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Report on network problem formulations, targets and preferences, including guidance and data on targets and optimal TEN-N design criteria

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NATURA CONNECT

Problem formulations, targets and preferences for the TEN-N design

D7.1 Report on network problem formulations, targets and preferences, including guidance and data on targets and optimal TEN-N design criteria

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Deliverable description	This deliverable is the output of task 7.1 and 7.2. This includes methods and data of quantitative and qualitative targets for species, habitats and their services as well as objective functions, constraints and design criteria for maximizing coherence, adequacy and resilience of conservation networks.
Keywords	Systematic conservation planning, favourable reference values, prioritisation, TEN-N, climate resilience, protected areas

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Table of Contents

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NATURA CONNECT

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List of Figures

List of Tables

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Abbreviations

AOH	Area of Habitat
BD	Birds Directive
CDDA	Common Database on Designated Areas
CR	Current Range
CV	Current Value
EEA	European Environmental Agency
FCS	Favourable Conservation Status
FRR	Favourable Reference Range
FRV	Favourable Reference Value
GI	Green infrastructure
HD	Habitats Directive
MS	EU Member State(s)
MS-BIO	EU Member State(s)-Biogeographic region(s)
NADEG	Expert Group on the Birds and Habitats Directives
NCP	Nature Contributions to People
NFF	Nature Futures Framework
NRL	Nature Restoration Law
OECM	Other Effective Area-Based Conservation Measures
PA	Protected area
PU	Planning Unit
SCP	Systematic Conservation Planning
SDM	Species distribution model/modelling
TEN-N	Trans-European Nature Network
WP	Work Package

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Working definitions

Biodiversity	Biodiversity is specified as the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part.
Bioclimatic components	Bioclimatic components constitute distinct geographical regions within species' distributions that are characterised by different environmental conditions and variability and can be used as surrogates for adaptive genetic variation.
Biodiversity conservation	The management of human interactions with genes, species, and ecosystems so as to provide the maximum benefit to the present generation while maintaining their potential to meet the needs and aspirations of future generations; encompasses elements of saving, studying, and using biodiversity.
Climate refugia	Areas of stable or near stable climate through time.
Climate resilience	A characteristic of the protected area network meaning that the network supports the preservation of areas that are crucial for species and habitats to persist under changing climatic conditions. These areas maybe important for several reasons: they can be climate refugia, or they can support critical populations either today or in the future, harness important evolutionary potential or support species dispersal through landscape as they are shifting their ranges.
Core habitat	Areas of higher quality habitat inside species' range. In literature, ranges can be divided between 'core' and 'edge' habitat to distinguish between high- and low-quality habitats inside species range. Here we use the term broadly to describe areas of higher habitat suitability, without referring to any specific threshold value of suitability.
Favourable Conservation Status	The Favourable Conservation Status is a key objective of the Habitat and Birds Directives. For species, it is considerable achieved when the species is maintaining itself on a long-term basis as a viable component of its natural habitats; the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future and there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis. For habitat, it is achieved when the natural range and areas it covers within that range are stable or increasing; the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future; the conservation status of its typical species is favourable.
Favourable Reference Value	Favourable reference values are benchmarks used to determine if species and habitats are in a Favourable Conservation Status. They are useful to assess conservation status, establish conservation goals, address conservation actions and monitor progress. FRV are often composed of different values according to the HD and can include both range and population estimates.

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Favourable Reference Range size	Range within which all significant ecological variations of the habitat/species are included for a given biogeographical region, and which is sufficiently large to allow the long-term survival of the habitat/species.
Feature	Commonly refers to the (spatial) data that is maximized or minimized in the context of systematic conservation planning. Such as for example the distribution of species or habitat.
Prioritisation	The part of SCP in which algorithmic approaches are used to identify solutions for a given problem formulation.
Problem formulation	In this context of this report referring to the methodological description of a systematic conservation planning study, highlighting critical aspects such as objectives and aims, data and prioritisation approach.
Protected area	A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.
Nature Futures Framework	The Nature Futures Framework (NFF) is a normative framework to describe positive futures for nature, to help developing scenarios and inform assessments of policy options across multiple scales. The NFF places relationships between people and nature at its core. Because people relate to nature in multiple ways, there are a wide variety of desirable nature futures, with different goals and visions which can be synergistic or in conflict with one another.
Solution	A (geospatial) outcome resulting from mathematically solving the problem formulation with available data.
Systematic conservation planning	A framework and stepwise approach towards mapping areas for conservation. Typically involves multiple steps such as the identification of a problem and the theory of change, data collection and preparation, conservation prioritisation, monitoring and evaluation.
TEN-N	Trans-European Nature Network. A strategically planned network of protected sites and corridors, building on the existing Natura 2000 network and other protected areas, as well as natural and semi-natural areas that build on other green infrastructure.
(TEN-N) Variant	In the context of the TEN-N this is understood as one plausible realization of the TEN-N with a specific parameter combination such as different costs, constraints and weights included in the conservation planning problem. Having different configurations allows to explore the solution space of what is possible and what is most sufficient.

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Executive summary

In Europe, current biodiversity conservation efforts are widely perceived to be inadequate to halt or reverse biodiversity decline. Area-based conservation measures, including the protection and restoration of areas, as well as ecologically functional green infrastructure supporting connectivity under climate change, are among the most effective tools for biodiversity conservation. **Strategic planning and the use of best-available data can support the design of a Trans-European Nature Network** (TEN-N) that is policy relevant and makes use of scientific evidence. In this document we outline the

1) policy ambition, past planning work across scales, and guiding principles for a TEN-N design (Section 1);
2) use of Favourable Reference Values (FRVs) concept to define Favourable Reference Range (FFR) sizes so that sufficient conservation efforts are implemented in Europe to support the long-term persistence of priority species listed in the Habitat and Birds Directives (Section 2);
3) framework to identify important areas for a climate resilient TEN-N, which captures species present and future core habitats and their connectivity while supporting species adaptive potential and accounting for the uncertainty of future changes (Section 3); and
4) how data and evidence collated from across the NaturaConnect project will be integrated using systematic conservation planning (SCP) to create plausible variants of TEN-N design (Section 4).

<u>Key results</u>

- **Most previous SCP applications in Europe have ignored key factors** such as different biodiversity dimensions and future biodiversity states, **and recent methodological advances**, such as the consideration of connectivity or competing land uses in spatial planning. Furthermore, these analyses rarely engaged stakeholders in the design of their work (see section 4.6 for our approach). There remains ample opportunity for SCP to support the implementation of European policy targets and the design of a TEN-N, provided that key design principles and stakeholder- and policy-informed choices are considered (Table 1).

- **Numerical information on Favourable Reference Range (FRR) sizes are currently missing for approximately 50% of the cases.** Each Member State reports species' FRRs

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at the level of biogeographical regions within Member States. Often these are expert-defined, reported as unknown or in the form of vague operators (e.g., ">" and ">>", implying that the reference threshold is “higher” or “much higher” than the current range size). We developed a repeatable and quantitative approach based on existing guidance, and **produced FRR estimates for 2,391 priority species in each combination of Member State and biogeographical region.** Our methods unify the way FRVs can be estimated across Europe and allow replacing all operators used in the reporting with quantitative estimates**.**

- Under future climate change, **not only will species ranges change, but also the heterogeneity of climatic conditions within these range’s changes**, with many species losing some parts of their current climatic components in the future. While preparing for future is necessary, **investments in the protection of future habitats now will, at least to some degree, reduce resources available for protecting present habitats**. We outline a framework to identify important areas for a climate resilient TEN-N, while analysing trade-offs between current and future conservation needs and exploring both risks and opportunities that emerge when resources are split between more certain present and uncertain future conservation.

- Using a pilot study with the data available so far, we show that **planning for conservation at the pan-European instead of individual Member State level ensures far better gains for species and habitats**. In addition, preliminary results for strict protection suggest that low-conflict strategies, such as **upgrading the level of strictness within current protected areas, produce far less benefits than strictly protecting new areas** of high importance for biodiversity. Central to the planning and development of TEN-N, we summarise how the different nature and socio-economic values, targets, preferences, connectivity, and climate resilience can be incorporated into SCP to design plausible variants of the TEN-N, and how this development has been informed by stakeholders.

Table 1: Lists key criteria and complexity factors that should be considered as well as how the NaturaConnect project will consider these factors in the design of the TEN-N. The design principles are introduced in Section 1.4.2.

TEN-N Criteria	Principle	Why important?	How done in NaturaConnect

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Sufficient coverage of biodiversity	Comprehensiveness	Biodiversity should be conserved in all its facets, taking into account different value systems.	Inclusion of a comprehensive set of species, habitats and ecosystems, while considering differing future visions and preferences.
Act where it is needed most	Adequacy	Identify those areas and actions that would best complement the existing network.	Use of state-of-the-art SCP algorithms in a flexible and transparent framework
Protecting enough	Adequacy	Ensure that species and habitats have enough area left to persist in the long-term	Setting explicit area-targets using best available data on FRVs
Robust to anticipated risks	Resilient	Threats to biodiversity could influence current and future efficiency of conservation.	Incorporation of effects of anticipated climate and land-use change in the prioritisation.
Uncertainty is incorporated and communicated	Resilient	Understanding the different risks and opportunities of alternative futures aids better decision-making	Explore performance of TEN-N in alternative futures to choose the best strategy and to find robust solutions
Politically just and socio-economically responsible	Equity	Capacities and responsibilities to conserve biodiversity are not aligned with its distribution.	Incorporate burden sharing and cost in the prioritisation as well as narrative scenarios for different variants of a TEN-N.
Meeting policy targets and visions	Efficient	Planning conservation actions should be policy- and stakeholder informed.	Design criteria informed by EU policy targets. Continuous engagement with stakeholders at the European level.

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1 Introduction

One of the key aims of the NaturaConnect project is to develop a proposal to create a coherent and resilient Trans-European Nature Network (TEN-N). With this document, we outline the criteria by which such planning can be conducted. Such a plan should elaborate specifically how conservation, ecological restoration and other land management options such as developing green infrastructure (GI) can contribute to a more coherent network across Europe, supporting the achievement of the EU Biodiversity Strategy 2030 and the targets of the EU Restoration Law.

1.1 General policy background

Preservation of natural habitats through the establishment of protected areas (PAs) is widely recognised as a key tool for halting the ongoing biodiversity loss (IPBES, 2019). In Europe, biodiversity decline is predominantly driven by habitat loss and fragmentation caused by land use changes, followed by pollution and direct exploitation and persecution (including hunting) of species (EEA, 2020a; IPBES, 2018). The European Union and its Member States (MS) have made multiple commitments to biodiversity conservation through central legal frameworks such as the Habitats Directive and Birds Directive. By the end of 2021, 26% of the EU land area has been protected (EEA, 2023). Natura 2000 sites, which are protected under the Habitats and Birds Directives, count for 18.6% of these areas and form the backbone of the reserve network, while the remaining 7.4% constitute of other national conservation designations. Together, these form the world's largest coordinated system of PAs.

Despite its relatively high coverage, the European PA network faces several challenges. While large in number, individual protected areas remain small and scattered across the continent. The coverage and management of PAs varies significantly between MS (EEA, 2023), and multiple studies have highlighted critical gaps in the representativeness (e.g., Moreno-Saiz et al., 2021; Spiliopoulou et al., 2023; Trochet and Schmeller, 2013), effectiveness (Santangeli et al., 2023) and connectedness (Bluhm et al., 2023; Sonntag and Fourcade, 2022; Staccione et al., 2023) of the current network. Most notably, the so far conservation efforts have failed to halt biodiversity decline in Europe (EEA, 2020a; IPBES, 2018). Europe faces high demands for land use, arising from agriculture, transport and urban development, and coupled with increasing competition for land for renewable energy production. In addition to pressures from land use, biodiversity conservation and the development of the European PA network is further challenged by climate change (Bednar-Friedl et al., 2022). Mean temperatures in Europe are anticipated to increase by 2.5-7 °C by end of the century, with greatest temperature shifts expected in the Mediterranean

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and Boreal zones (EEA, 2024; Hlásny et al., 2021). Around 60% of European species are expected to lose suitable climate inside currently protected areas (Araújo et al., 2011; Casazza et al., 2023), potentially jeopardizing the effectiveness of past conservation efforts. Only protected areas in the high-latitude Fennoscandia and Britain, and in mountains such as the Alps, the Pyrenees and the Carpathians are expected to gain more species than lose them in the future. Loss of suitable climate is expected to be more severe in Natura 2000 sites as these tend to be located on more flat areas where temperature change velocity is higher (Araújo et al., 2011).

In 2020, the European Commission adopted a new Biodiversity Strategy for 2030, introducing specific goals, funding and legal mechanisms to support and strengthen biodiversity in the EU, with the aim to put Europe's biodiversity on the path to recovery by 2030 (European Commission, 2020; Hermoso et al., 2022). Two central pillars of the Strategy are to establish a larger EU-wide network of PAs and to launch an EU Natura restoration plan (Table 2). More specifically, the EU aims to protect 30% of its land by 2030, one-third of which will be strictly protected, including all remaining primary and old-growth forests. Additional protection should be implemented in a manner that enchases the coherence of existing Natura 2000 network and forms a Trans-European Nature Network (TEN-N), supported by ecological corridors, that is ecologically connected and resilient against anthropogenic pressures such as habitat loss and climate change. In addition, the EU recently adopted the Nature Restoration Law which sets an overall binding target to restore 20% of the EU land area and more detailed targets to specific habitats and species (European Commission, 2024). Each MS will be responsible of designating additional protection and developing a national restoration plan aligned with the Restoration Law requirements. However, the above targets are to be met at each biogeographical region and all MS are expected to do their fair share in achieving the targets (European Commission, 2020).

Table 2: Targets in the EU Biodiversity Strategy 2030 that are relevant for the problem formulation work in the NaturaConnect project.

Target 1	Legally protect a minimum of 30% of the EU's land area and a minimum of 30% of the EU's sea area, and integrate ecological corridors, as part of a true Trans-European Nature Network.
Target 2	Strictly protect at least a third of the EU's protected areas, including all remaining EU primary and old-growth forests.
Target 3	Effectively manage all protected areas, defining clear conservation objectives and measures, and monitoring them appropriately.

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Target 4	By 2030, significant areas of degraded and carbon-rich ecosystems are restored. Ensure there is no deterioration in conservation status of habitats and species; at least 30 % of those not already in favourable conservation status reach that category or show a positive trend

1.2 Systematic Conservation planning (SCP) in support of EU Policy

Historically, criteria for the implementation of Natura 2000 have differed across countries (often because of opportunism, available funding, political will and timeliness) leading to a heterogeneous network in terms of size, coverage and management, and there is often a difference between theory and practice of selecting new protected areas (Prendergast et al., 1999). Consequently, the existing European protected network, albeit large in total extent, consists of many small and often poorly connected PAs, whose performance as a whole is sometimes questioned given declining European biodiversity trends (EEA, 2020a, 2020b; Hermoso et al., 2022). To ensure that the European PA network is fit for purpose, meaning that the implementation of targets 1 and 2 of the EU Biodiversity Strategy maximally contribute to achieving target 4 (Table 2), any extension should ideally consider not only the local site value but also the contribution of each PA to the broader network. Here approaches that bring together best available data, tools and expert knowledge could provide an entry point towards designing a more-coherent Trans-European Nature network (TEN-N).

The implementation of protected areas (PAs), restoration and conservation management require the consideration of a range of different datasets and constraints, many of which often can conflict with each other (Geldmann, 2024). For example, given available areal and often financial constraints it might not be feasible to adequately protect all of biodiversity. Algorithms can help to identify those areas that best conserve biodiversity given all available evidence (Cabeza and Moilanen, 2001). Here the scientific approach of systematic conservation planning (SCP) provides a robust framework that ranges from problem identification, data collation and integration to (mathematical) optimization as an alternative to identify priority areas for conservation. Systematic conservation planning utilises techniques from decision theory and operations research to cost-effectively allocate conservation resources across alternative candidate sites, with the aim of maximizing biodiversity gains. SCP approaches are one of the key tools and state of the art in protected area design globally (Cabeza and Moilanen, 2001; Margules and Pressey, 2000; Moilanen et al., 2009; Sinclair et al., 2018) and have been widely applied in Europe (see

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section 1.3). They allow for the flexible integration of multiple datasets and the assessment of synergies and trade-offs with regards to different forms of managing land and sea.

1.3 Review of past SCP applications in Europe

Systematic conservation planning (SCP) has a long history in Europe with numerous applications across scales. To gain a comprehensive overview, we conducted a systematic review of the scientific literature covering SCP applications across realms (terrestrial, freshwater, marine) and scales (local, national, regional and pan-European). Our aim was to identify where and how SCP has been applied in a European context, while exploring the properties and data used in past studies as measures of planning complexity. With regards to planning complexity, we assessed if studies a) addressed connectivity in any way, b) considered competing land uses or costs, c) had a specified policy aim and d) involved stakeholders in any way. Although the review focused exclusively on applied work published in scientific studies, we acknowledge that SPC is also regularly used in EU grey literature, such as impact assessments, spatial planning guidelines and reports, we here focus exclusively on scientific applications of SCP. Further methodological details on study selection criteria, the extracted information and a full list of studies can be found in (Jung et al., 2024).

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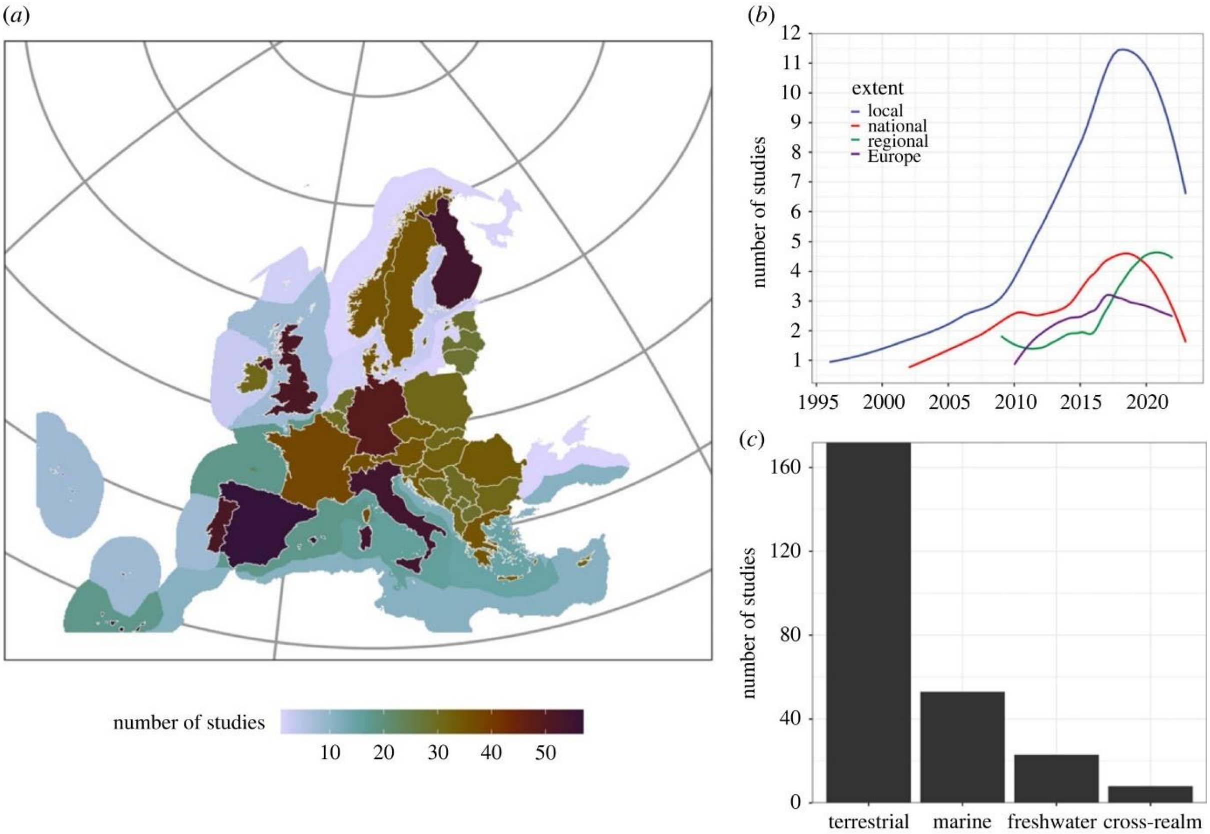

Figure 1: Spatial and temporal patterns of conservation planning studies in Europe. Shown are the spatial distribution (a), the temporal trend of studies separated by spatial extent (b), and the number of studies by realm (c). Figure as presented in (Jung et al., 2024).

In total, we found 266 suitable studies covering 40 individual countries, or broader regional and European extents across the period from 1996 to 2023 (Figure 1). Most European SCP studies focused on local scale applications (54% of all work) with the least studies (11.3%) covering the entirety of Europe at larger scale (Jung et al., 2024). Few studies accounted for connectivity (37%) or competing land-uses (54.4%, often in the form of approximated costs) and remarkably, very few studies (11.1%) involved stakeholders in the conceptualisation or execution of their study, although 68% of all studies aimed to be relevant for or to influence one or more policies (Jung et al., 2024). Overall, these results show that most past SCP applications ignored several key factors and crucially we found that not a single study accounted for all aspects of planning complexity that might be preferable in a well-designated spatial plan of conservation priorities.

1.3.1 Past European-scale applications

There have been a few previous scientific studies that identified European-level priorities for complementing the Natura 2000 protected area network. For example, in a first attempt (Jantke et al., 2011) tried to identify priority regions of expanding Natura 2000 sites for wetland species across Europe, and in another attempt incorporated socio-economic costs (Jantke and Schneider,

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2011). However, they generally ignored other facets of biodiversity (e.g. different taxonomic groups, ecosystems) and aspects of complexity such as connectivity or future conditions. Other studies have expanded on the taxonomic scope of this earlier work (Arponen and Zupan, 2016; Kukkala et al., 2016), assessing representation and gaps across Europe, often also considering equity considerations at EU and EU MS level (Kukkala et al., 2016; Müller et al., 2020). Yet a common theme of these earlier works is the focus on biodiversity representation and gaps, often ignoring other important criteria such as (socio-economic) costs, resilience and connectivity.

In recent years studies have increasingly expanded both the amount of biodiversity data and constraints included. Notably, Hermoso et al. conducted a multi-action prioritisation aiming to identify areas for expansion of conservation and green infrastructure (GI) in Europe (Hermoso et al., 2020). Differentiating between a continental and national-scale planning framing they identified priorities areas that most efficiently achieve species, habitats and nature contributions to people (NCP) targets (Hermoso et al., 2020). Later O'Connor et al. assessed areas with high conservation value for biodiversity as well as NCPs, finding that balancing both can achieve greater benefits if the right areas across Europe are selected (O'Connor et al., 2021). For restoration the most comprehensive spatial assessment to date has been made by Chapman et al., who identified restoration priorities for species and carbon sequestration across Europe, while taking into account future production constraints (Chapman et al., 2023). These recent works, however, did not consider connectivity or future conditions, ignored any engagements with stakeholders and did not align their assessment specifically to ambitions of the EU Biodiversity Strategy, such as for example identifying strict protection or constraining conservation priorities to 30% of land area.

Overall, our review highlighted that there does not exist a single study of European extent that fulfils common complexity criteria (Jung et al., 2024), while also being fit for purpose in supporting the goals of the EU Biodiversity strategy, such as where to expand strict or conventional protection and restoration efforts. There is thus a need to identify priorities for multiple actions (conserve or restore) that are optimized jointly across multiple values of nature (species, habitats and NCP) in a way that accounts for feasibility (in the form of socio-economic costs, burden sharing), while also accounting for climate change and land use change scenarios, and ecological connectivity.

