28, 3016–3034 (2009).

Toward ecological integrity and connectivity in Natura 2000

Restoration under a rewilding framework can include a wide array of actions directed to enhance functional connectivity, natural ecosystem dynamics and the role of species in ecosystems. In order to support these actions, a European-level and integrated assessment on the state of these three key aspects determining the ecological integrity of ecosystems has been missing. Such an assessment is needed, for example:

- To quantify the degradation level of terrestrial ecosystems in European landscapes;
- To identify gaps in large-scale ecological connectivity among protected areas, including the Natura 2000 Network;
- To identify priority areas for rewilding projects;
- To support the implementation of national, European and global-level restoration targets.

In this project, we aimed to provide a set of tools to help implement large-scale ecological restoration using a rewilding framework. Previous outputs related to this project have discussed scientific evidence for implementing rewilding as a pragmatic approach to restore more complex and functional ecosystems[12]; have provided a framework for rewilding actions that explores beneficial interactions between society and nature[9]; and have delivered a methodology for assessing progress in rewilding projects[13]. Here we present the first results of a novel assessment of the ecological integrity of European terrestrial ecosystems according to the three key components of restoration under rewilding. We also present the results of a connectivity analysis of the Natura 2000 Network and the priority corridors that should be included in conservation and restoration planning towards European-level Green Infrastructure.

The technical details of the analyses presented in this document can be found in the following URL: https://www.idiv.de/en/biodiversity-conservation/research/rewilding-policy.html

12. Fernández, N., Navarro, L. M. & Pereira, H. M. Rewilding: A Call for Boosting Ecological Complexity in Conservation: A call for rewilding in conservation. CONSERVATION LETTERS 10, 276–278 (2017).
13. Torres, A. et al. Measuring rewilding progress. Philosophical Transactions of the Royal Society B: Biological Sciences 373, 20170433 (2018).

The conservation context: wildness in Europe

The trophic functions of European wildlife

Wildlife in Europe has collapsed over the last few millennia as a result of the intensive transformation of habitats and direct persecution and harvesting of species. However there are many examples showing, that once these pressures are relaxed, many species have the capacity to recover and expand to recolonize landscapes where they were previously extinct. Effective protection of nature, together with restoration initiatives, have been instrumental in facilitating this process and without these dedicated actions the defaunation of Europe would have been even more dramatic[14].

Charismatic species like the European bison, hunted to extinction in nature during the first decades of the 20th Century, now thrive in a few protected areas thanks to pioneer reintroduction programs that started to be implemented in Poland after World War II. By the end of the 19th Century, only 100 Alpine ibexes remained. Today, the species is catalogued as a species of least conservation concern having expanded throughout the Alps Mountains range, thanks to dedicated restoration efforts including the legal protection of habitats and multiple translocations. More recently, efforts to mitigate the critical conservation status of the Iberian lynx are reversing a steady population decline, whose population by year 2000 numbered only 100 individuals, distributed in only two areas. Currently, as a result of reintroduction and translocation programmes that have been supported by European LIFE funds and by national and regional public administrations, complete species extinction has just about been averted with Iberian lynx slowly recovering towards a better conservation status.

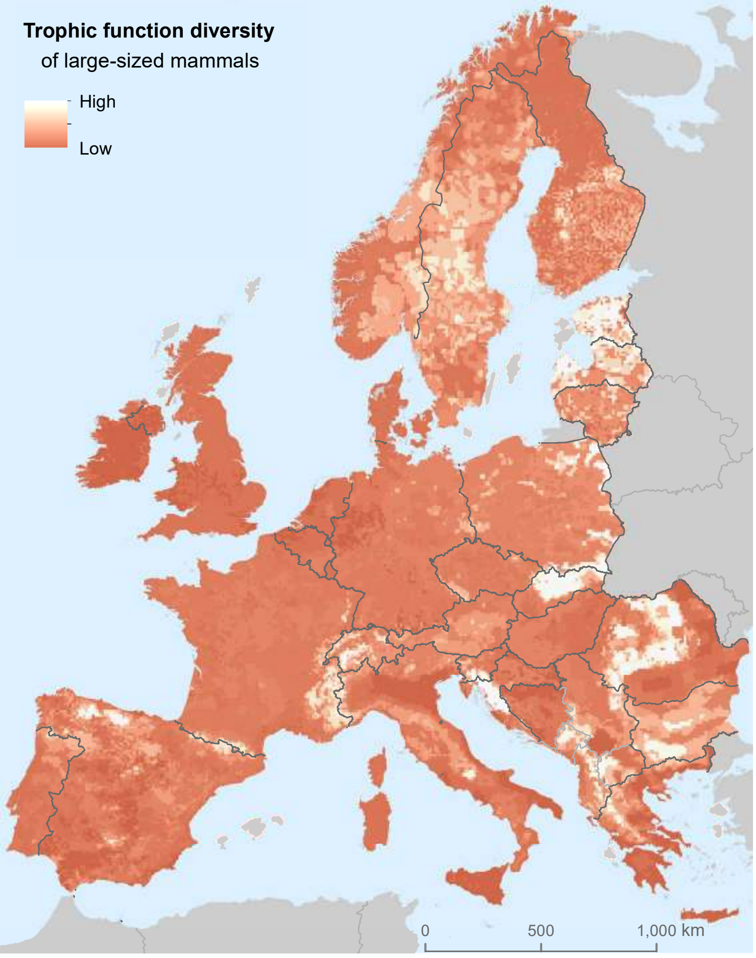
Large wildlife activities such as browsing and grazing by herbivores, natural predation and seed dispersal by carnivores and carrion consumption by scavengers can provide key services reducing fuel loads and the disease transmission in wildlife.

Across Europe, large amounts of suitable but unoccupied habitat remain for the recovery of wildlife in landscapes where species were once extirpated[15,16]. Despite examples of initial recovery for some species and a general comeback of wildlife[14], the diversity and abundance of wildlife in Europe, especially of large-bodied animals, is only a shadow of past levels; levels that are in most cases insufficient to accomplish the critical ecosystem functions in which these species are involved.

Restoring large-bodied species is important for ecosystem functions

One of the most pervasive but often overlooked effects of anthropogenic global change is defaunation[17], consisting in far-reaching declines in both the distribution and abundance of many animal species with profound consequences for ecosystems. Worldwide, defaunation has been particularly severe for those species with the largest bodies. Yet, large-bodied species play unique roles in ecosystems and their extirpation impoverishes the functions and services that these ecosystems can provide. For example, at sufficient numbers of individuals, large herbivores are able to maintain richer vegetation mosaics, they positively affect biodiversity of smaller animals and plants and they even reduce fuel loads in natural habitats, contributing to the regulation of fire regimes. Large carnivores provide beneficial services reducing disease transmission in wildlife through natural predation and removing carrion, whilst bears are effective seed dispersers given a high fruit diet. The restoration of nature can only be fully accomplished through facilitating a widespread recovery of large-sized species and their unique ecological roles.