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1.4 Planning for the TEN-N in NaturaConnect

1.4.1 Analytical aims and theory of change

One of the objectives of the NaturaConnect project is to create a technical framework and decision-support tool for assessing where and how the European protected area network (Natura 2000 + nationally designated sites, CDDA + Other Effective Area-Based Conservation Measures, OECMs) can be expanded. We aim to apply SCP to identify options for a future Trans-European Nature Network (TEN-N) that is resilient, coherent and adequate in safeguarding European biodiversity. Any proposal for expansion should ideally align as closely as possible with European policy ambitions such as those proposed by the European Biodiversity strategy and the Nature Restoration Law. Identifying priorities for conservation and restoration usually involves several key decisions, such as the choice of the biodiversity features requiring conservation actions, the conservation targets assigned to them, or other parameters involving threats and opportunities such as actions towards addressing impacts of climate change. Because each of these decision can greatly affect the spatial allocation of conservation priorities, in NaturaConnect we explore different criteria and preferences for setting conservation priorities, and as consequence we will not produce a single TEN-N blueprint, but multiple so-called 'variants' of a TEN-N (highlighted in section 4 and Table 9), each placing different emphasis on individual factors such as for example the importance of threatened species, cost-efficiency, land-use leakage effects or climate resilience.

The consideration of different TEN-N variants also emphasizes the point that proposed SCP solutions are not normative but can only be considered an initial proposal for a more coherent, resilient and adequate TEN-N that can be taken as input for national and sub-national planning and implementation. Although we have elicited extensive feedback by stakeholders at different stage of the planning process (but see section 4.6), there is no central European planning authority that would guide implementation *per se* as this responsibility falls upon MS and/or regions with them. The purpose of the TEN-N variants is predominantly but not exclusively to a) raise awareness of potential "sweetspots" and areas of cross-country collaboration, b) evaluate the feasibility of expanding the TEN-N according to EU policy goals and assess the conservation benefits and trade-offs of doing so, c) provide MS with a baseline "blue pause" of potential areas for further investigation and discussion with on local stakeholders. We thus envisage the

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outcomes of the European-wide planning exercise as a baseline consistent with European policy goals and upon which further discussions can be build.

1.4.2 Design principles

Designing a comprehensive, adequate and resilient TEN-N requires tackling the double challenge of considering 1) the potential optimal placement of individual sites (strict and conventional protection) and 2) the selection of these sites so as they complement existing and proposed new sites in a network (Figure 2, (Rodrigues and Cazalis, 2020)). To design such a network an integration of a range of different datasets using robust algorithms is usually necessary. Furthermore, the identified TEN-N variants should adhere to a set of principles and quantitative criteria on which they can be evaluated to avoid identifying planning options that do not bring the expected benefits (Maxwell et al., 2020; Rodrigues and Cazalis, 2020).

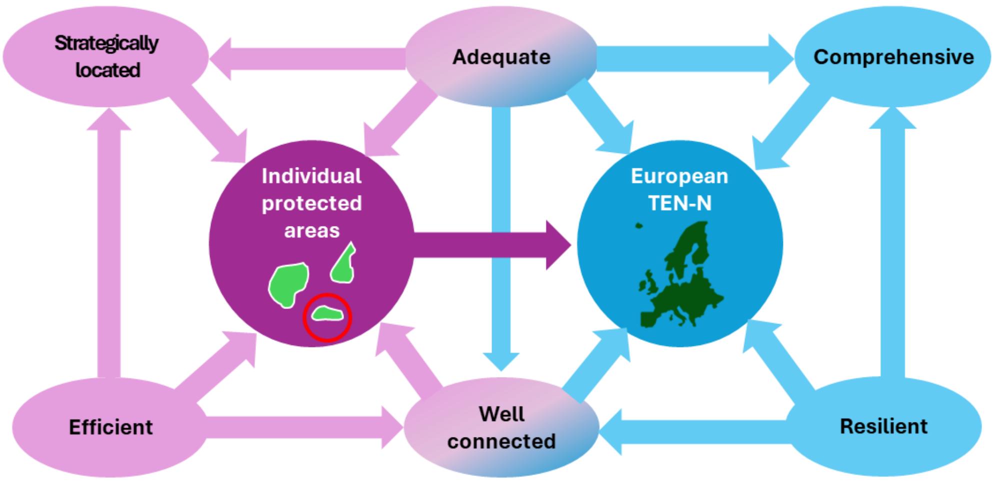

Figure 2: Designing a TEN-N builds on the dual challenge of identifying effective individual sites that are also contained within a wider network (Figure inspired by (Rodrigues and Cazalis, 2020)).

To design and evaluate the TEN-N variants created by WP7 from the problem formulation we will apply set of principles informed by CARE principles and IUCN guidelines (Dudley, 2008). CARE stands for **C**omprehensiveness, **A**dequacy, **R**esilient and **E**fficiency, basic principles that should be met in any suggested expansions of the protected area network and that we define in the context of NaturaConnect as follows:

- With **Comprehensiveness** we mean, for example, that any future protected areas should aim to secure a broad range of biotic elements, e.g. different types of species, habitat types or locally relevant features of conservation concern. Here any expansion of the network should ideally not only consider those features that have been observed or that are presently there, but also consider what could be there now or in the future.

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- **Adequacy** relates to the properties of the outcome of the decision-making problem and whether, for example, an identified new protected area network - or set of sites where conservation management could be adjusted - is able to secure enough of the area of the features in the decision problem for its purpose. This can be related to habitat amount, number of populations or even individuals in the network and can be evaluated based on the specific targets defined in the problem formulation (e.g., how much is enough).
- With **Resilient** we refer to the fact that the twin challenges of anticipated future climate and land-use change affect the effectiveness of any protected area establishment, as species shift their distributions and climate risks to biodiversity increase. The network of future protected areas should include important climatic refugia and safeguard those areas that allow species to disperse and persist under future conditions, also supporting connectivity among selected sites now and in the future.
- **Equity and Efficiency** in area-based conservation planning aims to secure that newly identified protected areas should be implementable, and that trade-offs and opportunity costs with other sectors (e.g. forestry, agriculture) are minimised. A just and equitable distribution of conservation efforts ensures that conservation efforts are to the extent possible not distributed in a way that would unjustly affect certain regions or stakeholders, thus supporting "burden sharing" of the network. Besides Equity and Efficiency, the E in CARE can additionally also stand for Effectiveness, which however is not assessed *per se* in the planning.

We recognise that other principles, particular those related to the legal status of species and habitats, management plans, finance and governance, are also important to consider; those are a natural consideration when it comes to direct implementation and on-the-ground discussions with stakeholders (e.g. public administrations, landowners, local communities). The principles applied here primarily aim at establishing a series of variants for a TEN-N that can serve as decision support tool and point of departure for further discussions at local and case study scale (WP8).

1.4.3 Study extent

For planning the TEN-N, we will primarily focus on the EU28+ countries, which includes all EU 28 Member States plus Switzerland, Norway, the Western Balkans (Serbia, Kosovo, North Macedonia, Montenegro, Albania, and Bosnia and Herzegovina) and the UK (Figure 3). The rationale for including the Balkans is that for cross-boundary and regional conservation efforts as well as for accounting for connectivity and resilience, those countries situated between EU countries need to be included. The spatial resolution of all analyses is 1 km^2, matching the

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resolution of the biodiversity (from WP3), NCP and costing (WP4), land-use scenarios (WP5) and connectivity (WP6) data (see section 4 for more details on the integration).

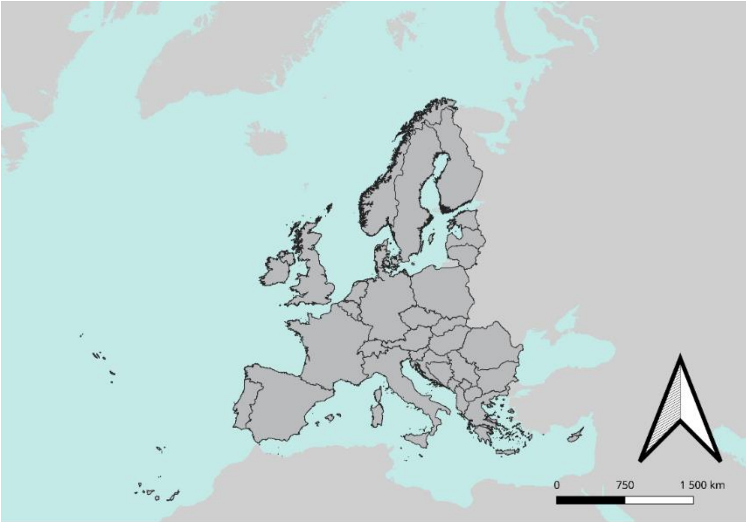

Figure 3: Extent over which this planning is conducted in WP7. Shapefiles originates from NaturalEarth (CC-BY) with map created in QGIS.

We acknowledge that this study extent excludes areas associated with the EU, such as the 13 overseas countries and territories (Aruba, Bonaire, Curacao, French Polynesia, French Southern and Antarctic Territories, Greenland, New Caledonia, Saba, Saint Barthelemy, Sint Eustatius, Sint Maarten, St Pierre and Miquelon, Wallis and Futuna), and 9 outermost regions (French Guiana, Guadeloupe, Martinique, Mayotte, Reunion Island and Saint-Martin (France), Azores and Madeira (Portugal), and the Canary Islands (Spain)). Although not included as part of this deliverable nor of NaturaConnect WP7 outputs, a separate prioritisation analysis for these outermost regions and overseas territories is planned for the near future following a slightly adjusted problem formulation given the differences in available data and information.

1.4.4 Linkages to other WPs

Underlying the problem formulation and identification of conservation priorities are data specifically created for this purpose in the NaturaConnect project. The final TEN-N variants will integrate various datasets created in other Work packages (WP3-6), as well as feedback received

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from stakeholder engagement at European and case study levels as feasible (WP1, 8). A full flow chart can be found in Figure 4 (for high resolution version see SI Figure 1).

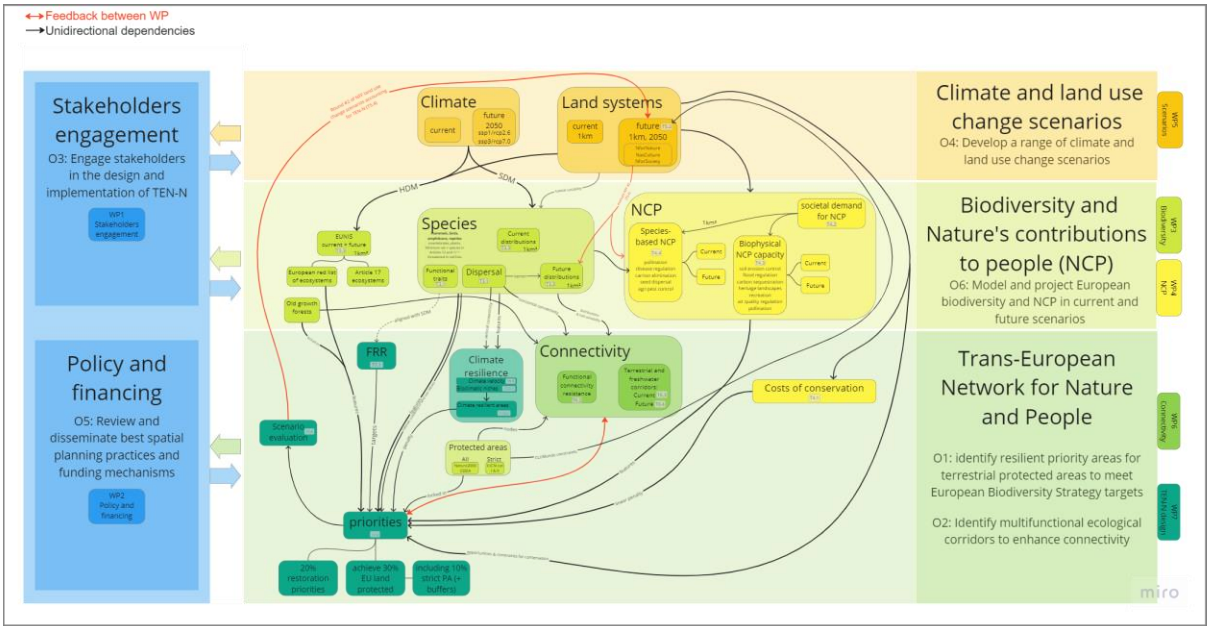

Figure 4: Flowchart of key data flows to and from WP7 created in miro™ . Key components are visually highlighted including for example different datasets (climate, land systems) and approaches (connectivity). Arrows in black indicate one-directional feedbacks, e.g. data only goes into the design of the network, while red arrows indicate bidirectional feedbacks, e.g. data is used in the network design and feeds back to other WPs .A version in higher resolution can be found in the Appendix (SI Figure 1).

With regards to linkages with other NaturaConnect WPs, we differentiate between one-directional and bi-directional feedback. One-directional feedback include for example the inclusion of critical datasets in the planning such as the estimated species present and future distributions (WP3), opportunity costs (WP4, (Spencer et al., 2024)) and estimates of Nature contributions to people (WP4). In contrast bidirectional feedback include linkages where prioritisation outputs are considered as both an input but also aim to inform the final outcomes of other WPs. Examples here include the inclusion and afterwards evaluation of land-use leakage effects (WP5), the consideration of connectivity in the planning design and feedback between current and proposed protected areas (WP6) and stakeholder feedback in the design and evaluation of the TEN-N as part of the planning (WP7, but see section 4.6).

1.5 Scope and objectives of this Deliverable

This Deliverable outlines the technical problem formulation, and critical considerations needed to identify potential areas for complementing the existing European protected area network and

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contributing to a more connected TEN-N. Based on the design principles (see above section 1.4.2) we describe in this deliverable:

i) the process of setting adequate area-based targets for species using Favourable Reference Values so that the TEN-N supports the long-term survival of populations (Section 2).
ii) how to incorporate future climate change in the network design and identify critical areas that are needed to support the climate resilience of the TEN-N (Section 3)
iii) how to use multi-criteria systematic conservation planning techniques to create priorities for protection, restoration and green infrastructure, describing the objective functions, constraints and design criteria while operating under various assumptions and stakeholder preferences (Section 4).

Besides reporting on the methods underlying the formulation of the planning problem, this deliverable also includes preliminary results with the data available up to this point.

Not included in this deliverable are the activities planned under T7.4 of WP7, which deals with performance evaluation of the TEN-N. Although we cover some of the indicators in Section 4.4, the full description of indicators and quantification thereof will be in Deliverable D7.2, that contains the full report and evaluation of all planning solutions, building on the problem formulation and data described here.

2 Favourable reference values

To build a TEN-N that is adequate, we need to know how much of biodiversity should be protected at a minimum (see Design criteria in section 1.4.2). In NaturaConnect, we aim to set such targets for all features included in the planning. Here we rely on the concept of Favourable Reference Ranges (FRRs) and leverage on existing frameworks to quantitatively estimate FRRs for European species at the level of Biogeographical Regions within Member States (MS-BIO). FRR is the distributional range within which all significant ecological variations of a species are included for a given MS-BIO, and which is sufficiently large to allow the long-term survival of the species. We homogenized and integrated FRRs estimates already provided by EU Member States (MS) using different analytical backgrounds and made them usable for systematic conservation planning approaches in the form of conservation targets. Even more importantly, we estimated FRRs for all species for which the FRR was not already provided by the MS. To do this, we used

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several alternative methods, depending on the availability of information for the identified species groups.

2.1 Introduction

Central in both HD and BD is the concept of achieving and maintaining a favourable conservation status (FCS) for priority animals, plants and their habitats (Bijlsma et al., 2018). A species is considered in FCS when it can sustain itself long-term as a viable part of its natural habitat; its natural range is neither currently diminishing nor expected to diminish in the foreseeable future, and there is, and will likely remain, enough habitat to support its populations over the long-term (Bijlsma et al., 2018; Trouwborst et al., 2017). In this context, FRR is a key reference threshold, as a species can indeed be considered in FCS when its distributional range is large enough to support its long-term survival. Notably, a species is at FCS when its range is not decreasing and is not smaller than the estimated FRR; therefore, when past favourable condition data are available, these are fundamental to derive FRR values-(Bijlsma et al., 2018) (Figure 5).

Parameter	**Conservation Status**			
	Favourable ('green')	**Unfavourable - Inadequate ('amber')**	**Unfavourable - Bad ('red')**	***Unknown (insufficient information to make an assessment)***
Range (within the biogeographical region concerned)	Stable (loss and expansion in balance) or increasing AND not smaller than the 'favourable reference range'	Any other combination	Large decline: Equivalent to a loss of more than 1% per year within period specified by MS • OR more than 10% below favourable reference range	*No or insufficient reliable information available*

Figure 5: Possible definitions of defining conservation status based on a species range (source/adapted from Bijlsma et al., (2018)).

According to Article 17 of the HD, every six years EU MS must update FRR at the MS-BIO level), and consequently report on the gap between the assessed status of the species and the relative progress towards the conservation objectives (EEA, 2020a). The most recent report, covering the period 2013-2018, shows that more than 60% of species are still in an inadequate conservation status (EEA, 2020a). These reports have some limitations due to the different methodologies (expert-based, quantitative) used by each MS, making cross-European comparisons and subsequent use in conservation applications challenging (Bijlsma et al., 2018). In addition, the report allows FRRs to be reported as unknown or in the form of operators such as ">" and ">>", implying that the reference threshold is "higher" or "much higher" than the current species status.

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Therefore, to improve the applicability of FRRs, it is necessary to recalculate them using a methodology that standardizes FRR values provided by different MS and different research agencies. The intent of this methodology is to leverage on FRRs already provided by MS, also in the form of operators, when possible, to estimate FRRs not already quantified and providing a modelling framework which can support MS in future reporting.

2.2 Overview of the analyses to estimate FRRs

We classified all species included in the HD and BD into six groups based on the taxonomic level of phylum/class (Table 3, – left column). We did this assuming more reliable estimates for taxonomically similar species, and because we assumed that the FRR values provided by MS follows uniform criteria for species belonging to the same taxonomic level or species that share the same habitat types, although this information is not clarified by MS in the HD and BD reports. The six groups were distinguished into three independent analytical frameworks (Table 3 – right column), based on the availability of relevant data gathered for FRR estimations (see next sections).

Table 3: Subdivision of the species considered in the compilation of FRRs into six different taxonomic groups, which are categorized into three analytical frameworks based on the information available in the literature and thus on the different methodologies developed for estimating FRRs

GROUPS OF SPECIES	SOURCE OF SPECIES/MS-BIO	ANALYTICAL FRAMEWORKS TO ESTIMATE FRRs
mammals	HD – IUCN	Details in Section 2.3
non-Chordata animals	HD	Details in Section 2.4
freshwater Chordata		
plants		
herpetofauna		
birds (only species breeding in EU)	BD	Details in Section 2.5

For each of these six groups, we assessed from literature, HD, and BD (step 1) the availability of ecological and life-history traits, as well as information on distribution and population size and trends, and quality of the habitat in regards of climate conditions and anthropogenic disturbances. We specifically considered only data from quantitative approaches, i.e., excluding approximate estimates based on expert opinions or unverified individual observations without statistical models providing confidence intervals. Further information was collected as complete

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taxonomy, that we deemed useful in estimating FRRs, and FRR by MS/BIO when provided by the HD and BD reports (Figure 6).

In step 2a), for all non-mammalian species, we evaluated for which combination of species/MS-BIO FRRs were already reported and, 3a) if they were provided, we used those FRRs in our database as response variable of predictive models, eventually making estimations for both training dataset and the species/MS-BIO for which FRR was not provided by MS based on the gathered species information (Table 4). Notably, we adopted a sequential approach based on data availability: i) Random Forest classification, ii) Random Forest regression, and iii) gap-filling (Figure 6, Details of the analyses in Sections 2.4 and 2.5).

In step 2b) For mammals, we used a more refined approach, as more information was available. After gathering information in the first step, we decided if FRR should be equal to the CV or greater than it, considering the feasibility in reaching them (further details below). 3d) When FRRs> CV, i.e. when a species has experienced a decline in the past and has been threatened by reversible threats, we set FRRs using different methods (Section 2.3), according to the availability of data: i) we considered historical distribution, when available in literature, to set FRRs (reference-based approach) (Section 2.3.1), and in alternative or in ii) we used model-based approaches according to the availability of data and population trends (Section 2.3.2). For species that have experienced a decline in the past but are now recovering, such as large mammals, we view this growth as vital for attaining a FCS. This outlook is supported by their recovery after substantial declines in Europe and the expectation that their populations will continue to grow in the coming years. Thus, in this case, we decided to adopt the Population Growth Models, in particular, the exponential growth models (Section 2.3.3). In this case of current stable or decreasing population trend, we took advantage of models performed by other studies, such as the Population Viability Analysis (see Section 2.3.4 for the full description). When demographic information was not available, for species or populations which have experienced a decline but whose trends of distribution and population may potentially increase, as an alternative or in

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combination to the other models, we adopted the range expansion model, based on the ability of species to disperse by 2030, using generation length and dispersal information (Section 2.3.5).

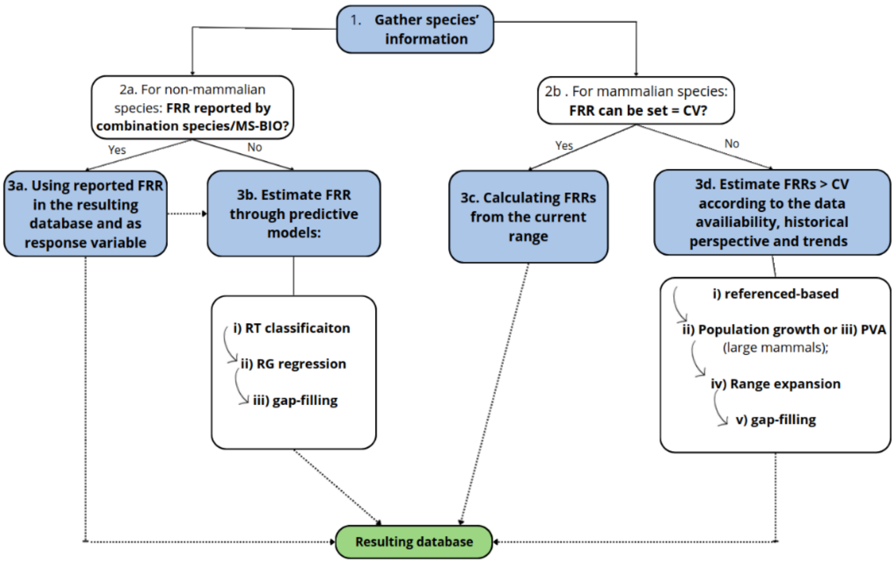

Figure 6: Summary of the general methodology to estimate FRRs for all combinations species/MS-BIO considered.

MS-BIO – spatial-explicit data

We gathered the map of European MS from Eurostat (2021, level NUTS 0). In addition, we downloaded the map of biogeographical regions within EU provided by the EEA (Roekaerts, 2002). We overlapped the maps of the MS and the biogeographical regions to obtain a map of the study area with all combinations MS-BIO. We did this in GRASS GIS v7.8.2, transforming the output as raster format with equal-area projection "EPSG 3035" and a spatial resolution of cc. 0.01 km^2.

Spatial data, ecological traits, life-history traits, population and range trends

For the six groups of species considered, we gathered or calculated information about the biology of each species, the suitability of the habitat at present and forecasted for 2030, the level of tolerance to human disturbance, quantitative values on distribution and population trends, an overview of species threats over time, and the current threats. These data (Table 4) come from HD, BD, literature, and WP3, and were used in the analyses to estimate FRRs, distinguishing frameworks based on data availability, as described in the next sections. A full list of data sources will be available as a part of D'Alessio et al. (*in prep*).

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Table 4: Set of species information gathered for the analyses to estimate FRRs.