14. Deinet, S., Ieronymidou, C. & McRae, L. Wildlife comeback in Europe: the recovery of selected mammal and bird species. (The Zoological Society of London, 2013).
15. Scharf, A. K. & Fernández, N. Up-scaling local-habitat models for large-scale conservation: Assessing suitable areas for the brown bear comeback in Europe. Divers Distrib 24, 1573–1582 (2018).
16. Kuemmerle, T. et al. Predicting potential European bison habitat across its former range. Ecological Applications 21, 830–843 (2011).
17. Dirzo, R. et al. Defaunation in the Anthropocene. Science 345, 401–406 (2014).



The trophic diversity of large mammal communities in European landscapes. Represented are the values of the functional diversity index weighting for higher values in areas with more different species according to their trophic functional traits (See table). Lighter areas sustain a higher functional diversity.

For this project, we have developed a novel set of indicators of the status and loss of trophic complexity associated to large-sized species in Europe. These indicators are based on the best available information on the distribution of species compiled from multiple data sources, including National Species Atlases, scientific publications, research and conservation project reports and the data from the Large Carnivore Initiative for Europe[18]. To calculate the magnitude of defaunation in Europe we have also estimated distribution ranges where each of the species could have persisted in the absence of anthropogenic pressures. Estimates exclusively include non-extinct native European species and were based on evidence from scientific literature describing written historic records and fossil data. High values of the index coincide with areas hosting a diverse community of species from different functional groups (see Table) and zero values are areas where large mammalian wildlife has been completely depleted. This indicator can be expanded in the future to include, for example, large raptors like vultures that play similarly important functions in ecosystems.

Table: Functional groups and species included in the trophic function indicator

Large grazer	European bison
Mountain bovids (mixed browsing/ grazing)	Alpine ibex, Iberian ibex, Chamois, Pyrenean chamois & Wild goat
Browsing cervids	Elk, red deer, reindeer & roe deer
Generalist ungulate	Wild boar
Omnivorous carnivore	Brown bear
Carnivore predators	European lynx, Iberian lynx & European wolf

Only about 5% of the area covered by the European Union and UK preserves or has recovered more than half of the baseline functional diversity. Extensive areas with relatively high functional diversity are still found, for example, in the major European mountain ranges, the Baltic countries and Sweden but these areas are patchily distributed and remain largely disconnected from each other by areas lacking a diversity of large wildlife. Even in terrestrial areas under legal protection there is still a high potential for restoring the important trophic functions provided by large wildlife.

Connected natural areas

The life cycles of many organisms require movement, such as animals, seeds, or spores within or across landscapes. For many species, the ability to move within a landscape is vital for re-colonising suitable habitats, allowing range shifts of populations in response to climate change, as well as gene flow. However, nature is increasingly threatened by human infrastructure expansion and agricultural intensification. In Europe, half of the continent's surface is located within 1.5 km, and almost all land within 10 km, from a paved road or a railway line[19]. Intensively managed agricultural areas also occupy about a quarter of the EU and are unsuitable for many species to inhabit or move across. Such pervasiveness of intensive land use causes considerable biodiversity loss via multiple mechanisms: reduced habitat quality (e.g., due to chemical pollution, noise disturbance); increased wildlife mortality due to vehicle collisions; and isolation in small populations.

Fragmentation and habitat loss poses a threat to all kinds of species but in general the most vulnerable ones are large-sized mammals

18. Large Carnivore Initiative for Europe. https://www.lcie.org/.
19. Torres, A., Jaeger, J. A. G. & Alonso, J. C. Assessing large-scale wildlife responses to human infrastructure development. Proc Natl Acad Sci USA (2016) doi:10.1073/pnas.1522488113.

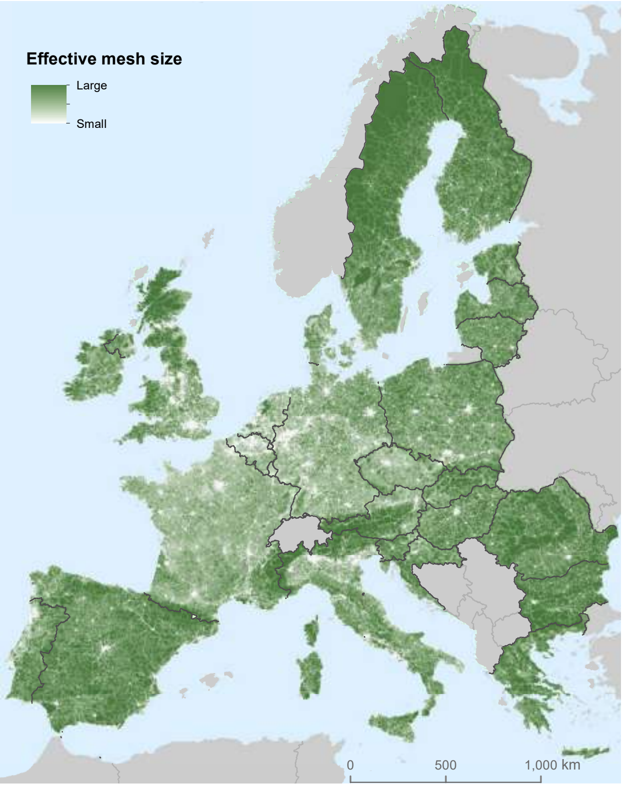
with lower reproductive rates and larger home ranges[20]. When compared with highly fragmented landscapes, roadless areas have shown to be more resistant to invasions by exotic species, more resilient to extreme weather events and insect outbreaks, and can provide better services for the maintenance of healthy soils, clean air and water supply[21].

Restoring landscape connectivity can be achieved by restoring natural habitat patches and riparian corridors in intensive agricultural areas or constructing wildlife passes over roads and railways to increase ecological permeability. Connectivity is therefore important to preserve the ecological integrity of ecosystems and is regularly used for planning and conservation purposes at local and regional scales, however, large-scale connectivity is insufficiently provided in planning and monitoring strategies, especially given rapid climate change.

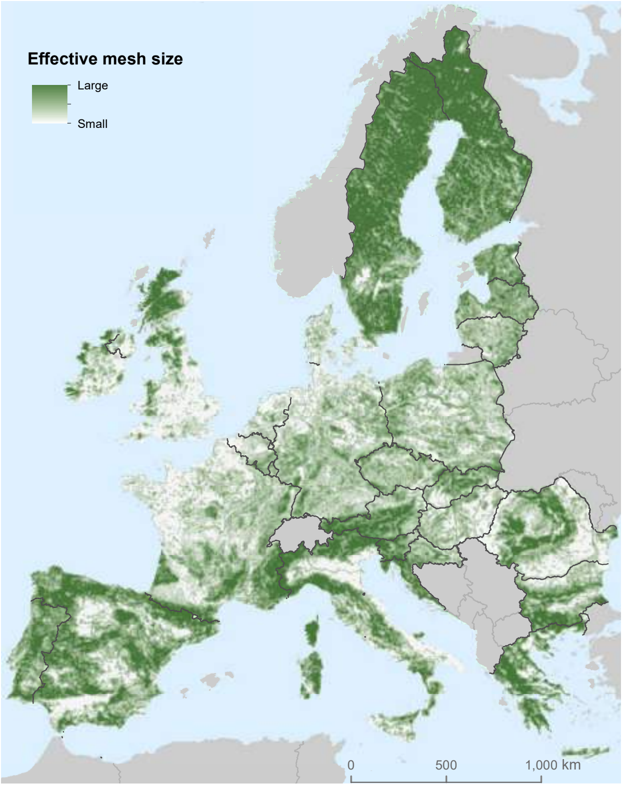
In our project, landscape connectivity is quantified by the effective mesh size of natural and semi-natural habitats defined by infrastructure (mainly roads and urban areas) and by intensively used agricultural areas. In the case of transportation networks, the index is consistent with a core indicator used to monitor changes in the fragmentation in Europe[22]. Effective mesh size is an expression of the probability of any two randomly distributed organisms being found in the same unfragmented patch; it indicates the degree to which the above-mentioned fragmenting features of the landscape may impede the movement of organisms.

Calculating the effective mesh size makes it possible to detect areas of low ecological fragmentation that could constitute good candidates for restoring the ecosystem integrity with a higher probability of success and also extends opportunities to assess potential paths for increasing connectivity across intensively fragmented areas. This is particularly important for finding the best connection paths to restore connectivity across highly fragmented natural regions such as in central Europe, where large extensions of intensive agriculture and build-up areas poses

20. Rytwinski, T. & Fahrig, L. Do species life history traits explain population responses to roads? A meta-analysis. Biological Conservation 147, 87–98 (2012).
21. Ibisch, P. L. et al. A global map of roadless areas and their conservation status. Science 354, 1423–1427 (2016).
22. Landscape fragmentation in Europe: joint EEA-FOEN report. (Europ. Environment Agency [u.a.], 2011).

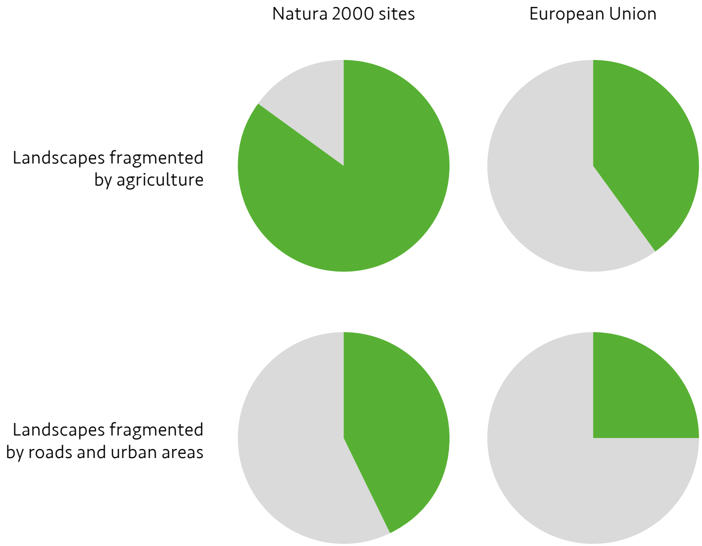


Landscape connectivity affected by urban fabric and linear infrastructure. Darker green are less fragmented areas.



Landscape connectivity affected by intensive agriculture. Darker green are less fragmented areas.

Effective mesh size in landscapes with areas of the Natura 2000 network compared with fragmentation in the European Union.*



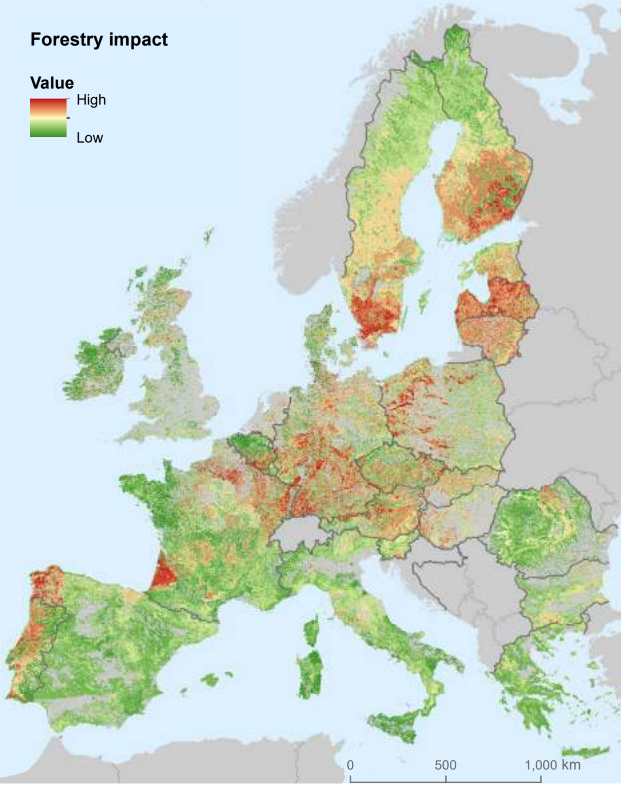
* Median values are shown

serious challenges for reconnecting natural landscapes.