TYPE OF DATA	DATA DESCRIPTION	GROUPS
Area of habitat (AOH)	Data from (Lumbierres et al., 2022). Raster data; 100 meters resolution based on habitat preferences and elevation ranges. Transformed to 1 km resolution	mammals
Species geographic range at global scale	Vector data, transformed to raster format with 1 km resolution (IUCN, 2023)	mammals
species population density (ind/km^2) at global scale	Data from COMBINE (Soria et al., 2021), IUCN (IUCN, 2023), and other sources in literature. Reported as estimated ind/km^2 at global scale	mammals
generation length	Defined as the mean age of parents of the current cohort, reflecting the turnover rate of breeding individuals in a population. Data from (Pacifici et al., 2013). Reported as years	mammals
Natal dispersal distance	Defined as the distance travelled by a species between the birth site and the breeding site. Data from COMBINE (Soria et al., 2021), IUCN (IUCN, 2023), and other sources in literature. Reported as meters	mammals
Species distribution modelling (SDM) outputs: continuous habitat suitability index and potential presence/absence (binary format) in the present and forecasted to year 2030	Raster data with 1 km resolution obtained from WP3, trained using as response variables climate, land cover, land use intensity, and soil (see WP3)	birds herpetofauna
Ratio between current species distribution range extent (CR) and habitat availability	Data from HD and SDM outputs; CR reported as range extent per MS-BIO in km2. Habitat availability is the extent in km2 of the potential presence of a species per MS-BIO, based on binary SDM outputs. Calculated using the formula CR/habitat availability. N.B. the data is not available for all species/MS-BIO	mammals non-Chordata animals freshwater Chordata plants herpetofauna
Tolerance to human disturbance (proxy derived from human population density)	For each species, we gathered occurrence records from the Global Biodiversity Information Facility (GBIF). Then, we extracted the correspondent level of human population density at the coordinates, using gridded human	non-Chordata animals freshwater Chordata plants

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	population estimates (Center For International Earth Science Information Network-CIESIN-Columbia University, 2017). The level of tolerance to human population density, as proxy for human disturbance, was set at 75th percentile of the gathered values. N.B. not found occurrence records for all species; Thus the data is not available for all species/MS-BIO	herpetofauna
species range trend	Data from HD. Birds data from BD; categorized as 'S' (stable), 'I' (increasing), 'D' (decreasing), ´F´ (fluctuating) ´U´ (unknown), reflecting the trend in a species' range over the preceding 10-15 years. This is the initial response variable in the models to estimate FRR for birds (Section 2.5). N.B. the data is not available for all species/MS-BIO	mammals non-Chordata animals freshwater Chordata plants herpetofauna birds
FRR operator	Data from HD; categorized as 'eq.' (CR = FRR), 'mt.' ('more than'; CR < FRR), and 'mmt.' ('much more than'; CR << FRR), indicating whether the current range is equal to, smaller than, or much smaller than the estimated FRR, respectively. N.B. the data is not available for all species/MS-BIO	mammals non-Chordata animals freshwater Chordata plants herpetofauna
Population trend	Data from BD; population trend during the last 10-15 years in a MS. Categorized as table (S), declining (D), fluctuating (F), increasing (I), or unknown (U).	birds
Mean population size	Data from BD; calculated mean between min population size and max population size, as reported in BD, per species in each MS	birds
Taxonomy	Data on species family, order, class, phylum, gathered from National Center for Biotechnological Information database gathered via the *Taxize package* in R (Chamberlain and Szöcs, 2013). For mammals, data from IUCN (2023) and COMBINE (Soria et al., 2021).	mammals non-Chordata animals freshwater Chordata plants herpetofauna

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		birds

2.3 Estimating FRR for mammals

After gathering the needed species' information, we distinguished species for which FRVs should be set equal to or higher than the current range size (Figure 6). We set FRVs equal to current values in two cases: 1) if a species is classified as Least Concern by the IUCN Red List (European assessment), its population trend is stable or increasing and it has not experienced a decline in the past, therefore its status can be considered favourable; 2) when the population is projected to decline in the future, as it is assessed as threatened according to the A3 or A4 criteria of the IUCN Red List (IUCN, 2023), or irreversible threats are threatening the species. Following the IUCN Red List guidelines, we considered irreversible those threats that arise when a population's size declines so drastically that recovery becomes impossible or unlikely within the timeframe of existing policies. Such threats also include those linked to significant and permanent habitat loss; for example, we considered urban sprawl and old-growth forest deforestation as threats that can destroy species' habitats with low possibility of restoration, even with altered management practices (IUCN, 2023). Additionally, the ongoing impacts of climate change may be irreversible due to the time lag between greenhouse gas emissions and the resulting ecological changes. Examples include the ongoing impact of climate change on species fitness and the loss of species habitats due to land use, which may become irreversible by 2039 (Calvin et al., 2023). In this case, we assumed that the range and population size cannot exceed the current values, since it is not feasible for the species to reach a higher reference value than the present one, but it must be ensured that this does not diminish. In this case, we calculate the CV from the current species' distribution map (IUCN, 2023) within the boundaries of EU Member States. Once WP3 projections, based on climate and land-use changes are made available, we will assess the difference in range between current and future, to possibly aim at higher FRVs.

Instead, the methods adopted to set FRRs when they should be greater than the CV (Figure 6), are fully described below and reported following a hierarchical order: i) Reference-based approach, ii) Population Growth Model; iii) Other population model-based approach (PVA), iv) Potential Range Expansion, v) gap-filling. For some methods we have also provided validation: this is the case of the population growth models, where the performance was assessed using R-square as validation measure. For other methods, such as the reference-based approach and potential range expansion, the nature of the approach is such that validation values cannot be provided. In the case of PVA, as we have used analyses from other studies, validation has already been carried out and is not necessary here.

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2.3.1 Reference-based approach

The reference-based approach consists of considering the historical distribution and population size during a period when the species was in a favourable state (Bijlsma et al., 2018). FRRs or FRP are set using empirical numbers, areas or densities that correspond to a specific historical baseline, found in literature. To outline the historical perspective of the species and determine the reference period to focus on, we relied on the information gathered about the period in which the distribution and population size have been more impacted (if impacted; Bijlsma et al., 2018). When we obtained FRP, we converted it into FRR, dividing FRP by the species density (individuals / km^2) found in the literature. We applied this approach especially to mammals, for which information in literature was available.

2.3.2 Model-based approaches

The population models allowed us to establish a favourable population size (FRP) and the distribution model the FRR. FRP and FRR are translated into each other using the density. The exponential growth model and Population Viability Analysis were adopted especially for large mammals (*Bison bonasus, Canis lupus, Gulo gulo, Lynx lynx, Lynx pardinus* and *Ursus arctos*), whose demographic information was available in the literature. We considered one or the other method, according to the historical perspective, current trend and data availability (see Section 2.2).

2.3.3 Population growth model

To perform Population Growth Models, we gathered national population estimates over time from various sources in literature. Our aim was to determine the rate of increase based on observed population growth and project the population size by 2030 as a favourable and achievable size. To achieve this, we used generalized linear models using the R software ('glm' function, R v4.4.0; R Core Team 2024). The models included annual population size estimates at the Member State level as the explanatory variable and the year of the estimate as the predictor. We applied Poisson regression, or negative binomial regression in cases of overdispersion. The model's coefficient represented the instantaneous rate of increase (r), which could be translated into the finite rate of increase (λ) of the population:

$$\lambda = e^r$$

We checked these models' performance mainly through the coefficient of determination (R-square). We tested two regression models: Poisson and negative binomial. To choose the best one, we also compared them through Akaike Information Criterion (AIC) and checked for overdispersion.

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In situations where the population trend was known but the rate of increase could not be calculated due to a lack of population data, we used specific rate of increase values from existing literature. When population data was overall estimates of population size, the population prediction in 2030 based on the computed regression, through the R function "predict.glm" (Schlegel, 2024) otherwise, starting from the most recent and complete population estimate and using the rate of increase obtained from the model, we extrapolated the population in 2030 through the formula:

$$N_{2030}=N_0 * e^{r*n}$$

Where N_0 is the latest population estimate, n is the number of years to reach 2030.

2.3.4 Population Viability Analysis

Population viability analysis (PVA) is a quantitative, model-based technique that assesses the probability of extinction or loss of genetic variation. It utilizes species-specific genomic, demographic, and abundance data, considering recognized threats to population survival and growth models (Shaffer, 2019). Conceptually this method establishes the size of a minimum viable population (MVP), estimating the minimum number of individuals needed for population survival (Shaffer, 2019). Here we used MVP estimates from PVA from various sources in literature and applied them to determine the FRP for each Member State and biogeographic region. This involved considering the number and distribution of existing populations (Bijlsma et al., 2018). For example, if the MVP was specified for a population in a particular combination of MS and biogeographic region, we calculated FRP values by multiplying the MVP by the number of extant populations in all combinations. Otherwise, when the number of extant populations is not reported nor found in literature, we assume that in each MS-BIOGEO combination a single population occurs.

2.3.5 Potential range expansion model

When we did not have historic data, specific demographic information and cannot use population growth models, but we have traits data (typically for Chiropteran and Rodentia species), we applied a simple range expansion method that assumes a constant establishment rate (Visconti et al., 2016). The process involved estimating the potential geographic range expansion by 2030, considering the species' dispersal capability and accounting for its generation length. We elaborated the expanded range starting from the most recent IUCN Red List species' range map and considering the dispersal capacity in time by each species, based on the following relationship:

Dispersal 2030= dispersal (km) * number of years to reach 2030 / generation length (years)

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To achieve this, we expanded the range starting from the most recent species distribution map (IUCN, 2023) and created a dispersal distance buffer using the GRASS function "r.buffer." Assuming all current species ranges refer to 2022, we projected the range maps for 8 years. In this method, we considered the extended distribution as a feasible FRR value. Information on dispersal distance and generation length was obtained from the sources listed in Table 4 for mammals. Note that this method was selected in absence of climate and land use model projection, to obtain preliminary FRRs. In addition, we assumed that a dispersal event would result in the establishment of a population that could successfully reproduce and propagate new individuals after each generation time. For these reasons, the potential range may be overestimated and the resulting FRRs should be adopted with caution.

2.4 Estimating FRR for non-Chordata animals, freshwater Chordata, plants, and herpetofauna (non-mammalian species of the HD)

We developed a framework for calculating FRRs in situations where detailed ecological traits and temporal, quantitative population trend data are lacking, a common scenario for non-mammalian species. Specifically, we designed a machine learning framework to estimate FRRs and subsequently identify conservation targets. As input data, we used FRRs already provided by MS as the response variable, with the gathered species information serving as predictive variables (Table 4, including variables for non-Chordata animals, freshwater Chordata, plants, and herpetofauna). The framework consists of two sequential methods:

A) Random Forest classification: This step estimates whether a species is in a FRR condition based on the predictive variables. Here, the response variable is the FRR operator, which we predicted for species within the same taxonomic group and biogeographical region for which the FRR operator had not yet been indicated by MS.

B) Random Forest regression: This method estimates the FRR using the numerical FRR values provided by MS or, in cases where the FRR operator was indicated by MS as "aeq." (meaning "equal to the current range"), by setting the FRR equal to the current range. Additionally, if the classification step indicated a species was in an FRR condition, we set its FRR equal to the current range. These values were used as response variables to calculate the desired outcome: a numerical FRR with a tolerance range (lower and upper limits) for all species. This includes both species for which the FRR had already been provided by MS and those for which the FRR was not previously available.

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This sequence of Random Forest classification and regression was applied to all species within each group across the biogeographical regions. For species for which FRR could not be calculated using these methods, the FRR was estimated by applying the mean FRR of species at the same taxonomic level within the respective biogeographical region, following the approach of Pacifici et al. (2013). Further details on the methods are provided below:

A) Random Forest classification: Many species in the HD have no operator indicated and no estimated FRR reported by the MS. Therefore, our goal with this model was to predict whether these species may be in FRR or not, based on the random forest predictions. We parameterised the RF classification model by testing a range of parameters for the number of trees to develop in the model (parameter ntree) from 300 to 3000, adding 300 trees at each iteration. Additionally, we tested the number of variables to consider randomly at each split (parameter mtry), with a range from two to the maximum (six) number of predictive variables. We used the *caret package* in R (Kuhn, 2008) to extrapolate best parameters based on the Accuracy score, calculated using five folds cross-validation test repeated three times. RF classification was run only if five response data per predictor were available, as a rule of thumb. As rarely binary response values were in equal number, we included the case weight option in the model to adjust the model's learning process, as suggested in unbalanced classification problems (Valavi et al., 2021). If RF classification with all variables was not performed for a biogeographical region, particularly if the number of data points with all variables for training was insufficient, or all factorial response data were of the same level, then we proceeded to run RF classification by sequentially removing each of the predictive variables up until a minimum of three, with all combinations of variables possible tested. In this way, species for which one or some predictive variable information was unavailable could still be included in the model if enough response data were available. The results of the RF classification are in 'yes'/'no' format, indicating whether our analysis has estimated the species to be in the conditions of FRR or not. If "yes", the FRR was set to CR and included as response variables in RF regression.

B) We applied a random forest regression using as response variables the FRR provided by MS and assigned by us through the random forest classification. We used again the predictive variables (Table 4) as independent variables. This time, R^2 was used as metric of modelling performance given the continuous response variable, still using five-fold cross-validation repeated three times. Predictions of the RF regression was run for both training species/MS-BIO, i.e. those for which FRR was already provided by MS and estimated by us through random forest classification, and for the remaining species/MS-BIO. This to achieve a consistent result for all species within an MS-BIO based on the collected information of the predictive variables, given

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that the details of the methods used by various research groups to set FRR for a species are generally not reported. Consequently, different methods may be used for different species, leading to results that could be biased by the chosen method. Results were calculated as a range of FRR (FRR min - FRR max) in spatial extent rather than as single value. This last passage was done by calculating the standard deviation (SD) of the Root Mean Square Error, which is the average magnitude of the errors between predicted and observed model estimates. This SD was then subtracted and added to the predicted FRR value, resulting in a minimum FRR and maximum FRR, respectively. Lastly, if FRR values exceed the extent of the MS-BIO area of belonging of the species, such extent was set as FRR, being the actual maximum range extent possible.

For the remaining species, for which FRR range was still not assigned due to missing predictive variables information, we followed the method outlined in Pacifici et al., (2013). Specifically, we grouped all species by taxonomic bins, first by MS-BIO and taxonomic order, then by taxonomic family, or class, respectively, if the grouped species were in insufficient number. we then calculated the remaining FRRs as the average FRR for each bin, with a min and max range calculated using the SD of the mean.

2.5 Estimating FRR for birds

In general, the framework for estimating FRRs for all breeding birds listed in the BD follows the framework outlined in the previous section 2.4 for non-mammalian species of the HD. However, there are three important differences to highlight:

- To our knowledge, the BD report does not provide any indication regarding FRRs, i.e., neither numerically assigned FRRs nor FRRs indicated by operators by MS, which is necessary to parametrize the RF classification models. However, one of the variables reported in the report is the long-term range trend, which can be stable (S), declining (D), fluctuating (F), increasing (I), or unknown. We used this variable as the response variable in RF classification, classifying species with a stable long-term range trend as being in FRR, while species that are declining, fluctuating, or increasing were classified as not being in FRR. Although fluctuating, decreasing, or increasing populations can also be potentially at FRR, there is no way to be certain of this. Therefore, we considered only stable populations to be at FRR, as per the definition in the HD, and considered remaining categories as unclear (comparable to pseudo-absence data). For species with an unknown long-term trend, the RF classification

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makes predictions based on the predictive variables input into the model (Table 4, including variables for Birds).

- The information available in the BD report regarding predictive variables differs from those in the HD. Consequently, different data were gathered for birds and used as predictive variables in the models (see Table 4, including variables for Birds).
- The information from the BD report is organized by MS, rather than by MS-BIO, as required for the FRV outputs in NaturaConnect framework. To address this, after running the models using species grouped by MS (differently than as described for non-mammalian species in Section 2.4), we converted the estimated FRRs from the species/MS level to the species/MS-BIO level. This conversion was done by applying the ratio of available habitat within each MS-BIO to the total available habitat at the MS level, using the binary SDM outputs from WP3, projected for the year 2030 (see Table 4 for further details). The estimated FRR was then proportionally adjusted based on the calculated habitat availability ratio within each biogeographical region.

2.6 Preliminary results

We provided quantitative FRRs for each taxonomic group, filling the existing gap in the HD or BD reports (Table 5, Figure 7). The taxonomic group with most species for which FRR was to be estimated by us is birds, with countries such as Finland, Greece, Italy, and Poland that were reported with very few species having stable range trend in the long period. Instead, mammal and herpetofauna species were the groups more covered by FRR provided by MS, although with some exceptions, such as Denmark and Croatia (Figure 7). For non-mammalian species, the RF classification models performed well, with an average accuracy of 0.78 ± 0. 0.87 Standard Deviation, particularly for Herpetofauna and in the Mediterranean BIO (Table 5 & Table 7, second column). However, the RF regression models performed less effectively, with an average performance of 0.33 ± 0.20 Standard Deviation. Better performance was for Herpetofauna and in the Black Sea BIO (Table 6 & Table 7, third column). In addition, From the Population Growth Models that we performed and selected for mammals, we obtained high R-square values, whose average value and SD are reported in Table 6 for simplicity.

The number of species to be considered at FRR presently varies from a minimum of 39.2 % for birds and a maximum of 60.5 % for herpetofauna (Table 5).

*Table 5: Summary table of the preliminary FRRs resulted by each taxonomic group, highlighting the values that were already present in the HD and BD reports and the remaining values provided using our approach (expressed as % out of the total species/MS-BIO combinations). * "either numerically or through the use of "aeq." operator, stating FRR = CR, ***

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*"in the form of stable (S) range trend in the long term", *** "based on aeq. operator + our estimates via Random Forest classification (N.B. analyses not-performed for mammals)"*

Taxonomic group	N° combination species/MS-BIO	FRR provided by MS *	FRR estimated by us	Species to be considered at FRR ***
Mammals	1,825	346 (19.0%)	1,479 (81%)	NA
Non-chordata animals	1,490	775 (52%)	715 (48%)	593 (39.8%)
Freshwater chordata	770	417 (54.2%)	353 (45.8%)	327 (42.5%)
Plants	1,414	945 (66.8%)	469 (33.2%)	842 (59.5%)
Herpetofauna	1,051	782 (74.4%)	269 (25.6%)	636 (60.5%)
Birds	6,140	1858 (30.3%)	4,282(69.7%)	2,408 (39.2%)

Table 6: Summary table of the modelling evaluation scores by groups of species. Standard Deviation (SD) in brackets. Accuracy classification is not reported for mammal species, for which we only calculated the R-square associated with the Population Growth models.

Taxonomic group	Accuracy classification	R-squared regression
Non-chordata animals	0.75 (± 0.06 SD)	0.25 (± 0.10 SD)
Freshwater chordata	0.72 (± 0.12 SD)	0.43 (± 0.12 SD)
Plants	0.75 (± 0.07 SD)	0.17 (± 0.08 SD)
Herpetofauna	0.86 (± 0.08 SD)	0.57 (± 0.18 SD)
Birds	0.79 (± 0.09 SD)	0.43 (± 0.11 SD)
Mammals	NA	0.87 (± 0.17 SD)

Table 7: Summary table of the modelling evaluation scores for non-mammalian species by biogeographical regions. Standard Deviation (SD) in brackets. N.B. in Black Sea, RF classification was not performed give absence of NA values across FRR operators.

Biogeographical region	Accuracy classification	R-squared regression
Alpine (ALP)	0.78 (± 0.06 SD)	0.27 (± 0.17 SD)
Continental (CON)	0.75 (± 0.10 SD)	0.37 (± 0.20 SD)
Mediterranean (MED)	0.91 (± 0.06 SD)	0.23 (± 0.12 SD)
Atlantic (ATL)	0.76 (± 0.06 SD)	0.50 (± 0.22 SD)
Pannonian (PAN)	0.82 (± 0.04 SD)	0.25 (± 0.17 SD)
Macaronesia (MAC)	0.77 (± 0.00 SD)	0.34 (± 0.00 SD)
Black Sea (BLS)	NA	0.65 (± 0.14 SD)

Note that we completely replaced the operators, so we did not specify the percentage of FRRs reported by MSs as ‘aeq’ indicated as an operator. As also for birds we used a different approach, we excluded from the FRR estimated by us, those that were set = CV by MSs reports. The estimated FRRs are uploaded on the NaturaConnect Zenodo community (see Data availability section 6),

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along with the appropriate metric (either Accuracy or R^2) of modelling performance for every species.

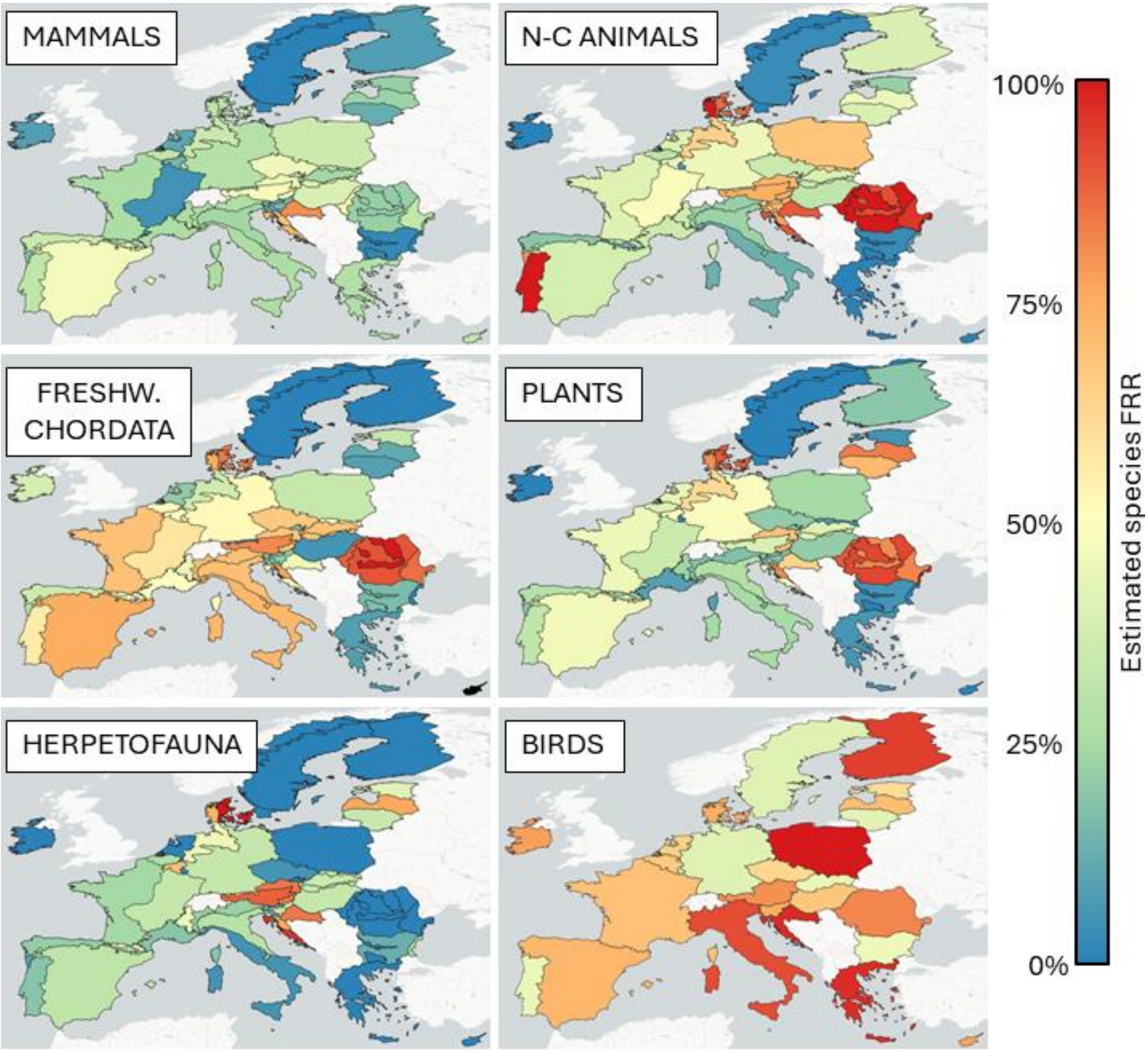

Figure 7: Percentage of estimated FRRs for each MS-BIO of the EU for all species listed in the HD, and for each MS of the EU for all bird species listed in the BD. N-C ANIMALS = non-chordata animal species listed in HD. FRESHW. CHORDATA = Freshwater chordata species listed in HD.