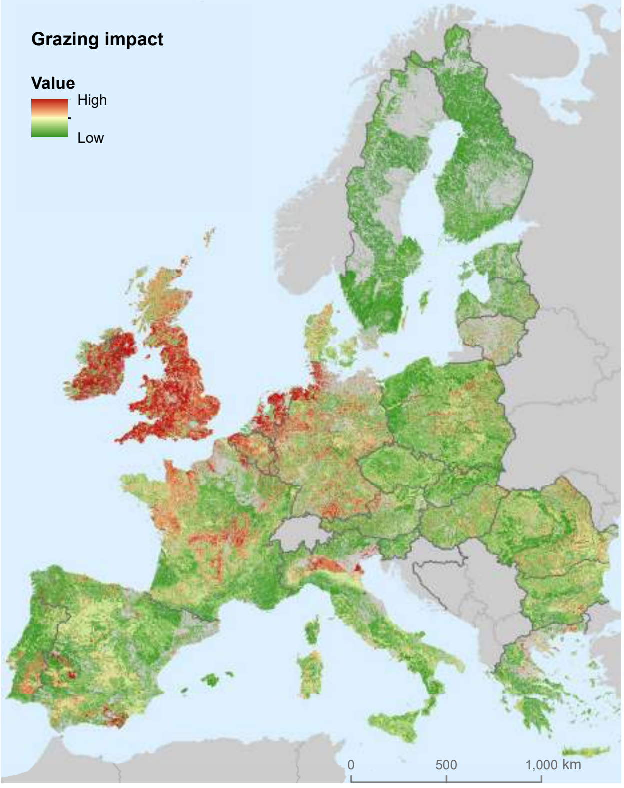
The fragmentation indicator shows that the landscape connectivity is higher in Natura 2000 sites and nationally designated areas than outside protected areas (see figure), indicating that the size of the habitat patches remain larger within those sites. These results illustrate the high potential of using the Natura 2000 network as a backbone for supporting efforts to increase the ecological connectivity across European landscapes.

Natural ecosystem dynamics

Generally, higher intensity land use alters natural processes including disturbance regimes, disturbance regulation and vegetation succession, degrading ecosystems such that they become less resilient to floods, fires and pest outbreaks. Land use intensity is the combination of the intensity of inputs, for example in relation to labour, machinery and fertiliser etc., and the intensity of resource extraction, of forest products or livestock production etc. Examples of intensive management practices include:



The distribution and intensity of forestry impacts in the European Union and UK (data not available for Croatia and Cyprus) measured as the net primary productivity (NPP) harvested in forests. Net primary productivity is a measure used to describe the accumulation of carbon in above and below ground vegetation.



The distribution and intensity of grassland impacts in Europe in the European Union and UK (data not available for Croatia and Cyprus).

- High intensity forestry that is characterized by decreased ecological productivity, amount of biomass retained in ecosystems and species diversity. In turn this has a negative impact on ecosystem services such as the climate cooling efficiency of forests[23].
- Practices like salvage logging after natural disturbances significantly reduce the amount of biomass available for life in forests and, as a consequence, result in impoverished diversity of saprophytic organisms critical to maintaining the nutrient cycling and the integrity of forest soils[24].
- High levels of grazing can result in degradation of ecosystems and their species diversity[25]. In contrast, low intensity levels of managed livestock and free-ranging domestic species are even considered beneficial in many regions of Europe to maintain the vegetation diversity of grassland and shrubland ecosystems and for the conservation of particularly sensitive species typical of open habitats.

Low or non-intervention management of natural disturbances can have important benefits for preserving ecosystem processes and biodiversity[26]. Therefore, an important goal of rewilding is to upgrade the functionality of nature through progressively reducing the human control of the ecosystem dynamics and the natural disturbances. Detailed, spatially comprehensive information on the magnitude of these human effects does not exist at the European level but a useful proxy for it is the amount of primary productivity harvested by people in each land use type. Human appropriation of primary productivity quantifies the removal of resources that would be otherwise available for many other organisms including food for animal species, organic matter for plants, fungi and microorganisms. When calculated separately for different land uses, it indicates the disturbance pressure exerted by humans on the affected ecosystems.

23. Naudts, K. et al. Europes forest management did not mitigate climate warming. Science 351, 597–600 (2016).
24. Thorn, S. et al. Impacts of salvage logging on biodiversity: A meta-analysis. J Appl Ecol 55, 279–289 (2018).
25. Socher, S. A. et al. Direct and productivity-mediated indirect effects of fertilization, mowing and grazing on grassland species richness. J Ecol 100, 1391–1399 (2012).
26. Lindenmayer, D., Thorn, S. & Banks, S. Please do not disturb ecosystems further. Nat Ecol Evol 1, 0031 (2017).

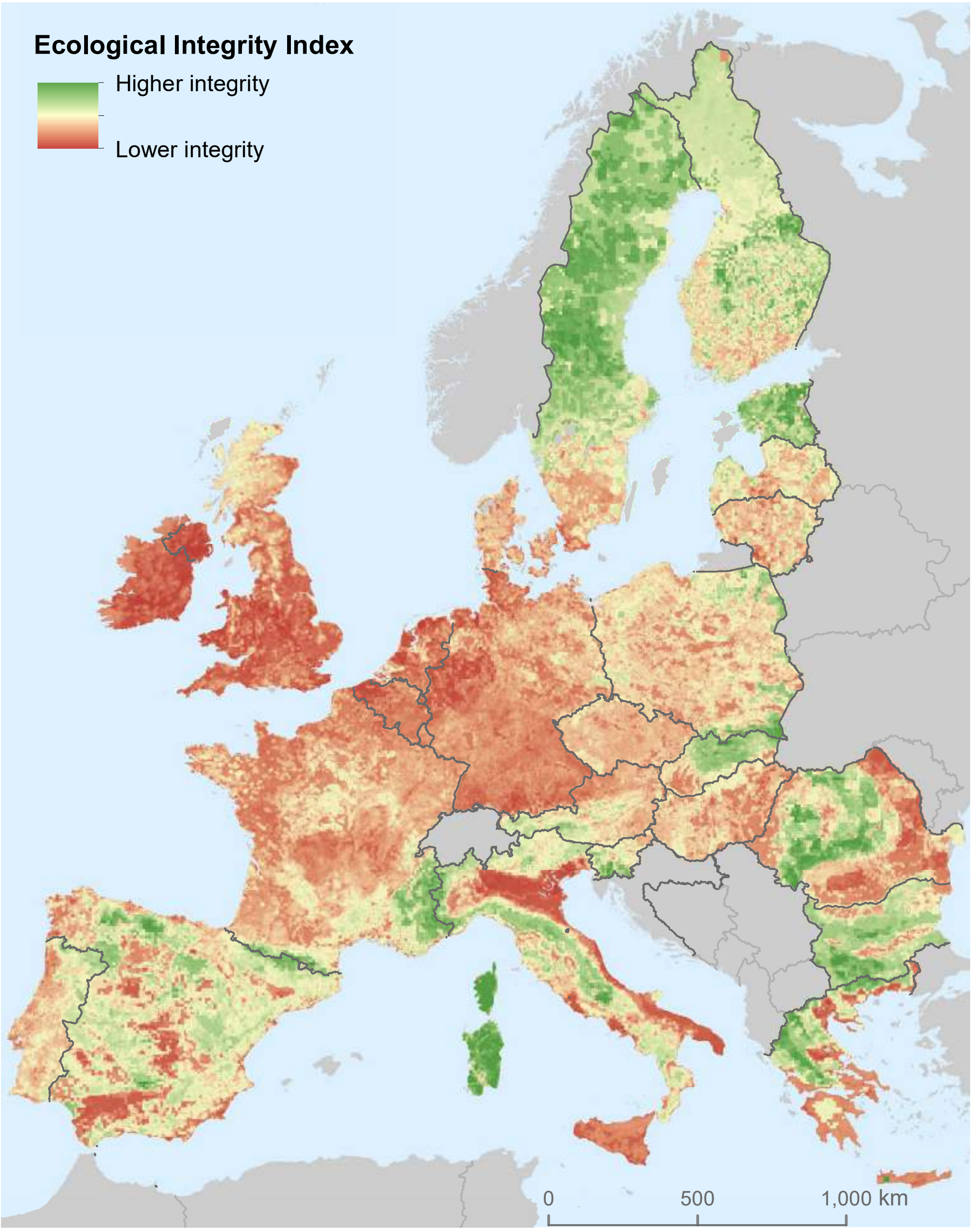
Assessing European landscapes

The three major components of "wildness" (trophic function, connectivity and natural dynamics) were combined into a single indicator of ecological integrity. This indicator aims to reflect the extent to which anthropogenic defaunation, fragmentation of the landscape and the continued extraction of natural resources, have altered the natural state of ecosystems. Importantly, this indicator can be also used to identify areas where the three different components interact determining suitable conditions for resilient and self-sustained nature. For example, high scores are associated with landscapes encompassing natural areas with minimal fragmentation, low intensity or absence of forestry and grazing activity and minimal defaunation of the largest-sized European animals.

The resulting indicator can also be used in combination with additional information about biodiversity and human pressures, to support more comprehensive restoration planning that benefits from the combination of local-scale and European-scale perspectives and insights. In this way, improving wildness can result in co-benefits for enhancing biodiversity and to combat climate change. For example, intensive forestry and grazing strongly impact the natural cycle of carbon[27]; alleviating these pressures can contribute to increased carbon sequestration in natural ecosystems.

Map of Ecological Integrity of European Union and UK landscapes. To build this indicator, the trophic integrity of large mammal communities, the connectivity of natural landscapes and human harvesting in natural and semi-natural areas are weighted equally.*

* Data not available for Croatia and Cyprus

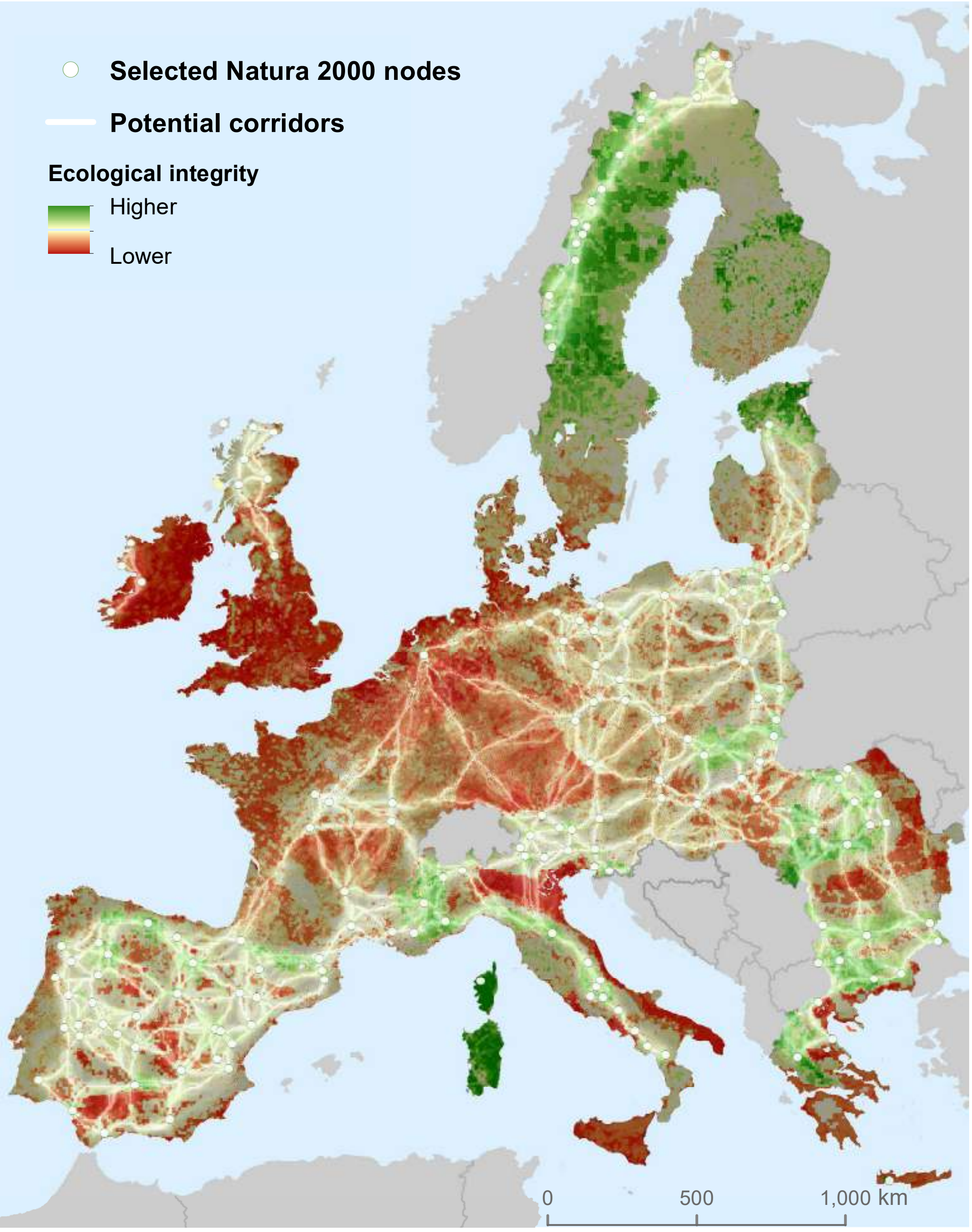


27. Haberl, H. et al. Human Appropriation of Net Primary Production: Patterns, Trends, and Planetary Boundaries. Annual Review of Environment and Resources 39, 363–391 (2014).