2.7 Discussion and conclusion

Our work successfully derived first modelled Favourable Reference Values (FRVs) for all priority species under the Habitats and Birds Directive across the various Member State-biogeographic region combinations in Europe. This achievement is significant considering the historical challenges associated with disparate methodologies and the qualitative nature of previous FRV reporting estimates. We have created a standardized set of FRVs that can improve the consistency and comparability of conservation assessments across Europe using a quantitative rather expert-

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based approach. Our methodology, which involved classifying species into taxonomically similar groups facilitated the application of hierarchical steps that expanded the scope of species for which FRVs could be estimated, thereby addressing the gap left by incomplete data in previous reports. The quantitative nature of our FRVs offers a clearer benchmark against which progress can be measured, thus enhancing the ability of EU Member States to track their conservation objectives and comply with Article 17 of the Habitats Directive.

We acknowledge that some of the Favourable Reference Values provided in our study are affected by the lack of comprehensive and expert-defined data, leading to approximate estimates. Specifically, for certain groups species (e.g. invertebrates, bats), the scarcity of ecological and life history information has limited the precision of our assessments. This has significantly influenced the results of the low R-squared for the regression models in estimating numerical FRRs. The high variability of the initial data and potential biases, in fact, does not allow for a very accurate estimation of numerical FRRs not yet provided by MS. The situation is different for the classification models, which performed adequately. Determining whether a species is in FRR condition based on a quantitative comparison with species in the same BIO is indeed a simpler problem and, therefore, potentially less prone to value bias due to the different approaches used by the MS to estimate FRRs. In general, we provided FRRs derived from both regression and classification (i.e., FRR = CR if the species was estimated to be in FRR) with the specific intent of giving the user the freedom to select the most appropriate reference values based on the performance calculated for the various groups and biogeographic regions, which are reported along FRR estimations in the provided tables. This uncertainty in our models once more highlights the necessity for close collaboration with stakeholders and national experts to refine our methods. Actively involving conservation practitioners and relevant authorities from different MS will be crucial to improve the accuracy of our FRVs and ensure they are robust and reliable for guiding conservation actions. Since the new reports for the HD with the FRVs are due in 2025, we hope to contribute to this process by providing our results where operators were present in the 2013-2018 report. We stress that the data-driven approach outlined here can be complementary to the existing expert-based delineation.

As a final step, we will identify expert groups at national and local level who will be responsible for reporting, and we will share our estimates for selected groups and countries with them to ensure the validation of the values provided.

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3 Climate resilience criteria

A climate resilient TEN-N must consider the risks that climate change poses to existing and newly established protected areas. On one hand, it would be strategic to protect areas with high levels of climatic stability, as these pose lower challenges for biodiversity. On the other hand, protecting areas that maintain climatic connectivity between current and future species distributions would also be very important. Additionally, maintaining the variability of species bioclimatic niche is essential to preserve their evolutionary adaptation potential. Here we combine these strategies into a single framework to identify climatic connectivity nodes that maximise the retention of climatically stable areas while prioritising the potential present-to-future connectivity for European species. In doing so we focus on the individual bioclimatic components within each species' distribution.

3.1 Introduction

Climate change poses a significant threat to biodiversity and conservation efforts, as areas currently sustaining species populations may become less suitable for their long-term survival. As a consequence, species will need to either adapt to new climatic conditions *in situ* or migrate to more suitable areas (Pecl et al., 2017). The existing network of protected areas (PAs), while indispensable for conservation, may not be strategically positioned to facilitate these critical transitions. With the anticipated magnitude of climate change, many habitat types and species are likely to become less represented in PAs, potentially undermining the effectiveness of static protection efforts in buffering climate-induced biotic changes (Heller and Zavaleta, 2009; Schlaepfer and Lawler, 2023).

The high uncertainty regarding the future magnitude of climate change and its local impacts also poses major strategical difficulties for any conservation and restoration planning (Buisson et al., 2010; Thuiller et al., 2019). The critical consideration lies in prioritising efforts to expand the TEN-N within a strategic framework that not only addresses current gaps and immediate threats posed by habitat loss but also aligns with the broader goals for biodiversity conservation amidst future climate change (Kujala et al., 2013; Pressey et al., 2007).

Over the years, systematic conservation planning (SCP) approaches have been developed and refined to integrate predicted species range shifts in response to climate change (Alagador, 2024; Kujala et al., 2013). Yet, the uncertainties surrounding the magnitude, rate and ecological

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consequences of expected future climatic conditions and species responses remains a major challenge (Kujala et al., 2013), reflecting the complex nature of this multi-faceted problem.

For instance, considering the climatic variability within species distributions is crucial for their adaptation and persistence in the face of climate change (Hanson et al., 2020). Prioritising areas with diverse environmental conditions helps preserve the evolutionary potential for species adaptation, and environmental variables can serve as proxies for adaptive genetic variation (Carvalho et al., 2011; Hanson et al., 2017). Spatial information on climatic risk can also be used to guide the designation of new PAs and corridors to areas where environmental conditions are shifting slower, giving species and populations more time to respond. In this context, accounting for ecological connectivity, the multiple dimensions of climate change, and uncertainty is crucial for developing a comprehensive approach to spatially delineate climate-resilient key areas for conservation across Europe.

3.2 Aims

The climate resilience criteria outline a practical and comprehensive approach to conservation planning that accommodates various dimensions of climate change, including climatic niche variability, present-to-future climate connectivity, and climate velocity. By focussing on multiple dimensions, we aim to address uncertainties surrounding future projections of species range shifts and ultimately move towards future-proof conservation priorities for expansion of the TEN-N.

Specifically, the resilience criteria aim to ensure that future TEN-N variants capture (*i*) species' core (highly suitable) habitats both now and in the future to allow space for species to persist as the environment changes, (*ii*) the climatic variability within the ranges of individual species, supporting the preservation of their full evolutionary and adaptive potential, and (*iii*) critically connected areas between species' present and future distributions that facilitate species range shifts while considering species-specific dispersal constraints. While identifying areas that meet these criteria, we also evaluate the unavoidable trade-offs that emerge as the emphasis on areas important for potential future distributions of species is incrementally increased in the prioritisation solution, or when priorities are based on how rapidly or slowly climate conditions are changing across the landscape.

We first identify climatically distinct clusters within each species' range (called bioclimatic components, section 3.3.2), then asses which areas are important to support the connectivity between the present and future locations of these clusters (connectivity analysis, section 3.3.3).

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Finally, we use spatial optimisation tools to identify priority areas for climate resilience that maximise the presence of core habitats and their temporal connectivity for all species and their bioclimatic components (section 3.3.5).

3.3 Data and methods

3.3.1 Data

We showcase the development and use of the climate resilience criteria on an example with a preliminary set of 38 European threatened terrestrial non-volant mammals, for which modelled habitat suitability maps for both present (time frame 1981-2010) and future (time frame 2041-2070, SSP3-7.0) were available by July 2024. Thus, we anticipate that the following results are preliminary, and they can be further subjected to updates during the following analysis iterations. The maps, produced by WP3 in NaturaConnect, focus on species listed in the Birds and Habitats Directives and are based on species distribution models (SDMs) produced at 1 km resolution for whole of Europe. They give the estimated habitat suitability at scale 0 (lowest suitability) to 1 (highest suitability), based on climate, habitat, and soil, reflecting essential environmental niche requirements for the species. More details on the methods and data underlying these estimates will be described elsewhere (D3.2 of NaturaConnect).

The recent acceleration of climate change casts doubts on the ability of species to adapt to rapidly changing environmental conditions (Garcia et al., 2014). Within WP5, the climate exposure of Europe was assessed calculating different climatic metrics: the local velocity (Loarie et al., 2009) distance velocity (Carroll et al., 2015; García Molinos et al., 2019) and magnitude of change (Williams et al., 2007). For more information see upcoming deliverable D5.2. Here we used local climate velocity to represent climatic risk in Europe, derived as the ratio between temporal and spatial gradient of climate change. This measure represents the distance (km per year) that an individual must travel to find similar climatic conditions to those at the starting location.

3.3.2 Bioclimatic components

We developed a framework to identify the key bioclimatic components of species distributions, except for species with restricted geographic range which were included as single entities in the analyses to avoid excessive fragmentation of their conservation priorities. In this case we followed the definition of “restricted-range” species given by the IUCN Red List as species with a range size smaller than 20,000 km^2.

We used the species distribution models (SDMs) developed in Task 3.3 to identify the key bioclimatic components within each species’ distribution. Each bioclimatic component was

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treated as an individual entity in all subsequent analysis. For each species above the 20,000 km² threshold (36 out 38 species of threatened mammals), we extracted the values of relevant climatic variables (the same used in Task 3.3 to produce SDMs, Karger et al., 2020, 2017) from within the SDM-predicted distribution range, which were firstly constricted to more closely align them with the observed distribution of species while still allowing for plausible areas of suitable areas. We used Self-Organizing Maps (SOMs), a type of neural network, to partition the climatic envelope within species distributions according to their climatic data. Due to computational constraints, we subsampled 1 million grid cells from the distributions of species with ranges larger than 1 million km². SOMs is a form of unsupervised learning which uses adaptive weights for data clustering. SOMs plots multidimensional data onto an X-Y plane (SOM grid of nodes), classifying locations with similar environmental conditions into nodes (Kohonen, 1982). Each node is characterized by a model weight vector that represents the means of the centroids in the SOM solution, or the distance of the node from the input data. Thus, a node can be considered as a proto-clusters, that represents the input dataset. The nodes are then organized on the grid so that similar proto-clusters, are positioned closer together, while dissimilar proto-clusters, are spaced further apart (Vesanto and Alhoniemi, 2000).

As second step then further reduced the number of nodes, or by applying k-means clustering to the codebook vectors obtained from the SOM (Vesanto and Alhoniemi, 2000). The optimal number of clusters for k-means was determined using the 'NbClust' package, considering four different cluster validation indices: silhouette coefficient (SC), Dunn index (DI), Davies–Bouldin index (DB), and Calinski–Harabasz index. The silhouette coefficient assesses cluster quality based on intra-cluster and inter-cluster distances. The SC coefficient is a measure of how similar an object is to its own cluster (cohesion) compared to other clusters (separation) and ranges from -1 (the observation is probably placed in the wrong cluster) to 1 (the observation is well placed); a value of SC around 0 means that the observation lies between two clusters (Rousseeuw, 1987). The Dunn index identifies clusters that are both compact and have low variance among their members. It represents the ratio between clusters separation (minimum distance between clusters) and compactness (maximum distance between data points of the same cluster), with range of 0 to infinite where larger values mean better clustering performance (Dunn, 1974). The Calinski–Harabasz index is calculated as the ratio of between-cluster dispersion to within-cluster dispersion. Higher values of the index indicate better-defined clusters (Caliński and Harabasz, 1974). The Davies–Bouldin index indicates the similarity between clusters and is a function of the ratio of the sum of within-cluster scatter to between-cluster separation ((Davies and Bouldin, 1979). The DBI spans from 0 to positive infinity. A smaller DBI denotes superior clustering

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performance, with values close to 0 indicating well-separated and distinct clusters. On the other hand, a higher DBI implies worse clustering results, where clusters may be overlapping or poorly defined.

Since those indices account for different aspects of clustering, we first defined the optimal number of clusters for each species according to each metric (i.e. the number that is associated to the best metric value); we then defined the final number of clusters per species as the average number of clusters across all metrics. Finally, after the selection of the optimal number of clusters per species, and the implementation of the K means clustering, we measured the goodness or validity of the newly formed clusters calculating again the above-mentioned metrics. We employed a minimum number of 3 clusters to avoid oversimplification of species bioclimatic components.

The result is a minimal set of clusters representing the major bioclimatic components within species distributions restricted only to above-threshold values of habitat suitability. Once bioclimatic clusters are identified, present and future predicted species distributions (from Task 3.3) were divided based on these clusters, resulting in bioclimatic component-specific maps for each species. Using a K-Nearest Neighbours (KNN) algorithm, we reclassified the entire present (time frame 1981-2010) and future (time frame 2041-2070) species distributions by assigning cluster based on the labels of the closest neighbours in the training dataset (SOM nodes), extending the clustering structure to all the points in the species distributions with habitat suitability above-threshold values.

3.3.3 Climate connectivity modelling

To account for species-specific climate-driven connectivity needs, we created two additional spatial data layers for each biocomponent that link their present and future distributions: (i) the present to future connectivity, and (ii) the future to present connectivity (sensu Kujala et al., 2013). The two connectivity layers were computed using a dispersal kernel-based distribution smoothing technique, referred to as "Interaction Connectivity" in spatial prioritisation tool Zonation 5 (Moilanen et al., 2022). In this technique, the original present and future distributions are transformed using information on habitat suitability of raster pixels in both layers, their Euclidian distance and species dispersal capability. The rationale behind the first connectivity model (present to future) is that through the transformation, highest values are given to areas within present distributions that are highly suitable and geographically close to the highly suitable future areas given species dispersal limitations. These represent sites within species current distribution from which individuals are likely to start migrating to future sites (*source*

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areas). In the second connectivity model (future to present), the highest values are given to highly suitable areas in the future that are well connected to highly suitable areas in the present, given species dispersal limitations. These can be thought as future sites in which the individuals are likely to arrive and establish first (*stepping stones*). By preserving *source areas* and *stepping stones* together with the present and future core habitats, our approach will assist species in reaching their future core areas as climate changes (Kujala et al., 2013).

Dispersal kernels describe the likelihood of a successful dispersal event between two habitat patches as a function of their distance (Hanski, 1998, 1994) and are commonly used to estimate the likely movement of individuals between the focal and reachable habitat patches in the landscape (Howard, 1960; Santini et al., 2013). Following the theoretical basis of spatial metapopulation dynamics, the dispersal likelihood decreases the further away the two patches are. Similarly, the likelihood increases with better dispersal ability but also with higher habitat quality at the starting patch which indicates higher density of individuals and hence larger number of emigrates. When used to estimate connectivity, also the habitat quality of the receiving patch is important, as arriving individuals are more likely to survive and establish a population in higher quality patches. Here we apply the concept on modelled habitat suitability maps which, instead of defined patches, have continues values of habitat suitability.

Mathematically, the connectivity calculation can be described by treating the present and future distributions of the same species (or their bioclimatic component) as separate spatial features j and k at different time steps (Figure 8). Transformation of feature j by distribution of feature k is defined as $p_{ij}' = p_{ij} \times C_{ijk}$, where p_{ij}' is the transformed value of feature j in cell i, p_{ij} is the original value of cells in j, and C_{ijk} is the connectivity of location i in j to the distribution of feature k.

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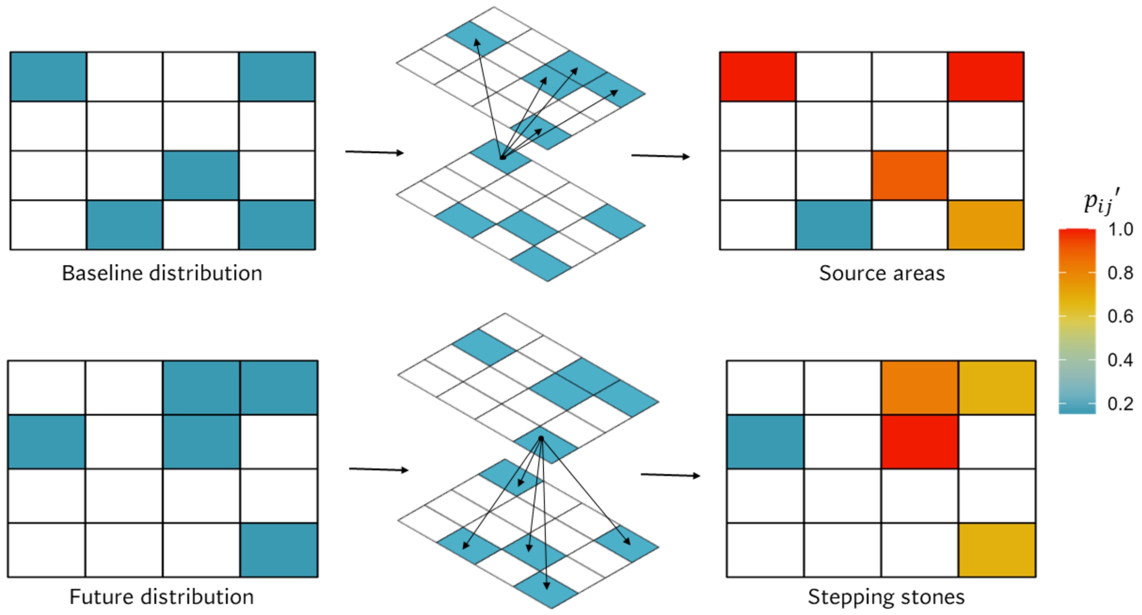

Figure 8: Illustration of the process for integrating climate connectivity in conservation prioritisation with Zonation. The original habitat suitability layer at one time point (e.g. present) is transformed into a connectivity layer by multiplying the suitability values of each cell with the connectivity between that cell and the cells of the same feature at a different time point (e.g., future distribution). In this illustration, we assume that distributions are binary (presence is blue, absence is white). In the resulting connectivity layers, warmer colours represent higher values, as a result of the combination of high habitat suitability and high connectivity.

All cells i are transformed, and C_{ijk} is a summation of all elements of the distribution of feature k, scaled by the combination of distance and species' dispersal capability. The connectivity of any grid cell i to grid cells in k is then calculated using a two-dimensional negative-exponential dispersal kernel:

$$p_{ij}' = p_{ij} \sum_{n=1}^{N} \exp(-\alpha d_{in})\, p_{nk}$$

where N is the number of cells in the landscape, α is the parameter describing the species-specific dispersal capacity, d_{in} is the Euclidean distance between cells i and n, and p_{nk} is the original value of cells in k.

For species-dispersal capacity, we used dispersal estimates following Santini et al. (2013), which used adult body mass, home range, and trophic level as proxies for dispersal. Adult body mass and trophic level data were sourced from the COMBINE database (Soria et al., 2021), while home range information was obtained from the HomeRange database (Broekman et al., 2023). Dispersal estimates were not scaled by time for the case study. However, the outlined method will be refined with data on generational length (see section 2.3.5). Given the interval of our time

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steps (current: 1981-2010; future: 2041-2070), we aim to consider the dispersal distances multiplied by the ratio between time interval and generational length for each species as a more accurate measure of dispersal velocity.

3.3.4 Accounting for uncertainty

We investigated the trade-offs that emerge when species (uncertain) future distributions are given more emphasis in the prioritisation solution. The rationale behind this analysis is rooted in the recognition that efforts to protecting species future habitats reduce the number of resources available to protect species current habitats as conservation budgets may need to be divided between more locations. At the same time, the uncertainty associated with species future distribution is far greater than that associated with current distributions (Beaumont et al., 2008; Buisson et al., 2010; Thuiller et al., 2019). Likewise, a comparable uncertainty arises when valuing habitat quality versus connectivity as we generally have better knowledge of species habitat needs than we have of their dispersal capability (Mendes et al., 2020).

To analyse the above-mentioned trade-offs, and to find the best solution for dividing resource between certain and uncertain features, we implemented the following weighting scheme for the spatial optimisation:

$$w(B_j) > w\left(C_{BF_j}\right) > w\left(C_{FB_j}\right) > w(F_j)$$

, where j is the index for species or a bioclimatic component, $w(B_j)$ represents the weight assigned to the present distribution, $w\left(C_{BF_j}\right)$ stands for the weight assigned to present to future connectivity, $w\left(C_{FB_j}\right)$ for the weight assigned to future to present connectivity, and $w(F_j)$ denotes the weight assigned to the future distribution.

We deliberately maintained future layers (without connectivity) as the least weighted feature. This strategy is aimed at addressing model overprediction in SDMs (Mendes et al., 2020), specifically targeting suitable areas in the future that may remain uncolonized due to dispersal constraints. The initial weight scheme is defined with descending values (1.0, 0.3, 0.2, 0.1). Present layers always receive a weight of one, while the weight for the connectivity and future layers varies, increase by 0.1 at each iteration until all layers reach 1.0. We then compared all these weighting schemes (N=10) with a prioritisation that does not account for climate change (i.e., 1.0, 0, 0, 0).

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3.3.5 Spatial prioritisation of climate resilience areas

We conducted a spatial conservation prioritisation using the Zonation 5 software (Moilanen et al., 2022). Zonation generates a hierarchical ranking of importance for each grid cell within the landscape by considering occurrence levels (i.e., habitat suitability) and connectivity among present and future distribution. The prioritisation process in Zonation is driven by a meta-algorithm and a marginal loss rule, rather than an objective function (see Moilanen et al., 2022 for the mathematical formulation). The meta-algorithm determines the ranking (ordering) of grid cells, while the marginal loss rule, operating within the meta-algorithm, calculates how much each feature is reduced when a cell is removed, aggregating these reductions into a cell-specific value. This allows grid cells to be compared, ranked, and ordered effectively. Although the meta-algorithm is fixed, users can choose from different marginal loss rules to influence prioritisation characteristics and maintain a balance between features. This approach guarantees a balanced solution across all features (present, future, and connectivity in this case) considered in the analysis. We used the default CAZ2 rule for marginal loss calculation. CAZ2 slightly reduces the average coverage of features in the top-ranked cells to enhance the coverage of the least well-represented features.

After identifying the most balanced weighting scheme in the uncertainty analysis, we implemented the final solution incorporating climate velocity as a 'direct cost' layer. Direct costs in Zonation adjust the priority ranking by dividing the cell's marginal loss measure by its associated cost, representing the anticipated expenses for maintaining appropriate conservation efforts within the grid cell. This means that Zonation will prioritise cells with slower climate change, which facilitates species adaptation, while penalizing areas with high climate velocity. This integration ensures that conservation efforts are directed towards areas where species adaptation is more feasible and effective in mitigating climate change impacts.

To measure the aggregate performance of the priority ranking solutions, we assess the proportion of bioclimatic components present and future distribution that was captured in the top ranked 10% of grid cells.

3.4 Preliminary results

3.4.1 Bioclimatic range components

For the 36 species analysed we found a mean value of 5 clusters, and a maximum number of 6 clusters for several species (Figure 9a).

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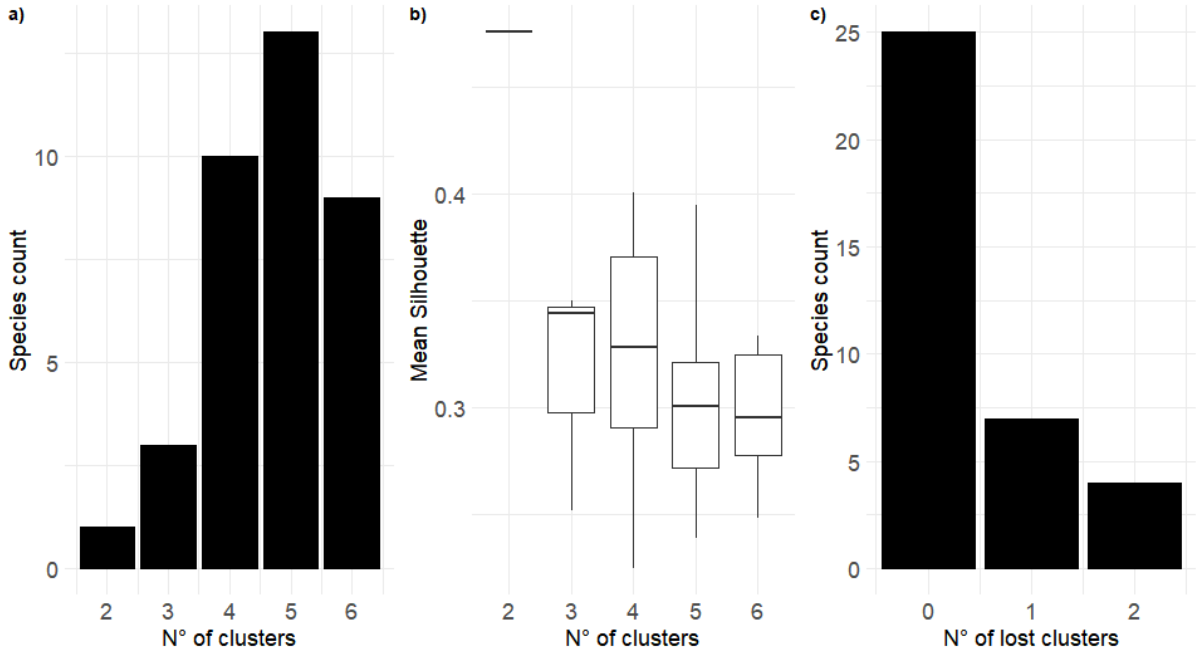

Figure 9: a) Barplot showing the frequency of bioclimatic components (clusters) across tested species .b) Boxplot illustrating the mean silhouette value per species grouped by the number of bioclimatic components (clusters). c) Barplot showing the frequency of species which are predicted to lose one or more bioclimatic components (clusters) in the future.