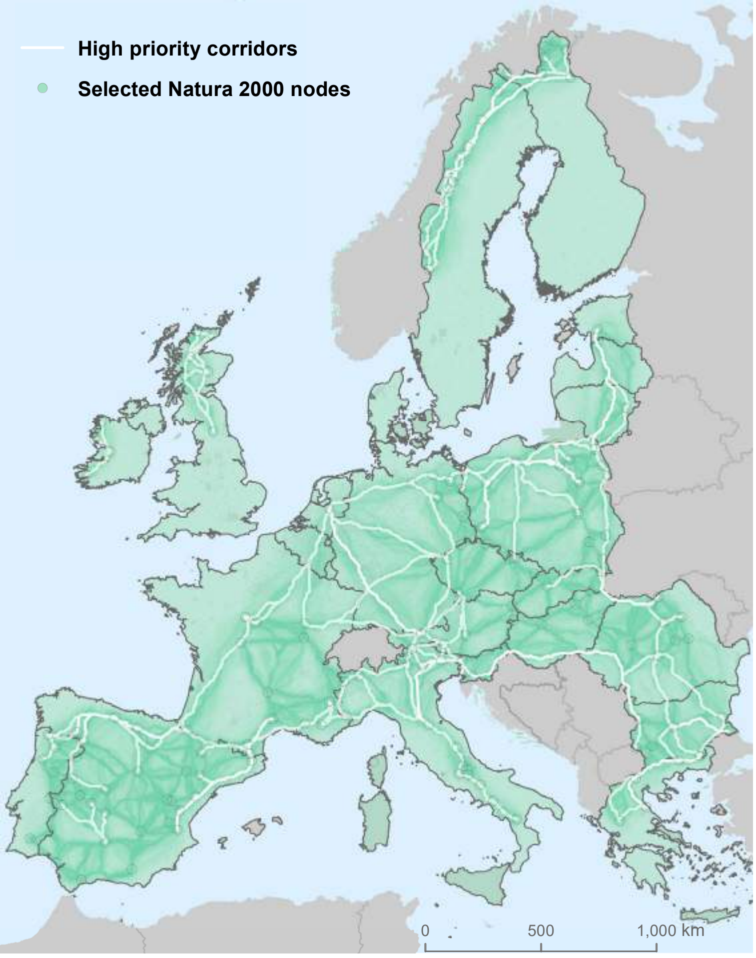
Increasing connectivity of the Natura 2000 network

Increasing the functional connectivity between Natura 2000 sites is required to address the long-term conservation of biodiversity in Europe. Currently, many sites within the network constitute a sort of "archipelago" embedded within large areas of intensively used, fragmented and wildlife impoverished land. Because of this, the Natura 2000 network is less effective for delivering its purpose to conserve species and habitats across Europe as it compromises critical ecological processes such as the movement of species and the genetic exchange. Developing green infrastructure with the Natura 2000 network as its backbone would efficiently contribute to the goals of the Nature Directives and support global biodiversity targets. However, no policy or legal instrument is yet in place to efficiently address this need.

To facilitate the establishment of a trans-European network of Green Infrastructure, restoring and maintaining ecologically functional and connected landscapes is of utmost importance. For this, new tools are required to be able to support design and implementation. The ecological integrity indicators developed in this



Potential corridors for large-scale Green Infrastructure connecting Natura 2000 nodes. In this analysis, nodes are clusters of Natura 2000 distributed in areas ≥500 km² and with at least 10% covered by high ecological integrity. Corridors have a higher probability to pass through higher-integrity areas and through other Natura 2000 sites.



A selection of high priority corridors that need to be preserved and restored in order to enhance the connectivity of the Natura 2000 Network.

Selection of Natura 2000 sites and priority corridors for enhancing large-scale ecological connectivity

We identified EU-level* priority corridors that need to be maintained or restored in order to connect large clusters of the Natura 2000 network. These analyses were based on different criteria for the selection of clusters to be connected: (1) a country-level stratification of priority areas, and (2) a stratification by European Biogeographical Regions. The identification of priority corridors followed these steps:

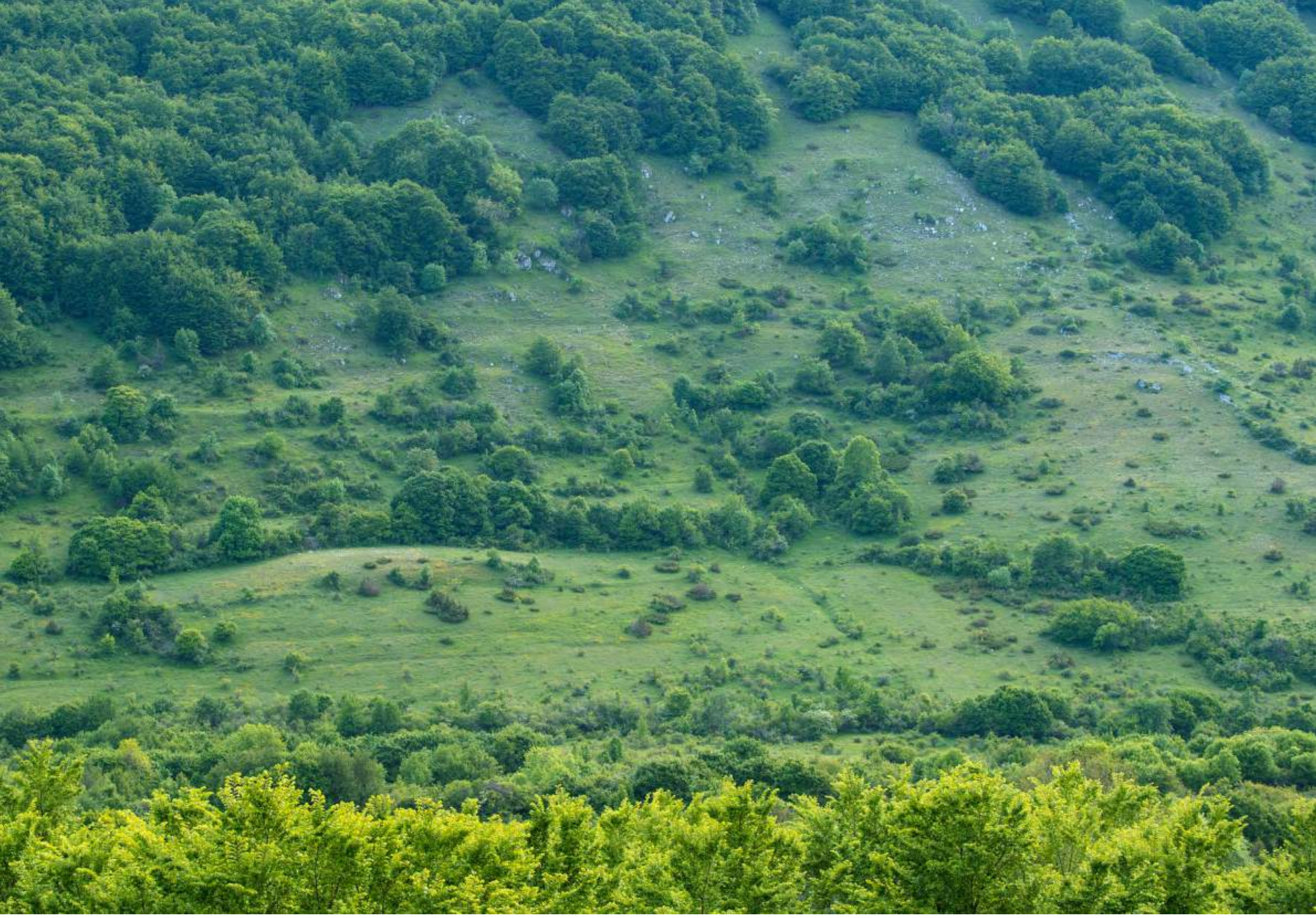
- Terrestrial landscapes with the highest ecological integrity according to our indicator were identified for each country and for each biogeographical region, respectively.
- Large (>500 km^2) clusters of Natura 2000 sites containing landscapes of high relative ecological integrity were selected as priority areas to connect.
- Then, an optimized configuration of corridors among these selected clusters was calculated using connectivity analyses[28], with connections following more likely those landscapes with higher ecological integrity and areas that already contain some Natura 2000 sites.
- Finally, priority corridors in which conservation and/or restoration efforts should be concentrated were identified according to scenarios in which the degradation or the enhancement of the ecological integrity would have a particularly high impact on the connectivity of the entire network.