The median silhouette value was S = 0.31, with a 3.31% negative value, meaning that a very small number of grid cells within species distribution had an uncertain classification (e.g. between two possible clusters). This result indicates good overall coherence of the distribution grid cells within each cluster (Figure 9b).

The reclassification is a conservative process, and species cannot gain any more clusters in the future, but we can follow the change in cluster distributions, with some of them increasing in size and others losing area. We found that 11 out of 36 species will lose at least one cluster in the future, meaning that all the grid cells belonging to a specific cluster in the present will be assigned to a different climatic cluster in the future, as the climate conditions change substantially (Figure 9c).

As an example, we present here the results for the grey wolf (*Canis lupus*). Grey wolf is a widespread species in Europe and its distribution reaches almost 6 million km^2, thus we subsampled 1 million grid cells before implementing the SOM, which then aggregated the species environmental space into 5000 nodes. The best number of clusters to divide this species' distribution nodes was 4 (Figure 10). Thus, the k-means clustering of the nodes produced 4

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clusters that slightly overlap, having a median silhouette of 0.26 with 3.6 % of negative values (Figure 10).

Figure 10: Example illustrating the distribution of sampled locations in the environmental space for the range of the species Canis lupus on the two most prominent PCA dimensions. The coloured areas represent the identified bioclimatic clusters, and similarly coloured symbols locations within the distribution that fall into these clusters. Larger symbols in the middle of the cluster represent their barycenter (the mean points of cluster).

The KNN used to reclassify the present and future distribution of the species *Canis lupus* had high classification accuracy and Kappa, respectively of 0.96 and 0.94. Present and future distribution are characterized by four clusters which reflect Mediterranean, Alpine, Continental and Boreal climate. Under present climatic condition, the Continental cluster (cluster number 3) is the largest one together with the Boreal cluster (number 4, Figure 11a). The grey wolf will not lose any bioclimatic components, but in the future, Mediterranean, Alpine and Continental clusters will all diminish in size in favour of the Boreal cluster which is going to expand in a south-west direction (Figure 11b).

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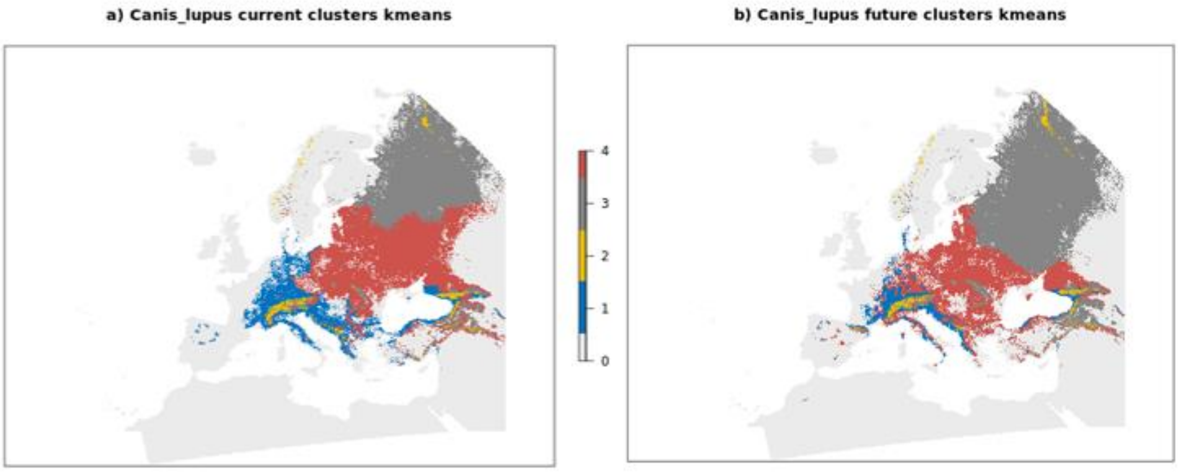

Figure 11: Example illustrating the range of the species Canis lupus reclassified with K-means clustering and KNN results for the current period a) and future period b). The coloured areas represent the identified bioclimatic clusters. We stress that these are preliminary results using first distribution estimates which will be further refined once final current and future distribution data becomes available (WP3).

3.4.2 Priority areas for climate resilience

When climate change is not considered and the spatial optimisation is based on present distributions only, the top 10% ranked areas in Europe cover on average 52% of bioclimatic present components and 36% of their future distributions. Our uncertainty analyses clearly show that when the weighting of future distributions is increased, trade-offs start to emerge (3).

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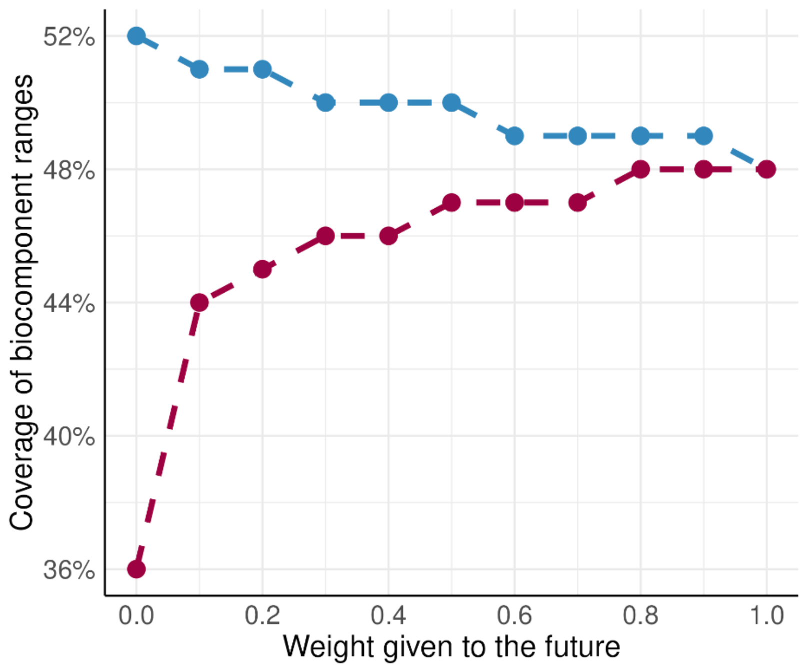

Figure 12: Trade-off curves for present (blue) and future (red) conservation levels, measured as the average proportion of species' range covered by the top 10% priority areas. The x-axis shows the weight given to future distributions in relation to present distributions in each prioritisation. At the value of 0, future distributions are ignored, and at the value of 1 they are weighted equally to present distributions. The reductions and gains in the conservation levels for present and future highlight the shift towards prioritising future core areas.

The curves in Figure 12 show that increasing the weight given to future biocomponents distributions results in a decrease in the protection of present distributions. For example, at a weight of 0.5, there is a considerable enhancement in safeguarding future distributions (an increase of 11% in coverage), though at the expense of a minor concession in the protection of species' present distributions (a decrease of 2%). Considering the large gains against acceptably minor losses, we chose this as the most balanced weighting scheme in the uncertainty step and used it for the subsequent analysis. We acknowledge that there may be different justifications for selecting the best weighting scheme.

Climate change clearly shifts the priority areas in need of protection in Europe (see Baseline and Future priority maps in Figure 13). The climate resilience prioritisation reflects both current and future protection needs, as shown, for example, in countries like the Netherlands and Sweden (Figure 13).

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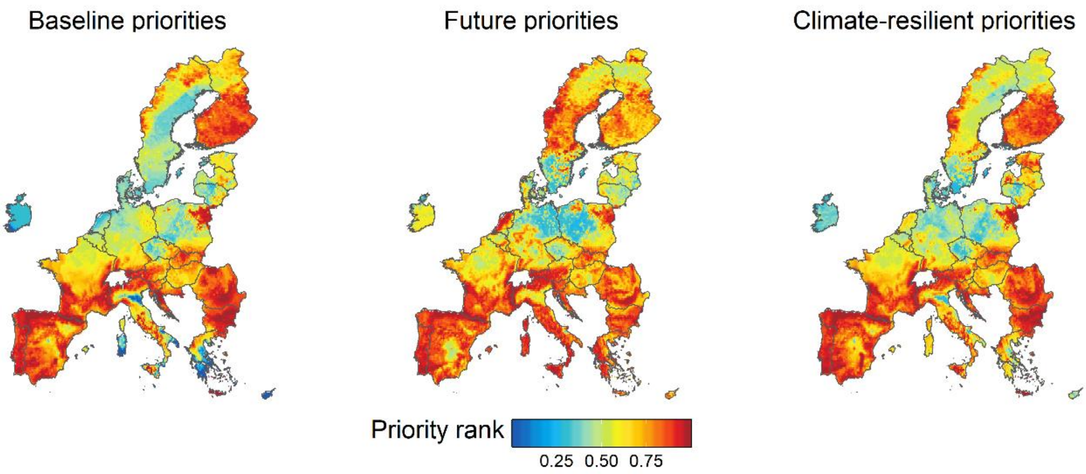

Figure 13: Priority ranking for the EU Member States for present, projected future distributions, and the retained optimal prioritisation weighting scheme (without accounting for climate velocity). The ranking of grid cells goes from 0 (lowest priority, dark blue areas) to 1 (highest priority, dark red areas).

By incorporating climate velocity, the final prioritisation map points out areas of high priority as those with optimal habitat suitability, connectivity between current and future distributions, and slower rates of climate change (Figure 14). These areas are expected to remain viable for biodiversity under changing climate conditions and provide a more feasible environment for species/biocomponents to adapt effectively.

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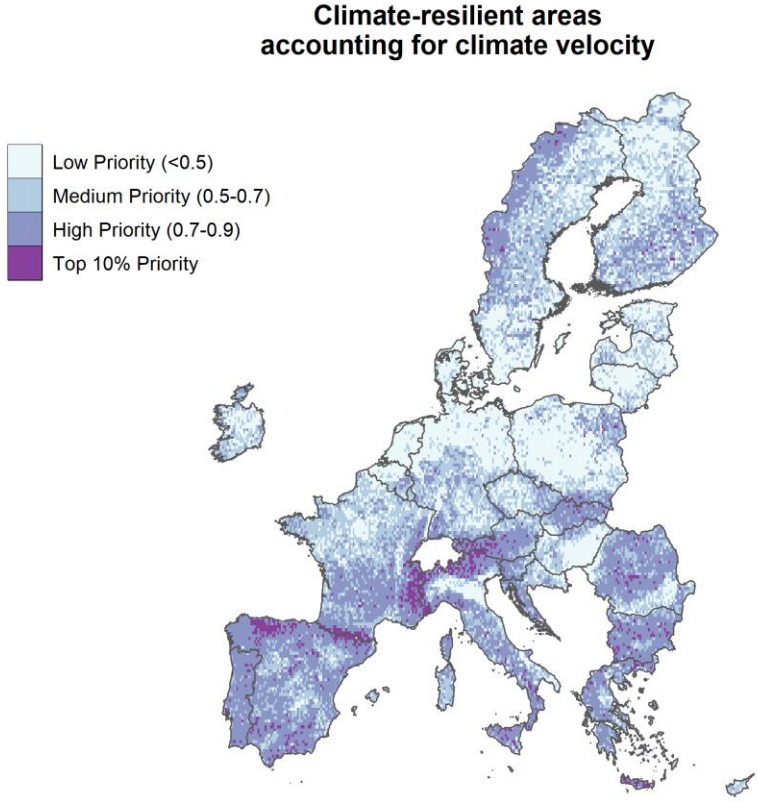

Figure 14: Priority ranking for EU Member States based on the optimal prioritisation weighting scheme, incorporating climate velocity.

3.5 Discussion and conclusion

Here we have described a practical and comprehensive approach to identify areas important to support the climate resilience of the TEN-N, accounting for the multiple strategies needed to aid species in adapting to the changing environmental conditions. The resulting priority rank map (Figure 14) illustrates the final climate resilience output that will feed into the variants of the TEN-N planning (see section 4 below) once the analysis is complemented with more biodiversity data.

Our work produced a robust protocol to split species distributions into bioclimatic components, and project how these will shift in the future under climate change. We have used these data to identify areas of high conservation importance to ensure present-to-future climate connectivity via a spatial prioritisation analysis, while minimising the risk of focussing protection on areas with high predicted levels of climate change. This information is key to support the planning of a TEN-N, as rapidly changing climatic conditions require that climate-resilience protection strategies are put in place.

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Importantly, our results show that several species are predicted to lose one or more of their bioclimatic components in the future in Europe, while other components will thrive. This means shift in climatic conditions might generate "winners" and "losers" not only among different species, but also among different populations of the same species. By maximising the retention of climate connectivity areas at the bioclimatic components level, our analysis can minimise the risk of erosion of species climatic niches.

While preparing for future changes is becoming increasingly important, any such plan is unavoidable challenged by the fact that the future is and remains uncertain. In our approach, we have tackled this by transparently analysing the trade-offs that emerge when resources are split between more certain present and uncertain future conservation needs and by showcasing how both conservation risks and opportunities can be explored (Figure 12). Through the incorporation of climate velocity, we have also emphasised areas of slower climate change, which has double benefits: 1) these areas are likely to remain suitable for species both now and in the future, presenting a low-risk conservation investment, and 2) the slower pace of changes gives local populations more time to adapt to the new environmental conditions. However, favouring these areas also has its downside, as quickly changing areas may still harbour highly important habitats for some species that are left without protection. In the cases of our species and their bioclimatic components, the average coverage within top ranked grid cells dropped from 50% to 16% for the present and from 47% to 21% for future distributions once climate velocity was included in the analysis. Future work, also considering a full set of data available from NaturaConnect, should focus on a more nuanced approach, which could be done by including the velocity maps as features with varying weight to balance the trade-offs that emerge between climate stability and e.g., present habitats of species.

We based our case study on the data that was available in July 2024, which is limited to a small number of species and includes only one future climate scenario. However, the presented approach can be easily replicated on larger datasets as these become available and with alternative future scenarios to explore their differences and, if needed, find consensus areas identified as high priorities in all alternative scenarios.

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4 Planning the TEN-N

4.1 Introduction

Here, we aim to identify the most important areas for protecting 30% of European land (including 10% under strict protection), for restoring 20% ecosystems, and for sustainable management of green infrastructure in Europe (Figure 15), in a way that adheres to best practices and design principles (See section 1.4.2) and is relevant for European conservation policy. Using Systematic Conservation Planning (SCP) and harnessing the various existing and newly produced datasets within NaturaConnect (Figure 15), we create a framework that explores different Trans-European Nature Network (TEN-N) scenarios across a range of different design criteria and constraints. We design the TEN-N variants to ensure: *i*) comprehensiveness and adequate representation of species, habitats and NCP; *ii*) connectivity and resilience to future climate changes; *iii*) feasibility through equitable sharing of conservation area between European countries and regions, and inclusion of stakeholder preferences and socio-economic costs.

Below, we describe the methodology, data and criteria that are incorporated into the design of the variants of the TEN-N. We showcase some preliminary results ('pilot', see section 4.4) from available data and how we used it to gather first feedback from European stakeholders (section 4.6).

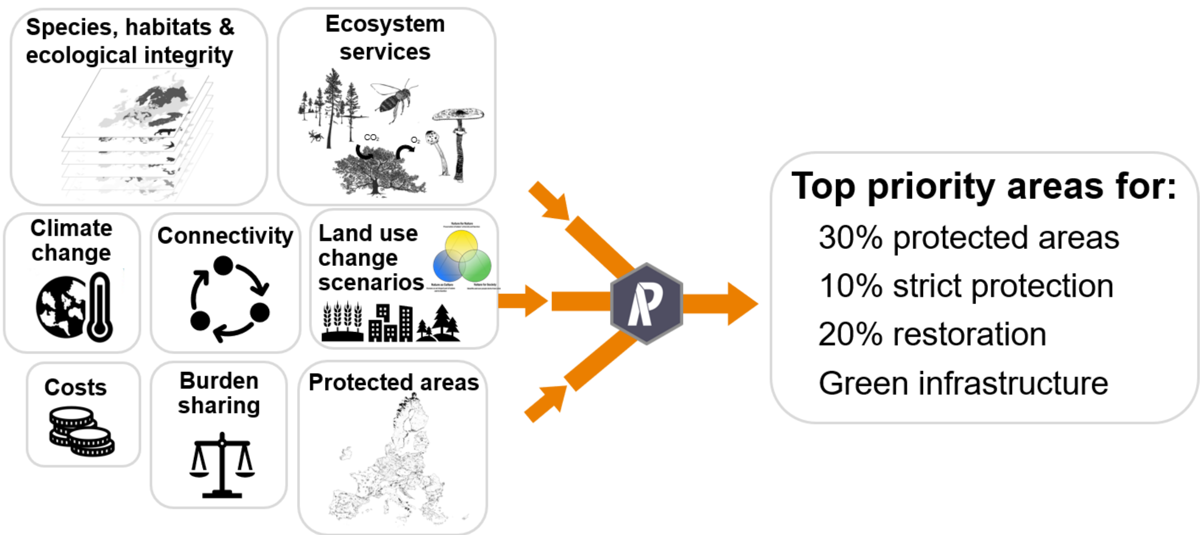

Figure 15: Overview of T7.3 planning objectives and overall aims, showing how different information from across the NaturaConnect project is combined in T7.3.

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4.2 Problem formulation

4.2.1 Biodiversity features

Species and Habitats. The spatial planning will include all species and habitats listed in the Annexes of the Article 12 Birds Directive and Article 17 Habitats directive, as well as the European red lists of species and ecosystems. We also cover any other native species for which suitable data is available and that might benefit from conservation efforts now or in the future. Existing policy guidance suggests that "*...additional designations will also focus on the protection of habitats and species that are not covered by the EU nature legislation and especially those identified in European or national red lists*" (European Commission, 2022). We highlight that in the context of the NaturaConnect project we primarily focus on terrestrial biodiversity, however inland blue infrastructure (rivers, lakes, wetlands) is also considered through the inclusion of semi-aquatic species (e.g. amphibians, water birds, otters, beavers, desmans). We use current and future distributions of species and habitat distributions from WP3 as features. We will use as zone-specific features the projections of the potential suitability of each land use class in all European grid cells, both in current and future climate scenarios. To connect the current and future distribution of the same species (or habitat), features are thus the weighted sum of the current and future SDM (per land use class suitability value). We build on the priority ranking map produced by T7.2 and use the optimal weighting identified in T7.2 to balance current and future distributions. We additionally collected stakeholder preferences on a sample of 81 delegates from 13 EU Member States (Finland, Sweden, Estonia, Latvia, Lithuania, Cyprus, Spain, France, Greece, Italy, Malta, Portugal, Croatia) using Menti (see section 4.6 and Appendix for more details). When asked the question "How much would you be willing to give away resources from the protection of species current habitats to protect their future habitat? (0-100%)", delegates responded with an average of 37.07%, but with a high variation between responses. We thus explore several variants with different weighting schemes balancing between present and future distributions. The variant reflecting average stakeholder preferences weights the future distributions with a factor of 0.37 and current distributions with a factor of 0.63.

Nature's Contributions to People. As features, we use current and future distributions which are being modelled and mapped by WP4. To connect the current and future distributions of each NCP, we apply the same weighting process as described for species. 19 NCP layers will be produced by WP4, accounting not only for NCP capacity (*sensu* (O'Connor et al., 2021; Verhagen et al., 2017)) but also demand when possible. They include: 12 regulating NCP (Pollination (Schulp et al., 2014a); Heat stress regulation in urban areas; Soil erosion protection; Carrion elimination; Carbon Sequestration (Mouchet et al., 2017; Schulp et al., 2008); Flood Protection

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(Verhagen et al., 2017); Agricultural pest control (Civantos et al., 2012); Mosquito biocontrol; Regulation of processionary pine moth; Regulation of tick-borne pathogens; Seed dispersal; Soil Erosion control) and 7 cultural NCP (Wildlife watching; Wild foods foraging (edible mushroom and vascular plants) (Schulp et al., 2014b); Accessibility of physical recreation (walkability); Forest recreation; Heritage forests and Heritage agriculture (Tieskens et al., 2017); Nature Tourism). Each NCP will be normalized between 0 and 1 and included in the prioritisations as an individual feature.

Other ecosystems of conservation importance. EU Commission Guidance on protected areas specifically notes that remaining primary and old-growth forests and any significant areas of carbon-rich ecosystems, such as peatlands, should be protected. We use the dataset on European old growth and primary forests from (Sabatini et al., 2018), as well as spatial data on carbon stocks and sequestration rates. We will also cover those species and habitats of major importance for reaching the ambition of the European pollinator strategy, such as for example High Nature Value Farmland (Matthies et al., 2023).

Accounting for ecoregional diversity. For species and habitats that are not assessed as threatened or U1/U2 at a European level, but for which local ranges are assessed as nationally threatened or locally U1/U2, simply including the pan-European distribution as a feature may not guarantee the preservation of the locally endangered subpopulation. Thus, we extract the national and biogeographical distribution of the sub-ranges of species and habitats that are assessed as regionally or nationally threatened (national red lists) or in unfavourable conservation status (U1 and U2) specifically in a biogeographic region or Member State. We include them as individual features, and weight them by threat status and geographic endemism (see section on weights). This means that the same species and habitat could be replicated multiple times as features whose protection is prioritised for: once at European level, considering the whole distributional range (see Figure 3 for the planning domain), and once for each biogeographic assessment (unique part of the range within a country and bioregion) with a U1/U2 assessment. Likewise, certain NCP (such as pollination, flood regulation) will be split geographically to maximize regional benefits – for instance, crop pollination in Spain is not replaceable with crop pollination in France – thus we will split certain NCP based on biogeographic and country boundaries and they will be treated as separate features. We will run additional analyses comparing different scenarios with and without feature splitting to determine the implications in terms of spatial patterns of protected area coverage and extent to which these TEN-N scenario contribute to achieving Target 4 of the EU Biodiversity Strategy, using protected area coverage of conservation features as a proxy for their recovery potential.

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4.2.2 Feature-specific Weights

A key element of SCP is the option to assign more importance to some features than others through the setting of weights (Arponen et al., 2005).

First, we account for conservation status (using both the IUCN red list status and Article 17 reported status) in the setting of weights. We built on previous studies to assign weights to ensure that threatened species and ecosystems are prioritised over non-threatened features (Jung et al., 2021; Pouzols et al., 2014). We define a weight w_f for each threatened species or habitat based on their Red List status (using both the Red List of Species and the Red List of Ecosystems). Species or habitats known to be Critically endangered (CR) or in bad conservation status (U2) were given a weight of 8, Endangered (EN) a weight of 6; and Vulnerable (VU) or unfavorable conservation status (U1) a weight of 4. Near threatened (NT) and Data Deficient (DD) species or habitats were given a weight of 2. All other species and habitats were given a weight of 1. For species, we used all available Red List assessments at the Global, European and national levels. For the full feature distributions, we obtained the red list weighting by averaging the value across European and Global red lists. For split species subpopulations, the red list weighting was the average across 3 red list assessments: National red lists, European red list and Global IUCN red list. Additionally, weights of habitats that were listed as priority in Annex I of the Habitats Directive were multiplied by two.