* At the time of publication Croatia was not included in these analyses due to a data deficiency for calculating some components of the ecological integrity indicator.

project provide valuable information that, when combined with spatial planning methods, can be used to assess the most suitable pathways to re-connect areas of high nature value.

We identified pathways representing important areas that need to be preserved and, in many cases, restored, in order to sustain a coherent network. These pathways connect a subset of clusters of Natura 2000 sites with high ecological integrity containing, for example, larger unfragmented patches of natural habitats, higher functional diversity of large-sized wildlife or ecosystems with lower harvesting impacts as compared to the surrounding landscapes. Finally, the configuration of these connections was designed to maximize the inclusion of other Natura 2000 sites in the connecting corridors (Box 2). The corridor configurations identified in this study thus help prioritizing conservation and restoration policies and projects, with appropriate funding, for the deployment of EU-level Green Infrastructure that contribute to the goals of the Nature directives.

28. Saura, S. & Torné, J. Conefor Sensinode 2.2: A software package for quantifying the importance of habitat patches for landscape connectivity. Environmental Modelling & Software 24, 135–139 (2009).



Connecting people with nature

Reconnecting people to nature in urban areas is increasingly recognised as a critical contribution to enhance people's well-being. Urban growth often creates higher social inequality, affecting well-being, health and social cohesion.

One way to face such issues is by designing more green spaces within and around the urban areas. There is an increasing body of research that demonstrates that urban greenspaces are critical in improving health. For example, studies show that death by respiratory and cardiovascular disease can be reduced by 6% to 8% just by living closer to greenspaces. Additional benefits include faster recovery from strokes and heart attacks and reduced rates of emotional depression[29,30]. Likewise, greenspace facilitates improved social cohesion and mental health whilst exercising in greenspace increases self-esteem and improves mood by reducing stress. In Denmark, studies showed that if children use greenspaces, it reduces the risk of developing schizophrenia[31]. In short, greenspaces are critical for healthy cities.

The indicators developed in this project are a useful source of information to assess proximity of the urban population to high-value natural areas. As an example, we evaluated the integrity of terrestrial ecosystems within a 50 km radius

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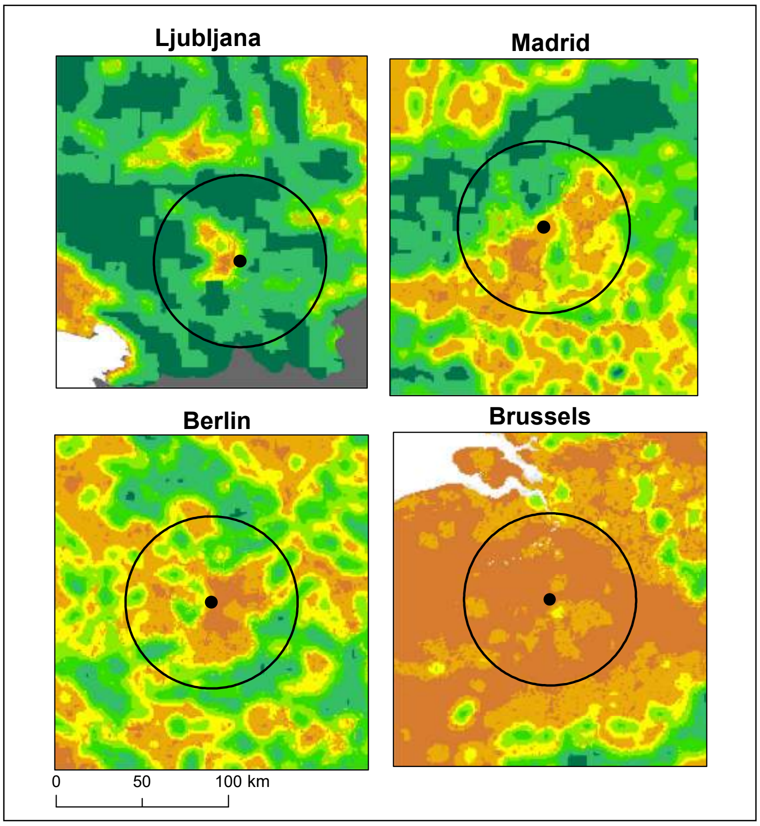
29. Hunter, R. F. et al. Environmental, health, wellbeing, social and equity effects of urban green space interventions: A meta-narrative evidence synthesis. Environment International 130, 104923 (2019).
30. Vienneau, D. et al. More than clean air and tranquillity: Residential green is independently associated with decreasing mortality. Environment International 108, 176–184 (2017).
31. Engemann, K. et al. Childhood exposure to green space – A novel risk-decreasing mechanism for schizophrenia? Schizophrenia Research 199, 142–148 (2018).