In addition, to reflect individual countries' conservation policies, we will explore an additional weighting scheme for species and habitats for which Member States pledge an improved conservation status and for which protected areas are indicated as an action to improve the status (this will be done in a single prioritisation variant in 2025, once more pledges are available).

Second, we account for the biogeographic endemicity, in the case of the split distributions of species and habitats. This is because, when the distribution of species and habitats is split by bioregion and country for the reporting under Articles 12 and 17 (see above), it introduces the risk of attributing equal importance to a species that is endemic of a bioregion or country, and a single subpopulation of species that are widespread across multiple bioregions and countries. To correct for this, we add a weight that is equal to the endemism of the species, *i.e.* the regional proportion of the total (European) range of the species (subpopulation range size / European range size). This value ranges from 0 to 1. A value of 1 means that the national/biogeographical region distribution is the only occurrence of the species or habitat.

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To combine these two types of weights (red list status and biogeographic endemism), we multiplied the weight reflecting endemism with the weight reflecting red list status, for each feature.

Finally, to reflect stakeholder preferences in the setting of weights, we collected stakeholder preferences both by means of a survey addressed to NADEG representatives in summer 2023, and in person to Member State delegates during the biogeographic seminars (Boreal and Mediterranean) but see section 4.6. The responses revealed a high variation in individual preferences such that overall, no single group of biodiversity feature emerged to be considered significantly more important than others. Therefore, by default we ensure equal weighting of the three main biodiversity values (species, habitats and NCP), so that $\sum w_{ncp} = \sum w_{species} = \sum w_{habitats}$. We further develop and compare scenario variants that explore a range of combinations of weights (low-medium-high) for each of the three biodiversity values, to evaluate trade-offs. For example, a variant that assigns a low weight to NCP, a medium weight to habitats, and a high weight to species would be set up so that: $2\sum w_{ncp} = \frac{1}{2}\sum w_{species} = \sum w_{habitats}$. Furthermore, we will create variants that vary the weighting of features to reflect value preferences in the Nature Futures Framework: cultural NCP and culturally valued ecosystems will be valued higher in the Nature as Culture scenario; in the Nature for Society scenario, ecosystems that provide regulating NCP will be assigned higher weighting; and in the Nature for Nature scenario, habitats and species will be assigned a higher weighting.

4.2.3 Feature-specific Targets

Targets represent the amount of the spatial distribution of each species or habitat that should at minimum be protected. For species, we use Favourable Reference Range values obtained by T7.1 as targets (see the section 2 on Favourable Reference Values), with the objective to minimise target shortfall for species not only across the 30% protected areas, but also 20% restored areas, and green infrastructure across Europe. For habitats and for NCP, we assign a target equal to their distribution area size (see Equation (2) below).

4.2.4 Constraints

Climate resilience. We use the outputs from T7.2 (conservation priorities accounting for temporal connectivity) as linear penalty with a negative penalty value (-1) to preferentially select climatically resilient priority areas. See Section 3 for further details.

Protected areas. We will use the protected area Member States pledges to extract the information on which types of protected area designations count towards the 10% and 30% and should thus be locked into the planning (if available before the end of the project). For all non-EU

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countries, and until all protected area pledges are available for EU countries, we will use Natura 2000 sites and nationally-designated sites (CDDA) as locked in constraints in the solution for the 30%. For the 10%, we use IUCN protected area categories I and II which are often the baseline definition for strict protection (Cazzolla Gatti et al., 2023). These are included as manual bounded constraints in the conservation zone, so that, at minimum, the proportional amount that is currently protected per planning unit gets selected in the solution (see below, equation 7). Note that old-growth and primary forests (Sabatini et al., 2018) are locked-in alongside strict protected areas, because EU guidance specifically mentions that all remaining primary and old-growth forests are to be strictly protected. Note that data on OECM (Other Effective area-based Conservation Measures) are not available and their definition is still debated, thus we will not include OECM as existing protected areas. However, we point out that OECM can be a tool to sustainably manage ecosystems outside of conventional protected areas (e.g. for ecological corridors and green infrastructure).

Green infrastructure. We will use the green infrastructure layer modelled by WP4 to prioritise the selection of green infrastructure when prioritising for Green Infrastructure, alongside other spatial data for biodiversity, connectivity and ecosystem services. This will help assess the multifunctional value of green infrastructure in terms for ecosystem services, biodiversity, and ecological connectivity.

Ecological corridors. We use the corridor probability layers for which are modelled by WP6 (specifically, T6.3) across a range of functional archetypes, to incorporate ecological connectivity in the planning. WP6 outputs are used as linear penalties with a negative penalty value (-1) to preferentially select essential ecological corridors in the solution. Corridors will always be included in the prioritisation for green infrastructure, by default; as well as in some variants of the prioritisation for protected areas. Then including connectivity in this way, we ensure that some of the areas selected for conservation or restoration will function as stepping stones for many European species.

Socio-economic costs. In SCP, costs refer to a constant that constrains the selection of a planning unit in the solution. Cost estimates can be quite impactful and drive protection priorities (Kujala et al., 2018). To analyse the trade-offs in including or excluding a cost layer, in the planning we will provide two sets of scenarios, one with flat area costs (i.e. the cost of selecting a given planning unit is equal to the area contained within) and a second set of scenarios that include socio-economic opportunity costs data which are outputs from WP4. Costs are specified and mapped at a $1km^2$ resolution by WP4, separately for each land system: urban, forest, croplands.

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When using costing data, we incorporate these costing data in the problem as linear penalties with a penalty score of 1. This penalty score of 1 ensures that the cost does not compromise achieving the area budget. To explore the implication of different local communities' willingness to pay for conservation under different value perspective, when costs are applied, they will be weighted differently for each NFF pathway. For example, for the Nature for Nature perspective we would apply lower than average weights across all management zones thus placing more emphasis on achieving biodiversity objectives with limited influence of the opportunity costs. In the Nature for Society scenarios high costs for strict and conventional protection could be applied so that more stringent forms of management tends to avoid areas with high opportunity costs, while any allocation to the green infrastructure zone would benefit from the ecosystem services provided by sustainable management, thus compensating the opportunity costs of setting aside part of land for conservation, and the reduced productivity in areas that are managed extensively (e.g. agro-forestry). In the Nature as Culture scenarios, we would apply high cost for the strict protection zone, standard costs in conventional protection and varying costs in each of the GI zone depending on their expected contribution to the protection and enjoyment of culturally significant features such as old-growth forest and high-natural value grassland or mountain ecosystems as example. A possible dataset to be considered for this is that of Tieskens et al., (2017).

Land-use change scenarios. We use the current land system map (Sandström et al., 2023), and three alternative nature-positive future land-use change scenarios, with the narratives underlying these scenarios having been informed by a stakeholder consultation process following the Nature Future's framework (NFF) (Fornarini et al., 2024; Pereira et al., 2020).

In the prioritisation we used the modelled NFF land-use scenarios (from WP5) to set the lower and upper bounds on what is feasible in a planning unit (in our case, a planning unit is a 1km^2 grid cell). This means that land-use change scenarios are not regarded as an inevitable future outcome but can instead be informed by complementary priorities for biodiversity conservation and restoration. For example, if the planning unit would be a conservation priority with the current land-use class (given its suitability for current and future distributions of biodiversity and NCP), then the current land use should be conserved, regardless of predictions in the (biodiversity-blind) land-use change scenarios. Conversely, if a grid cell would be a top priority (for current and future distributions of biodiversity under climate change) under a land-use class that is different than the current land-use class, then this would qualify as a priority for 20% restoration.

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4.3 Prioritisation

Prioritisations for restoration, conservation, strict protection, and green infrastructure (GI) are run in sequence. This ensures some hierarchy in the contributions of different types of actions towards the protection and recovery of biodiversity, such that: conservation and restoration should have the biggest contribution to biodiversity targets; and GI should only highlight the remaining areas of biodiversity importance that could not be achieved through conservation or restoration. The proposed sequence is:

(1) Identify top priorities for 20% restoration. Feasible restoration transitions are informed by the current and future land system maps (per NFF scenario). The 20% top priorities for restoration will highlight where restoration can have the highest benefits for biodiversity, including within existing protected areas, in accordance with EU policy guidance.
(2) Identify top priorities for 30% conservation, locking in the restored transitions from step 1.
(3) Identify top priorities for 10% strict protection within the 30%.
(4) Prioritise green infrastructure by ranking the rest of Europe in terms of multifunctional value for connectivity, green infrastructure, NCP and any remaining gaps in species and habitats coverage. Conservation and restoration are locked in.

We solve the problem as a linear programming problem, using the Gurobi solver for fast identification of the optimal solution (Gurobi Optimization, 2024). We use a minimum shortfall objective function across multiple management zones, minimizing the shortfall to targets among features. Mathematically, the problem formulation is expressed as follows (see parameters defined in Table 8):

$$min\left[\sum_{p}^{P}\sum_{z}^{Z}\sum_{f}^{F} w_f\left(\frac{(t_f - r_{f,p}k_{f,z}x_{p,z})}{t_f}\right)\right] \quad (1)$$

where:

$$t_f = \begin{cases} FRR_f, \text{if } f \text{ is a species and } FRR_f \text{ is available} \\ r_f, \text{otherwise} \end{cases} \quad (2)$$

$$x_{p,z} \in [0,1] \quad (3)$$

$$k_{f,z} \in [0,1] \quad (4)$$

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subject to:

$$\sum_{p}^{P}\sum_{z}^{Z} x_{p,z}c_{p,z} \leq B \tag{5}$$

$$\sum_{p}^{P}\sum_{z}^{Z}(D_{i,j,p,z} \times x_{p,z}) \leq B, \forall\, i \in P_{EU-MS} \text{ and } \forall\, j \in Z_{EU-MS} \tag{6}$$

$$d_{p,z} \leq x_{p,z} \leq 1 \tag{7}$$

The problem is solved over a total of Z management zones, which are the combination of 3 management actions (conserve; restore; GI) and 16 land use - land cover classes (bare/rocks/shrub; low/medium/high intensity forest; low/medium/high intensity arable crops; low/medium/high intensity grasslands; villages/peri-urban/urban; permanent crops; wetlands; water/glacier).

Each prioritisation has its own budget B (30% area for protected areas; 10% area for strict protection; 20% for restoration; and incremental increase of budget to 100% area for green infrastructure), which is expressed in the amount of area (or the number of planning units) selected (see equation 5).

Table 8: List of key parameters in the problem formulation

Parameter Name	Symbol	Purpose
Planning unit	$p \in P$	Identifies the specific planning unit where the action is applied. In our case, planning units are 1km^2 grid cells.
Management zone	$z \in Z$	A specific management zone in the planning formulation
Feature	$f \in F$	A specific feature included the planning process, such as for example a species or habitat distribution, or the NCP value expressed as ecosystem capacity to provide the NCP x societal demand for the NCP.
Amount	r	The amount of area of a given feature f (*i.e.* its range)
Target	t	A specific area target set to each feature f that is expressed in the same unit as r_f
Weight	w	A weighting set specifically for a given feature w_f and that it determines its weight relative to other features f
Contribution	$k_{f,z} \in [0,1]$	The contribution k is a zone-specific parameter that defines the contribution that a specific feature f has to a

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		management zone z. Note that this parameter is not used if we use the suitability values of each land use class per feature per planning unit. In this case, the term $r_{f,p}k_{f,z}$ becomes $r_{f,p,z}$
Decision	$x_{p,z} \in [0,1]$	A constant stating the total share of the planning unit p for the zone z that is being selected.
Solution	$x_{P,Z}$	The total of the decision space for all given planning units P and zones Z
Cost	$c_{p,z}$	Cost of selecting a given zone and planning unit. Here the cost is simply proportional to the amount of (terrestrial) area in a grid cell – this is to be able to express the budget in terms of area, to reach the 30%, 20% and 10% area targets in the EU Biodiversity Strategy. Note that this cost here is different from the socio-economic cost layer, which is included separately, as a linear penalty.
Linear constraints	D	Linear constraints to be applied to the decision problem given as lower and upper bounds per planning unit p or $\forall j \in I$ as set of planning units p within a given area.
Manual bounded constraints	$d_{p,z}$	Proportion of planning unit p and zone z that is currently protected and/or old growth forest, that must be included in the solution at minimum (set as the lower bound).

4.3.1 Identifying the 30% for Europe

Top priorities for protected area expansion are designed to complement existing protected areas and to close conservation gaps by minimizing target shortfall for all features.

The conservation prioritisation is solved over a total of 16 different management zones that reflect land use classes. Contributions of each feature to each zone will be informed by SDM projections (in the case of species). Distribution data for each biodiversity feature will thus contain the suitability value of each management zone (based on the suitability of the land use class) in each grid cell. For habitats and NCP, we will create zone-specific feature layers, based on the compatibility of each habitat (using EEA dataset on ecological groups) or NCP (from WP4) with each zone (or land-use class). Furthermore, we will create three variant scenarios that reflect each NFF scenario: in the Nature as Culture prioritisation, we will use the Nature as Culture land use change scenario to set the upper and lower bounds, and assign higher weights to culturally valued features; in the Nature for Society prioritisation, we will use the Nature for Society land use change scenario and assign higher weights to features associated with regulating NCP; and in the Nature for Nature prioritisation, we will use the Nature for Nature land use change scenario and assign higher weights to features that are intrinsically valuable (species and habitats).

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The Kunming-Montreal Global Biodiversity Framework indicates that each country should protect 30% of its territory; and the EU biodiversity strategy states that the 30% should be achieved at the level of the European biogeographic regions. Thus, we create a set of scenarios that achieve 30% at the level of countries, in accordance with global policy; and a second set that achieves 30% at the level of biogeographic regions, in accordance with EU policy.

Note that EU Member States are expected to include in their protected area pledges the amount of area that will be additionally designated for the 30% and 10% in each biogeographic region. However, as we learned at the Biogeographic Seminars, it is expected that many Member States will go beyond the amount pledged to the European Commission. Thus, we do not use pledges to assign area budgets to individual Member States. However, we will use the protected area pledges to extract the information on which protected area designations count towards the 10% and 30% and should thus be locked into the planning (if available). Until the protected area pledges are available for all countries, we will run two sets of variants for the 30%: one that expands on Natura 2000 sites only (making up around 18% of the EU surface); and another than expands on all protected areas, including Natura 2000 sites and any other nationally-designated sites (which together cover a total of 26% of the EU surface).

4.3.2 Identifying the 10% areas for strict protection

The 10% are nested within the 30%. We extract protected area designations from the WDPA and lock into the 10% all protected areas classified under IUCN categories I and II (unless this information is made available through the protected area pledges consistently for all countries).

There is currently much discussion surrounding the criteria for strict protection designation, both in the academic community (Cazzolla-Gatti et al., 2022) and among conservation policy-makers and practitioners (as evident from the Biogeographical Seminars). Strict protection may focus on supporting the recovery of natural processes, through reductions of human interventions, protecting threatened species or ecosystems; species and ecosystems that are sensitive to disturbances; or all biodiversity and ecosystems to optimise conservation benefits across the tree of life (Virtanen and Moilanen, 2023). Additional criteria and constraints could include, for example, focusing strict protection within high ecological integrity areas, areas of high graphic complexity, roadless areas, or areas of low land use intensity, among others. We will develop a range of different variant prioritisations for strict protection to evaluate the implications of different definitions of strict protection across different biodiversity indicators. Ultimately, the criteria for designing strict protection are rooted in value preferences, thus we will provide alternative scenarios of protected area expansion that reflect the Nature Future

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Framework alternatives, using feature-specific weights in the prioritisation (see section about weights, 4.2.2). For instance, in the Nature for Nature pathway, one would assign higher weight (preference) to the intrinsic value of species and ecosystems; in the Nature for Society pathway, a higher weight would be assigned to the instrumental benefits of species and ecosystems for human society and wellbeing (e.g., carbon sequestration, pollination of croplands, disease control).

Note that, it might be possible to first identify priorities for the 10% strict protection, and then the 30% (with strict protection expansion priorities locked in), provided that the priorities for strict protection together with existing (non-strict) protected areas do not exceed the 30% area budget. This decision will ultimately depend on protected area pledges by Member States, as the pledges will indicate which and how much of the existing protected areas should count towards the 30%.

The 10% is an EU-level target, which does not need to be evenly distributed across European Member States. This implies that some countries may designate more, or less, than 10% of their area. This was confirmed by EU representatives and Member State representatives. For example, Sweden has already pledged over 10% of strict protected area coverage. Hence, by default we will not implement burden sharing for the 10%, allowing the 10% to be designated anywhere within the 30% across Europe. However, some countries (e.g. France) already have interpreted the 10% in their own national strategies. To evaluate the implications of this, we will create and compare scenarios with national burden sharing *vs.* with no burden sharing for the 10%.

One aspect of feasibility when it comes to strict protection is whether a site is already under some form of protection. EU guidance suggests that the 10% can occur outside of existing protected areas; this was confirmed by Member States representatives at the Biogeographical seminar. Yet, some delegates expressed that, in some countries, it may be easier to upgrade existing protected areas to strict protection, rather than designate a completely new area for strict protection. Thus, we will propose a set of scenarios for strict protection that constrain the selection of the 10% to within existing (non-strict) protected areas.

Stakeholders have confirmed that important drivers for the 10% are socio-economic costs and land tenure (see Annex SI Figure 1, and (NADEG, 2023)). Land tenure information is not openly available for all European countries; but we will provide a set of scenarios that include socio-economic costs in addition to biodiversity features.

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4.3.3 Identifying the 20% for restoration

Policy guidance suggests that restoration should be carried out preferentially within protected areas by 2030, thus restoration and conservation are not mutually exclusive. Therefore, we setup the problem to allow some amount of the 20% of restoration priorities to be achieved within the 30%. Note that the amount of restoration that is to take place within or outside protected areas is subject to further discussions as National Restoration plans (NRPs) are developed and guidance from the European Commission becomes clearer. Restoration priorities are based on the land use change scenarios transitions: we identify the top 20% that are feasible according to the NFF scenarios and that are most beneficial for biodiversity and NCP.

Restoration includes 10 unique management zones. 3 zones are associated with restoring natural or semi-natural ecosystems (restore wetlands; restore low-intensity forest; restore low-intensity grassland). 7 zones are associated with de-intensifying land uses: de-intensify forest (high to medium); de-intensify grassland (high to medium); and de-intensify croplands (high to medium; high to low; medium to permanent; high to permanent; medium to low). Note that bare/rocks/shrubs and water/glaciers are considered constant in the NFF scenarios thus they can be conserved, but not restored.

EU policy guidance specifically states that restoration should preferentially take place within Natura 2000 sites until 2030. Thus, we will create additional restoration prioritisation variants that constrain restoration (transitions defined above) to take place within Natura 2000 sites. Note that, because the NFF scenarios are set up in a way that prevents land use class transitions within existing protected areas. We will set up the restoration prioritisation in a way that will always allow transitions that restore or de-intensify land use classes within protected areas.

We do not implement burden sharing specifically for the 20% because i) it is not specified by EU guidance and ii) there is strong variation in the levels of ecological degradation across different countries in Europe, thus the 20% priorities for restoration should be targeted in the areas that would be most beneficial for biodiversity.

4.3.4 Priorities for green infrastructure

Priorities for green infrastructure (GI) consists of a ranking of the remaining landscape that is not allocated to conservation or restoration, in terms of its importance for biodiversity, ecological connectivity, and NCP. Green infrastructure priority ranking complements the priorities for protected areas and restoration which are locked in. We iterate across multiple prioritisations that incrementally increase the budget area, starting from the combined area for conservation and restoration, up to the whole study area. The final map of GI is the average of these incremental

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solutions, that highlights areas in need of sustainable managed for biodiversity and NCP, outside of conservation and restoration.

The connectivity maps (WP6 output) are used as a linear penalty (negative penalty score), to ensure the selection of any important corridors that are not within the 30% (WP6), in addition to filling in any remaining gaps in coverage for species, habitats and NCP. The output ranking thus reflects important multifunctional corridors that should be sustainably managed.

4.3.5 Overview of analysis variants

There is not one single realization of how a potential TEN-N could look like, but rather different variants each with their own parameters and setup. We will compare the performance of a range of different variants to investigate synergies, trade-offs, and co-benefits. For example placing a higher weight on carbon mitigation efforts can decrease the targets achieved for species and habitats (Jung et al., 2021; Strassburg et al., 2020). There can however exist a certain "pareto optimum" where synergies and co-benefits result in plausible best possible solution that satisfies the most targets.

Table 9: Overview of different scenario variants.

Scenario variant	Key parameter	Description
Relative importance of biodiversity values, from low to high	weights	In these variants we will vary the weight given to certain groups of features in the prioritisation: species, habitats, cultural NCP and regulating NCP. Certain variants will reflect value preferences to match the three Nature Future Framework alternatives.
Protected areas	Manual bounded constraints	Protected areas used as baseline for the 30% (Natura 2000 only or all protected areas). Natura 2000 only, vs. all designations (including Natura 2000 plus all national designations). Note that we expect EU Member States to provide information on which national designations count towards the 30% and towards the 10%, as part of their protected area pledges. When this information is made available for all Member States, we will use this to extract the protected areas used as a baseline for the 10% and 30% prioritisations.
Climate resilience (outputs from T7.2)	Linear penalty (penalty score -1)	Variant that includes climate refugia and climate-resilient priorities identified in Section 3.

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Connectivity probability (outputs from T6.3)	Linear penalty (penalty score -1)	Variant that includes the probability of functional/structural connectivity into the prioritisation
Socio-economic costs (T4.1)	Linear penalty (penalty score 1)	Create variants of the TEN-N with or without costs.
Plausible LULC future (T5.2)	lower and upper bounds for management zones	Different realised variants for the NFF (one for each NFF corner, e.g. Nature for Nature, Nature for Culture, Nature for Society). The NFF determine the possible decision space within a planning unit.
Burden sharing for the 30%	Linear constraints	Added constraints for equal area sharing of the 30% between i) countries, or ii) biogeographic regions, or iii) no burden sharing (i.e. allocate areas freely in Europe).

4.4 Preliminary results

4.4.1 Aims of the pilot

The aim of the pilot was to test out a first draft version of the TEN-N problem formulation of Task 7.3 using preliminary data available as of September 2023. We develop scenarios for the expansion of the European network of protected areas to reach the conservation objective of 30% protection and 10% strict protection. In addition to testing the workflow, the first pilot results and the general concept was used to inform national and regional conservation authorities of our work via different channels, including NADEG and the Natura 2000 Biogeographical Seminars organised by the European Commission. It should be stressed that the pilot is not using any of the novel datasets created through the NaturaConnect project and that future patterns of a TEN-N might differ. We also stress that key considerations in the construction of a TEN-N, such as resilience criteria, connectivity or accounting for climate change impacts or displacement of future land-use scenarios are not yet accounted for. Further – as this information is not yet available - we rely in many cases on initial assumptions with regards to biodiversity targets, pledged area of European Member States and assumed costs of implementation. These factors will be improved upon as the data created within the NaturaConnect project becomes available.

4.4.2 Methodology and data used

Below we describe aspects of the data and methodology that is specific to the pilot and differs from the main TEN-N design methodology described above.

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For the Pilot, the study area was restricted to EU Member States (*i.e.*, excluding the UK, Switzerland, Norway, Balkan countries). We worked at a 10x10 km^2 resolution, matching the available distribution data for species and habitats.

We used the Species Distribution Models (SDM) developed in the EU-funded project BIOCLIMA that was available in 2023. These are SDM of terrestrial vertebrates, arthropods and plants which were modelled at 100 km^2 resolution for all species listed in the Nature Directive Annexes. All modelling was done by in the integrated modelling framework *ibis.iSDM* coded for R (Jung, 2023). For habitats, we extracted the distributions reported by Member States under Article 17 of the Habitats Directive.

We also used different target setting in the pilot than for the TEN-N design described above. We set the targets as follows:

- For species and habitats that are threatened or in unfavourable conservation status (U1 and U2), the target is to protect 100% of their range. This also applies to national subpopulations (given national red list assessments, and national Article 12 and Article 17 reported data).
- For other species and habitats, we formulate the target to minimise the distance to extinction risk or ecosystem collapse, respectively, according to IUCN Red List criteria:
    - For species, we used criteria defined in the IUCN Red List of species, building on previous work (Fastre et al., 2019; Jung et al., 2021), where R_s is the total range size of species s: $t_s = \min(max(2{,}200\ km^2, 0.8\ R_s), 10^6)$
    - For habitats, we used the IUCN Red List of Ecosystems criteria (Keith et al., 2022, 2013). Criterion A specifies that the geographic distribution of a habitat - R_h - should not decline by more than 30% within a 50-year period. Criterion B2 specifies that R_h should be at least 5,000 km^2. Therefore, the area target for habitats is: $t_h = \min(max(5{,}000\ km^2, 0.7\ R_h), 10^6)$
- For carbon sequestration, we set the target to protect 50% of the total carbon sequestration potential of European ecosystems.

We developed and ran 6 alternative prioritisation scenarios that explored priorities for the expansion of protected areas to reach 30%. We varied i) the set of existing protected areas on which to expand on, and ii) the geographical level at which the objective of 30% protected area coverage should be achieved:

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- 3 sets of variants for sharing conservation area across boundaries: i) 30% at the Member States level, ii) 30% at the biogeographic region level, or iii) 30% at the EU level. For comparison, we also created a variant with 27 separate prioritisations (one for each Member State).
- 2 sets of variants for expanding i) on Natura 2000 sites only, or ii) both Natura 2000 and other nationally designated sites (CDDA)
- For the priorities for strict protection, we built two variant scenarios that explored the implications of 2 aspects of feasibility: upgrading level of protection within existing (non-strict) protected areas and minimizing costs.

For strict protection we specifically focused on species (or subpopulations) and habitats that are listed as threatened or in unfavourable conservation status (U1 and U2), which we assumed are most in need of strict protection. We did not apply a burden sharing constraint for strict protection. Instead we created one scenario that optimised only based on species and habitats distributions without feasibility considerations, and a constrained scenario which included constraints on existing protected areas, and costs. In the constrained scenario, priority areas for strict protection could only be selected within existing (non-strict) protected areas; and with lower cost (hence, minimizing chance of conflict).

4.4.3 Preliminary results

For each scenario, we explored (i) *where* the top priority areas fall across European Member States and identify areas of overlap, and (ii) *how much* could be gained in terms of the representation of species and habitats distributions, for both conventional and strict protection. Our preliminary results suggest that a prioritisation within Member States leads to suboptimal gains for European biodiversity. We found that priority areas designated at the national level tend to cluster around the borders of countries, as highlighted by previous studies (Kukkala et al., 2016). This is because national prioritisations place a strong focus on species (or habitats) that are nationally rare, even though they may be common elsewhere, leading to a less cost-effective solution at the continental level. Conversely, a European-wide planning selects priority areas that are more cost-effective, complementary and irreplaceable at the European level, with higher gains for conservation in the same amount of area. Therefore, EU-wide collaboration between Member States is critical for achieving the best conservation outcomes.

In the European-wide priorities without burden sharing constraints, protecting the priority areas could more than double the amount currently protected in the case of threatened species (Figure 16), Article 17 species, species in unfavourable conservation status (U1 and U2). However, the

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priority areas are unevenly distributed across Member States, raising concerns of feasibility. The prioritisation at the European level with burden sharing between Member States provides a good compromise, with larger gains for biodiversity than in the 27 separate national prioritisations, while accounting for a fair distribution of conservation areas between countries (Figure 17). Results suggest that this intermediate scenario with burden sharing enables to effectively balance ecological benefits with policy constraints, by optimising for the whole of European biodiversity while ensuring equitable sharing of conservation area between Member states (or biogeographic regions).

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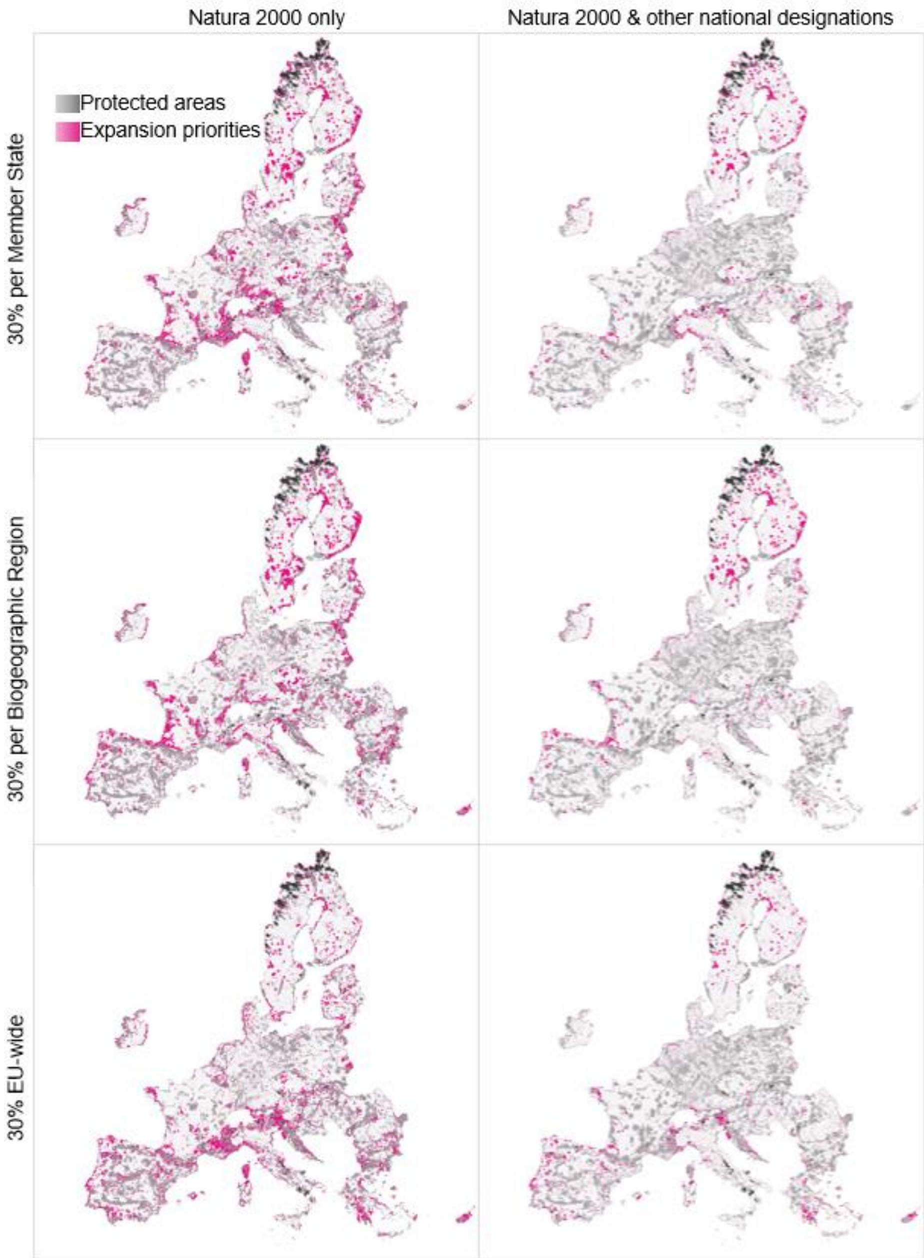

Figure 16: Maps of 6 variant scenarios for 30% protected area coverage. Scenarios vary in the constraints to distribute conservation area equally across Member States (top row), biogeographic regions (middle), or without burden sharing (i.e. anywhere in Europe) (bottom); and in the protected areas considered as a starting point: Natura 2000 only (left column) or all protected areas, including Natura 2000 sites and other nationally designated (CDDA) sites (right). In each map, the priority areas in pink expand on the protected areas in grey.

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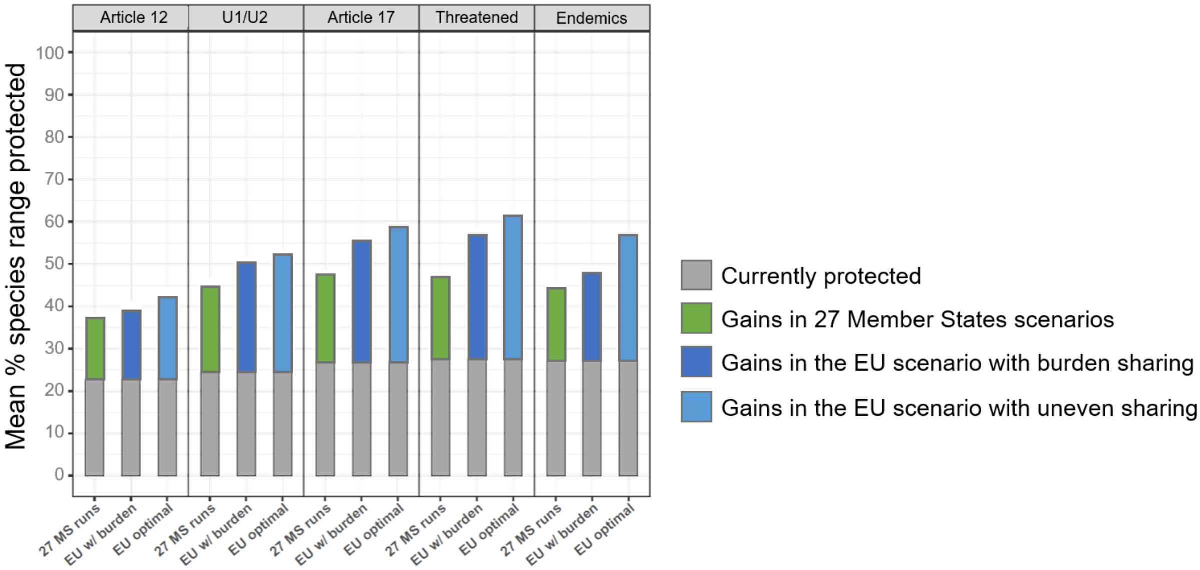

Figure 17: Cross-border coordination is key for high conservation outcomes. The bar plots show the potential conservation gains in each scenario. The panels show the different groups of species of conservation concern. Represented in grey is the amount of biodiversity currently protected in Natura 2000. In green would be the potential biodiversity gained when planning separately for each Member State. In light blue, the amount of biodiversity that would be gained if we planned at the European level with 30% of conservation area in each Member State. In dark blue, the amount of biodiversity that would be gained if we planned at the European level with unequal distribution of conservation area between Member States.

Regarding strict protection, we found that gains for threatened species and habitats were much higher in the optimal scenario (where feasibility considerations are ignored) than in the constrained scenario which focused on feasibility, constraining the selection of sites to those already under some form of protection and that are less costly (Figure 18). This highlights the question of the trade-off between ecological benefits and feasibility. In some cases, we may need to protect places that are home to threatened species and habitats even if they are more costly or difficult to protect.

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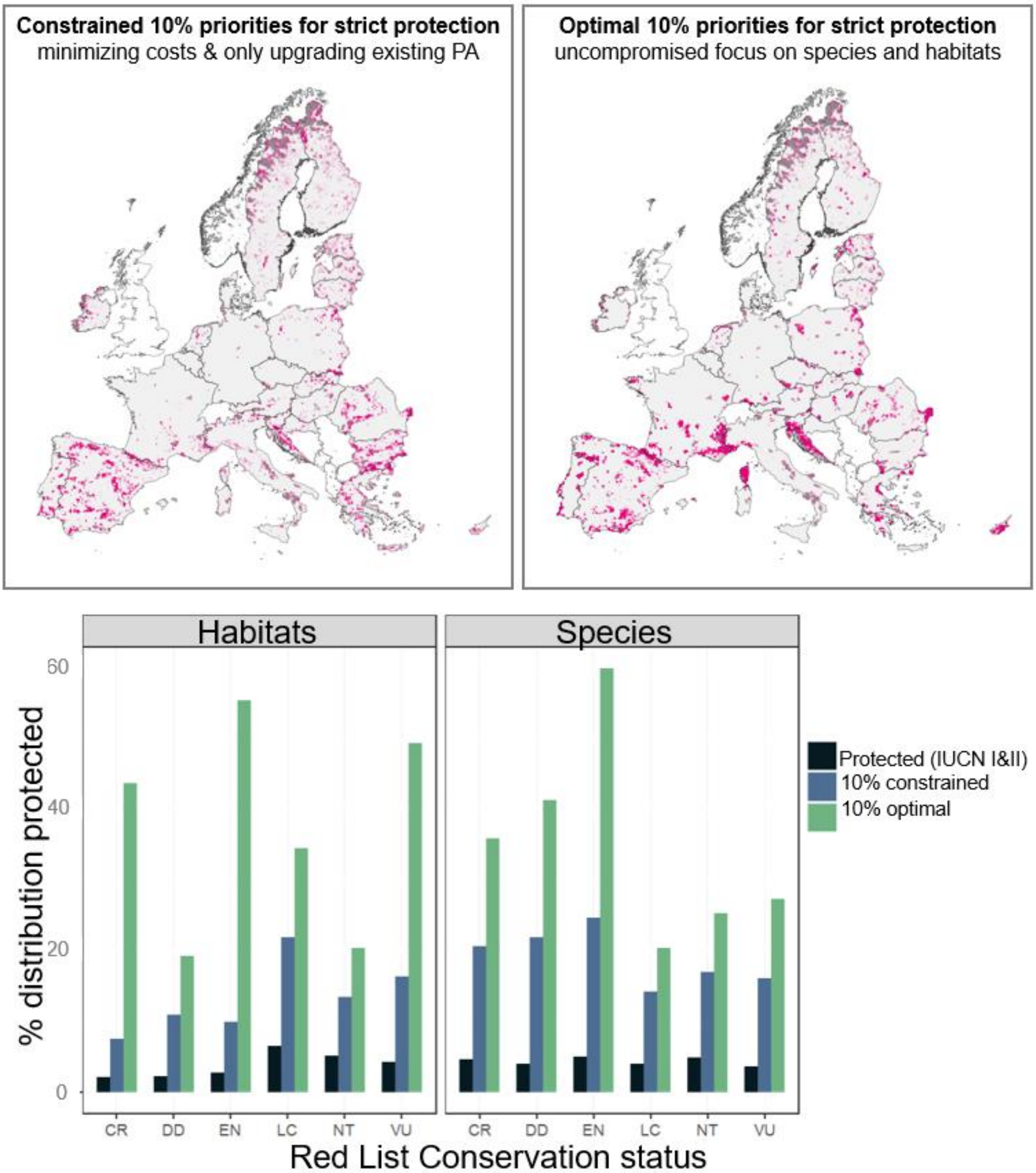

Figure 18: Comparison of 2 variant scenarios for the 10% strict protection in Europe in terms of spatial patterns (maps) and potential for conservation gains for habitats and species (barplot).

4.5 Discussion

Our pilot analyses confirm that planning for conservation at the European level ensures far better gains for species and habitats, than when planning within national boundaries (Eckert et al., 2023; Kukkala et al., 2016; Pouzols et al., 2014). Coordination between Member States is thus key for achieving the best conservation outcomes. However, for the sake of policy-relevance and feasibility, protected area planning should factor in burden sharing of conservation between

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Member States and/or biogeographic regions. In line with global and European conservation policy, we propose to make use of scenarios that optimise for conservation at the European scale while ensuring a fair sharing of conservation areas across Member States, and biogeographic regions.

In addition, preliminary results for strict protection emphasise the risks of prioritising conservation efforts in low-conflict areas that may be lower priority from a biodiversity perspective (Dinerstein et al., 2019). We will strive to deliver scenarios that explore the trade-offs between different key objectives addressing environmental, social and economic values.

The project can also assist in exploring options of trading conservation area, where for example biodiversity-poor Member States would support the conservation in other countries that have a higher share of European conservation priorities.

We showed that priority areas and associated gains for conservation vary with the set of protected areas considered as a starting point. Going forward, we aim to use the pledges to select the set of protected areas to consider as part of the 30% objective, if and when they are made available for EU Member States. In the case where such pledges are not made available by MS, because of political or capacity reasons, we aim to provide plausible evidence on where priority regions could be under different variants (see Table 9).

The definition of strict protected areas in Europe has yet to be clarified. The choice of which species and habitats should be strictly protected in addition to old-growth and primary forests, and what type of management and activities are allowed in strict protected areas, impacts the prioritisation setup and objectives. Even though policy guidance indicates that the 10% target should be achieved at the European level with no indication of burden sharing, it might be politically more feasible to distribute new strictly protected areas evenly across Member States and/or biogeographic regions, similar to the 30% target. We will propose criteria for the identification of species and habitats that need to be strictly protected, for example informed by the types of threats that can be mitigated by designation for strict protection.

Going forward, we will continuously improve these prioritisation scenarios. Some noteworthy improvements in the upcoming scenarios include:

- higher spatial resolution ($1km^2$),
- we will plan not only for conservation but also for restoration and sustainable management in green infrastructure, making use of land use change scenarios. The

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output maps will further indicate what land use class is to be conserved, or restored, where.

- increased comprehensiveness by considering a broader set of taxa, as well as essential ecosystem services (WP3 and WP4).
- Inclusion of favourable reference values to set conservation targets for each feature (T7.1).
- Inclusion of ecological connectivity (T6.3) and resilience to climate change (T7.2) in the planning, given projections for species future habitat suitable ranges.
- Assessment of implications of different definitions of strict protected areas.

4.6 Stakeholder engagement

Stakeholder engagement for the analysis framing and preliminary results of the spatial prioritisation had four different objectives: 1) The first objective was to understand current planning approaches in different Member States, 2) The second objective was to present the project and preliminary results to relevant stakeholders to receive direct feedback, 3) The third objective was to elicit targeted feedback on specific parameters or concept of the analysis workflow, and 4) objective was to enable stakeholders to investigate preliminary results in more detail in provide feedback on the maps of different scenarios.

A key platform for the first two objectives were the Biogeographical Seminars, a multi-stakeholder cooperation process aiming to enhance the effective implementation, management, monitoring, financing and reporting of the Natura 2000 network at a biogeographic level organised through the European Commission (https://biogeoprocess.net/). It provided an opportunity to present the project aims and hear first-hand of preferences and implementation issues around the planning for the TEN-N, as well as make contact to delegates from government, science, industry and other societal groups from all Member States and hear about national conservation planning approaches.

We attended the seminar series with the aim of disseminating the concept and first pilot results (section 4.4, addressing objective 2) and providing the option to hear feedback to a total of 332 people from different sectors and organizations (SI Table 1) during five meetings between September 2023 and June 2024 (addressing objective 3). Feedback was received in an open way through questions after the presentation and discussions during the seminar, which were written up a summary notes, and in a structured way via use of online questions. Before the attendance at the seminars, we shared an anonymous survey with the NADEG group with questions about

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NATURA CONNECT

parameter preferences in the TEN-N design (section 4.2 above, and see Table T2 in Appendix), which returned a total of 12 responses, covering all Biogeographical regions. Due to the low response rate, several survey questions were asked via Mentimeter during some of the events to get confirmation of the representativeness of the anonymous responses from NADEG (see Figures S1-S6 in the Annex).

Based on the set of responses from NADEG and the Boreal and Mediterranean seminar attendants, we found that preferences of Member States representatives that we were able to obtain aligned with the choices made for the pilot analysis. Overall, the presentations of the first results and general strategic approach were met with great interest, indicated by questions after the presentations and personal communications during the seminars. We recognize that the participants to the seminars are not an exhaustive set of decision-makers and other stakeholders for which these tasks are relevant and we are working towards extending the consultation process further to complement these groups, through considering sub-national agencies involved in planning of conservation and restoration actions. Several spontaneous exchanges about possible closer collaboration emerged during the seminars, however, to ensure to reach out to all Member States with an offer on closer collaboration, we emailed 41 institutions (108 individual government representatives with 2 still to received) across all EU Member States, except for France, Portugal and Finland due to the engagement on the national level via the case studies. The outcome of the engagement efforts will be reported at the end of the project. To facilitate following up with government authorities that are responsible for the TEN-N planning and implementation, key aspects of the draft methodology were written up as NaturaConnect's first science brief (O'Connor et al., 2024). The participation at the seminars and the close collaboration with the commission during the content preparation phase leading up to the events has resulted in other invitations and analyses, such as an additional analysis of fragmentation in Natura 2000 sites. One key realisation with large implications was that the development of a relevant workflow for the prioritisation of strictly protected areas will require more in-depth discussion among Member States, the commission, and the project. Despite having trialled a specific approach in the pilot phase of NaturaConnect, we now aim to adjust the methods based on the ongoing deliberation process.

To achieve the third objective of considering feedback on the problem formulation and parameters in the workflow, the information gathered at the seminars, both summary notes and responses from online questions were used to inform analysis where it was applicable. A strong focus during the seminars was on the conservation status improvement pledges, with many countries putting considerable effort into identifying species and habitats that might benefit most

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from conservation measures. We aim to produce a set of scenarios for protected area expansion where habitats and species included in conservation status improvement pledges and for which additional designation or habitat restoration determined as needed measures are preferentially selected. These scenarios should identify ways in which additional designations best contribute to realize MS ambitions to achieve target 4 of the EU Biodiversity Strategy. We will also be continuing the engagement with stakeholder about the expert validation of species and habitats targets (e.g. FRV, see section 2) and performance assessments of area-based pledges. Examples of successful inclusion of gathered feedback into the problem formulation include the use of the Menti results on future protection (see SI Figure 4), initial design and parameter choices such as weights (section 4.2.2), and choice of burden-sharing variants (Section 4.3.1). It should be noted that core aspects of the analysis workflow were pre-determined by policy documents and laws, and stakeholder preferences were elicited predominantly to understand different priorities in different countries that could help to identify most relevant scenarios. Based on what we learned at the Biogeographical Seminars, we have chosen to reduce the number of analyses with unconstrained burden-sharing (30% to be achieved at the EU level with no lower or upper limit on any countries' effort), and only present one scenario that could illustrate the best-case scenario. The focus has now shifted on scenarios where 30% is achieved either or both for each bioregion and MS, to reflect EU guidance and what we learned at the BGSs from country delegation, as this will provide outputs more relevant for decision makers.

Several other issues that were discussed during the seminars still need to be integrated into the analysis and planned scenarios. Targeted outreach is currently planned to address remaining open question, for example on indicators for T7.4, on the appropriateness of our favourable reference values, on strict protection definitions or on the desired functionality of software to be used for the upcoming engagement on discussion preliminary results in detail under objective 4, which will be reported on later in the project once it has happened. Several topics that were important to Member States will be useful to consider as part of the performance evaluation of the TEN-N variants (Task 4.7, to be reported in D7.2). These could include for example suggestions on the minimum size of protected areas, the exploration of the trade-off with closing protection gaps, or the production of specific summaries based on Article 17 habitats, which are widely used by MS.

We stress that stakeholder engagement is a continuous process, and the most important efforts regarding objective 4 will start in 2025 until the end of the project, where feedback on the first results in 1 km resolution will be gathered. The targeted discussions on scenario results will allow us to identify possible issues in underlying methods or data, or political or economic challenges

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in certain priority locations, and have iterative discussions with stakeholders while we add complexity with additional data layers on climate, land use, Nature's Contributions to People and connectivity.

5 Next steps

The results presented in this deliverable describe and showcase a) a methodology how to identify FRV based on available data for a broad range of taxa in Europe including the description of initial results, b) a framework for the identification of climate-resilient priority areas and first preliminary results describing areas with high climate connectivity and c) a description of the problem formulation for identifying different variants of the TEN-N as well as a draft pilot results based on available data so far. All these results allow us to draw some first conclusions with regards to ambitions and opportunities of safeguarding current and future biodiversity in Europe.