Map of capital cities at different ranks of ecological integrity, Ljubljana being the highest and the City of Brussels the lowest. The color gradient represents the ecological integrity value with the lowest in dark orange and the highest in dark green.

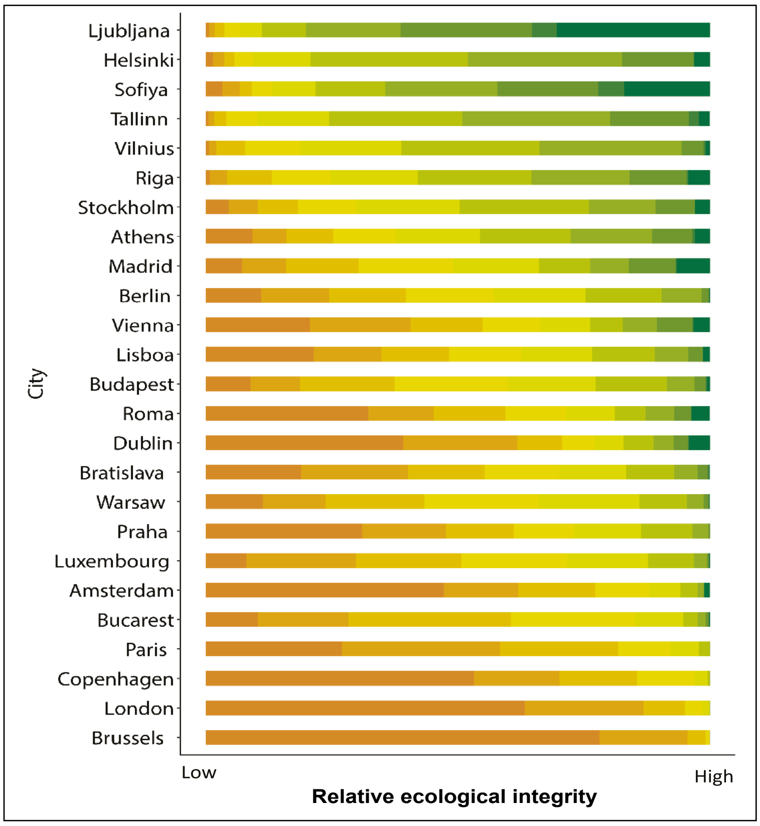
surrounding European capitals to identify which cities have close access to high-quality nature and also to highlight the opportunities for improving urban resident health through green-space enhancement. Some of the capital cities surrounded by the highest ecological integrity are well known as cities that actively promote a healthy living environment through the conservation of nature (e.g. Paljassaare conservation area in Tallinn). Capital cities showing a much lower index point a clear need towards urgent action to restore ecosystems in and around those cities.

The benefits of urban and peri-urban green-space extend beyond health and are reflected in the economy and resilience of communities. Having nature closer to people can improve local economies through eco-tourism for example (e.g. the expenditure by visitors to sites of the Natura 2000 network have been estimated at €50-85 billion/year[32]. Adding to this, investing in restoring and rewilding landscapes surrounding cities can reduce threats from natural disasters, illustrated by the restoration of floodplains along the River Rhine, which resulted in better protection against floods by increasing its capacity to retain more water.

European Parliament building in Brussels – scoring as one of the lowest in ecological integrity.

Some of the capital cities surrounded by the highest ecological integrity are well known as cities that actively promote a healthy living environment through the conservation of nature.

This project also highlights the role of cities in relation to European ecological integrity. Cities with low ecological integrity deserve actions to improve such integrity and can look to other European cities with higher ecological integrity for inspiration. For example, the Ljubljana region ranks as one of the areas in Europe showing a higher ecological integrity value, good ecological connectivity to its hinterland and a high functional diversity species (at least relative to the impoverished levels across much of Europe). The city serves as an example to others of the wider importance of developing green infrastructure throughout Europe, including the role of urban greenspaces in that design.



Ranking of European capitals according to their ecological integrity performance. The color gradient represents the amount of area under different ecological integrity values with the lowest integrity in brown and the highest in darker green.

Cityscape of the Slovenian capital Ljubljana, scoring as one of the highest in ecological integrity in Europe.

32. European Environment Agency. Protected areas in Europe: an overview. (EEA, 2012).

Putting nature back on the map

Wild nature is slowly recovering in many areas of Europe after centuries of steady degradation. This process has been only possible thanks to positive societal change in favor of environmental protection and an increasing awareness that functional ecosystems with better preserved biodiversity can provide multiple benefits.

Farmland abandonment, which is predicted to continue in Europe in the next decades over millions of hectares (mostly of low-productive land), can provide an opportunity for new management policies aimed at recovering landscapes with higher-value nature. In this way, rewilding in these areas could eventually provide new services to society such as carbon sequestration, recreation and regulation of natural disturbances.

A wildlife comeback is also occurring naturally in some regions of Europe which represents an opportunity to sustain more functional biodiversity and the ecological processes with which these species interact. In addition, active restoration is also needed to enhance ecosystem functions in many other degraded ecosystems, for exampling through alleviating pressures in managed forests and grasslands, restoring functional megafauna, and increasing connectivity in landscapes highly fragmented by intensive agriculture and infrastructures.

In these ways, the goals of the Nature Directives can be supported through expanding the areas covered by self-sustained ecosystems and by increasing the connectivity of the Natura 2000 Network through extensive degraded landscapes, where restoration action is urgently needed.

Farmland abandonment, which is predicted to continue in Europe in the next decades over millions of hectares, can provide an opportunity for new management policies aimed at recovering landscapes with higher-value nature.

A European-level perspective of nature restoration should consider the following guidelines:

Pursueing ecosystem functions

Rewilding pursues enhancing ecosystem functions through synergistic actions towards recovering the biodiversity integrity and reducing the human influence on natural ecological processes. To plan these actions, both large-scale and local-scale insights about the state of biodiversity and ecosystems need to be jointly considered.

Ensuring assessments at European scale

The assessments presented in this document have been done using the same methodologies across Europe and by combining consistent data for all studied countries. The results are, therefore, particularly suitable for supporting European-level restoration planning.

Improving coherence and connectivity

These methodologies and the results can help identifying EU–level priority areas and corridors for conservation and restoration, to improve the overall coherence and connectivity of the Natura 2000 network, and in particular for supporting designs of large-scale Green Infrastructure of added EU value.

Following a similar approach for aquatic systems

Restoration of functional freshwater ecosystems and at land-water interfaces can be similarly guided by methodologies based on a rewilding framework including, for example, impacts on connectivity, the human control of natural river flows and the trophic complexity of aquatic biodiversity.