Next steps

This deliverable describes the methodology of T7.1, T7.2 and T7.3 of the NaturaConnect project. Although preliminary results and proof of concepts are presented, these results do not yet consider all the data created by the NaturaConnect project. All preliminary results have been uploaded to Zenodo of the different tasks (see Data availability below 6) and will be updated with new versions as final data from WP3, WP4 and WP5 of the project becomes available. A full quantitative and qualitative performance evaluation and description of the TEN-N will be described in Deliverable D7.2, including all data and feedback received up until then. This will also include a description of the performance evaluation (T7.4, omitted here) and the indicators used to evaluate the TEN-N variants in terms of the design principles (section 1.4.2). Not only will it then be possible to (quantitatively) compare different TEN-N variants, but also to identify the 'sweet spots' of areas that achieve multiple benefits across variants.

The problem formulation outlined in this deliverable has been informed by and discussed with stakeholders at the biogeographical seminars (NADEG), the European commission and other sectoral and national representatives (but see section 4.6 and deliverable (Schnepf et al., 2024)). Moving forward a critical next step will be the gathering of feedback on initial draft versions of the TEN-N and – where possible and sensible – adaptation of the problem formulation or resulting maps. An important part will also be the communication and dissemination of the results. We will place all final layers on an interactive web explorer ("NaturaConnector") as well as create easy overview factsheets for each European Member State (D8.1).

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NATURA CONNECT

6 Data availability

All primary results highlighted in this deliverable have been made available on the NaturaConnect Zenodo community (https://zenodo.org/communities/naturaconnect/). Preliminary data have been uploaded (FRV target: 10.5281/zenodo.13748185, bioclimatic components 10.5281/zenodo.13378751, resilience criteria 10.5281/zenodo.13733840, pilot results: 10.5281/zenodo.13748141) and will be further updated with new versions as more and finalised data becomes available from the project. Given that input data and results were at the time of this deliverable still preliminary and accompanying manuscripts not yet published as preprint, these uploads are placed under an embargo that expires at latest by the end of the NaturaConnect project duration in July 2026.

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NATURA CONNECT

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Supplementary Information

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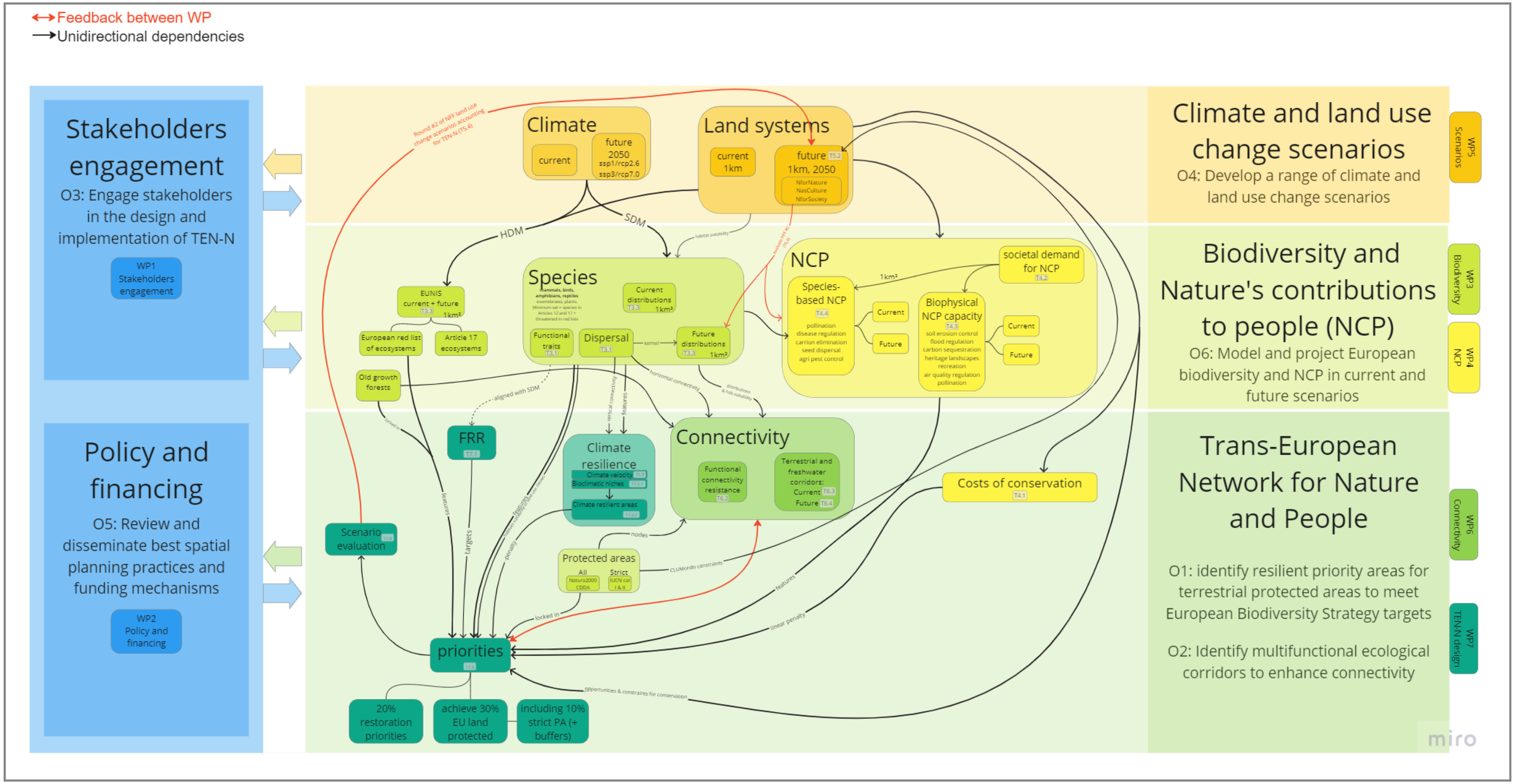

SI Figure 1: Flowchart of key data flows to and from WP7 created in miro™ . Key components are visually highlighted including for example different datasets (climate, land systems) and approaches (connectivity). Arrows in black indicate one-directional feedbacks, e.g. data only goes into the design of the network, while red arrows indicate bidirectional feedbacks, e.g. data is used in the network design and feeds back to other WPs.

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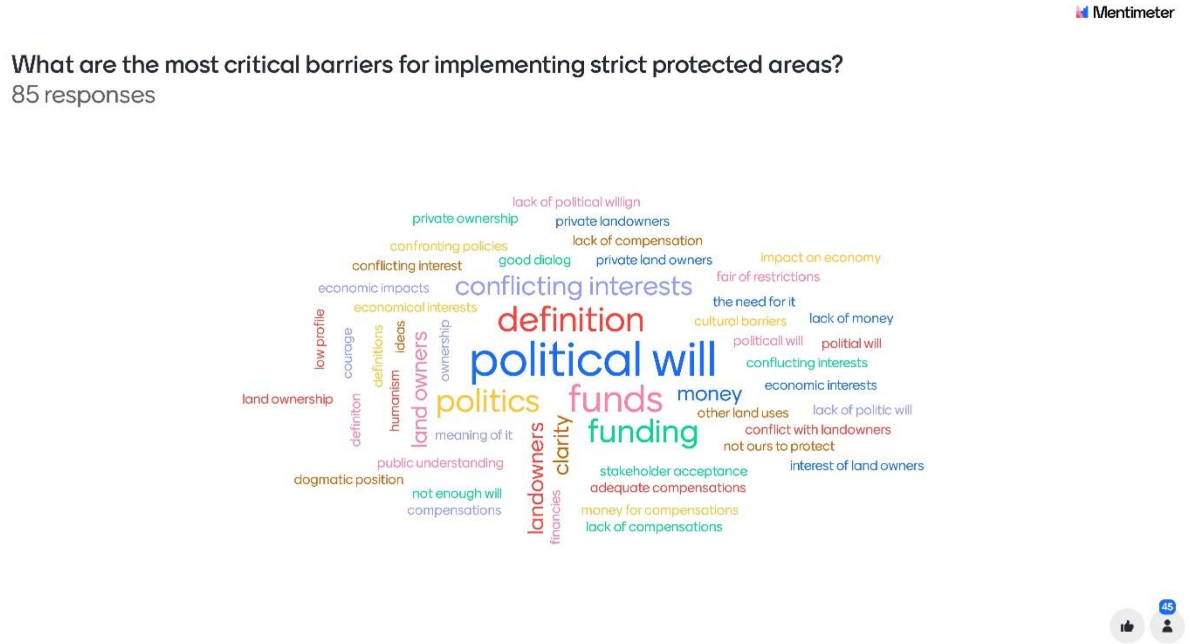
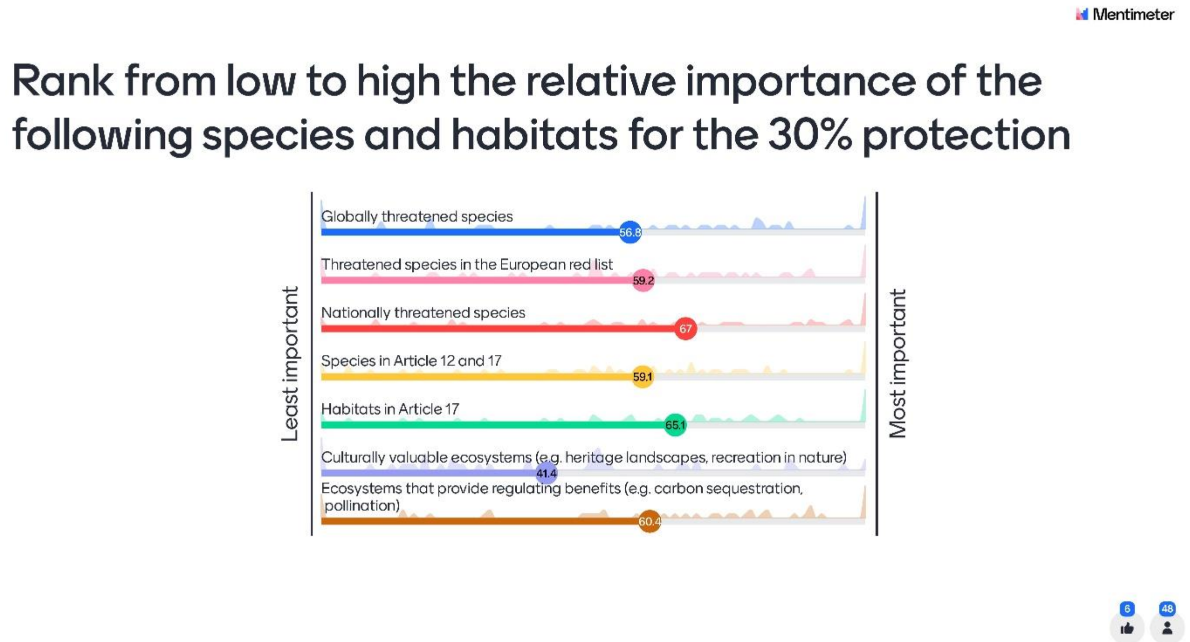


SI Figure 2: Word cloud of answers related to critical barriers for strict protection at the Boreal Biogeographical Seminar.



SI Figure 3: Question on biodiversity preferences at the Boreal Biogeographical Seminar. The broad range of priorities confirms the assumption that scenarios are necessary, and a broad inclusion of biodiversity data is justified.

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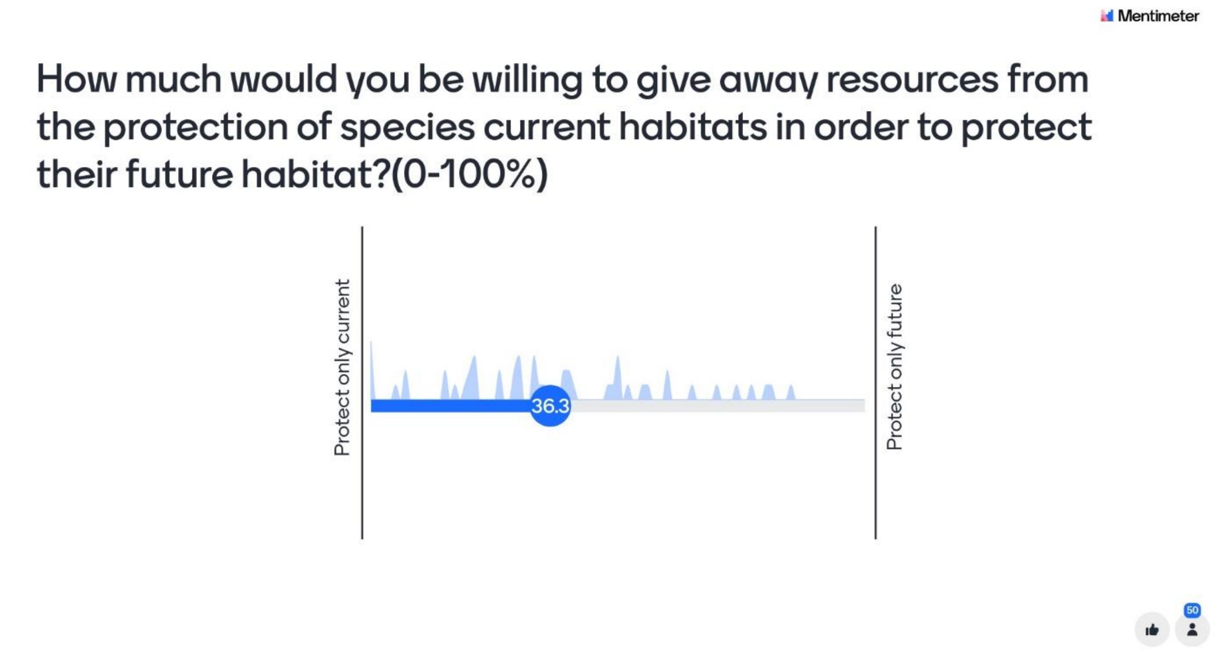
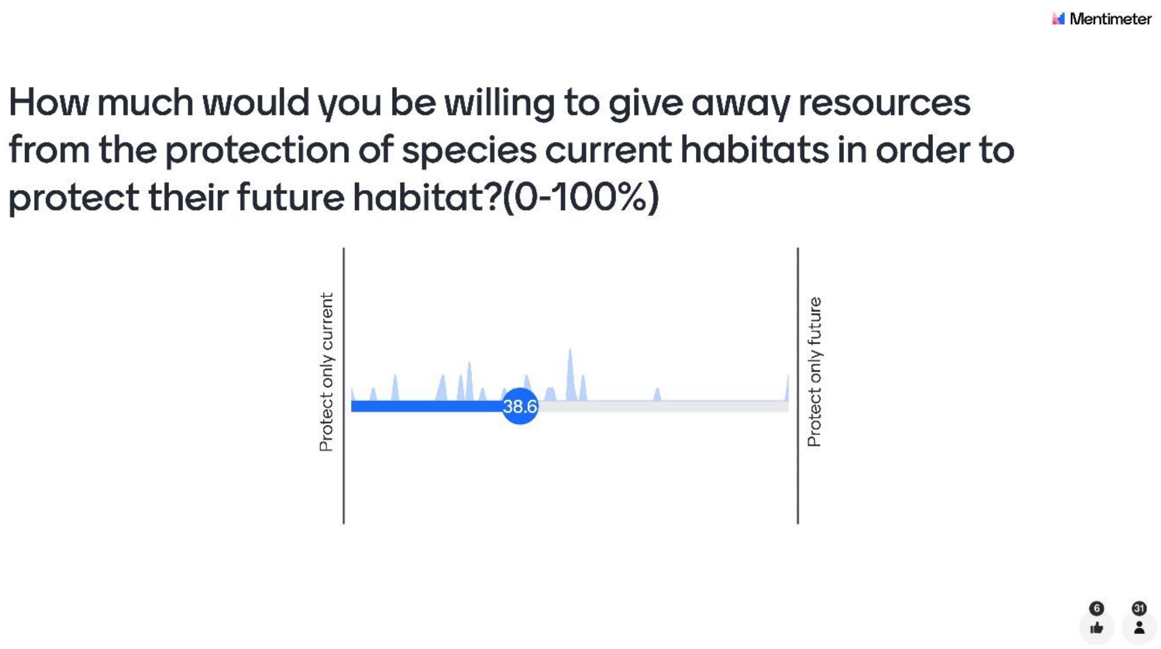


SI Figure 4: Attendees at the Boreal Biogeographical Seminar were asked how much they would prioritise current against future efforts if current and future species distributions do not overlap. The broad range of responses confirms that scenarios will be important to provide decision-support for different preferences.



SI Figure 5: Attendees at the Mediterranean Biogeographical Seminar were asked how much they would prioritise current against future efforts. The responses were similarly broad as in the Boreal seminar, confirming the need to run scenarios.

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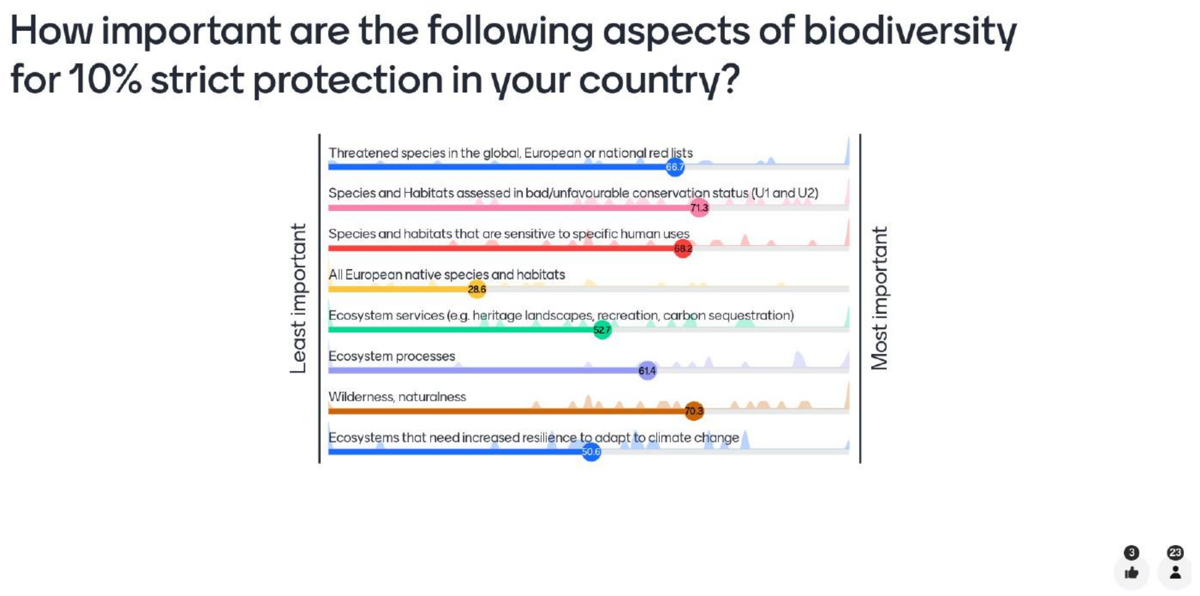

SI Figure 6: The responses at the Mediterranean Biogeographical Seminar were similarly broad as in the Boreal, confirming that the inclusion of a broad set of biodiversity features and weighting schemes is justified.

SI Figure 7: Due to the high biodiversity value of the Mediterranean region, an additional question and the strong focus on the topic in this regional seminar, a more detailed question on priorities in strictly protected areas was asked. The responses reflect the diversity of opinions on the topic, which has been a challenge during all seminars to come to a coherent agreement of possible strategies and definitions.

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SI Table 1: Summary table on the number of participants from different stakeholder groups across all 5 seminars. Note that some people or institutions belonged to two groups, so the sum in this table is slightly higher than the total number of participating individuals.

Stakeholder group	Number of participants
government	182
ngo	52
science	43
forestry	14
Organising committee	9
water	8
EC	7
other	6
PA management	6
consultancy	5
hunters	4
LIFE projects	4
landowners	3
EEA	2
industry	2
third party land-use management	2
Non EU	2
agriculture/livestock	2

SI Table 2: Questions to NADEG group in anonymous survey to confirm analysis parameters.

Question #	Question
1	Which biogeographical regions are present in your Member State?
2	Species and habitats: should we treat any of these features as more important in our analysis than others?
3	If you are interested in specific subsets of species or habitats, please provide a brief description
4	Would you want us to include regulatory services provided by nature in our analysis? For example, pollination, disease regulation, seed dispersal, regulation of agricultural pests, soil erosion or floods, or carbon sequestration?
5	Should we include any of these features in our analysis in addition to criteria of biodiversity?

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6	Would you want us to include cultural services provided by nature in our analysis? For example, game species for hunting, foraging of berries or mushrooms, wildlife watching, recreation and tourism, heritage forests or heritage agriculture
7	Should we include any of these features in our analysis in addition to criteria of biodiversity?
8	If you have any other important criteria regarding biodiversity or ecosystem services in mind that should influence the selection of new protected areas, please provide a comment or suggestion here
9	Are you interested in seeing how the amount and locations of protected areas change when different additional criteria to the presence of biodiversity features are used to prioritize locations?
10	If you checked "other", please give a brief description
11	Are economic considerations of interest to include in our analysis, such as management costs, economic losses, or acquisition costs
12	Should we include any of these features in our analysis in addition to other criteria?
13	If you have indicated interest in any of the "other" options above, or have any other important criteria regarding economic considerations in mind that should influence the selection of new protected areas, please provide a comment or suggestion here
14	Are technical or political considerations of interest to include in our analysis, such as support or resistance from society, capacity to do required work, support or resistance from industry or policy groups
15	Should we include any of these features in our analysis in addition to other criteria?
16	If you have any other important criteria regarding political or technical considerations in mind that should influence the selection of new protected areas, please provide a comment or suggestion here
17	Are there other limiting factors or barriers that you would like to see considered in our analysis than economic or technical/political criteria? If so, could you give a brief description?
18	Are you interested in seeing how the amount and location of strictly protected areas change when different criteria, including biodiversity features, natural services, and economic, technical and political considerations are used to trigger strict protection?
19	If you are interested in specific subsets of species or habitats, please provide a brief description

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20	Are you interested in seeing how the amount and location of strictly protected areas change when different criteria of regulatory services from nature are used to trigger strict protection?
21	Are you interested in seeing how the amount and location of strictly protected areas change when different criteria of cultural services from nature are used to trigger strict protection?
22	If you would like to see any other important criteria than the ones we listed here to consider in our analysis, could you give a brief description?
23	Would you want to see different criteria of constraints included when we run our analysis for strict protection than in our analysis for the 30% target?
24	Are economic considerations of interest to include in our analysis, such as management costs, economic losses, or acquisition costs?
25	Should we include any of these features in our analysis in addition to other criteria that trigger strict protection?
26	If you have any other important criteria regarding economic considerations in mind that should influence the selection of new protected areas under strict protection in our analysis, please provide a comment or suggestion here
27	Are technical or political considerations of interest to include in our analysis, such as support or resistance from society, capacity to do required work, support or resistance from industry or policy groups?
28	Should we include any of these features in our analysis in addition to other criteria that trigger strict protection?
29	If you have any other important criteria regarding political or technical considerations in mind that should influence the selection of new protected areas under strict protection in our analysis, please provide a comment or suggestion here
30	National conservation strategy 30% target: Do you think your country could pledge to provide more than 30% of its area to the 30% target?
31	National conservation strategy 30% target: Do you think your country could pledge to provide less than 30% of its area to the 30% target?
32	Feeling treated fairly usually depends on the match between official rules and own values. Should we produce plans for new protected areas to reach the 30% target across Europe that use specific criteria to account for a fair distribution of conservation efforts per Member state and/or biogeographical

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	region? We could produce maps and figures that show the difference in the network configuration between different strategies.
33	Do you have a preference or idea for a specific criteria that should determine how much countries contribute to the overall 30%?
34	Do you have different preferences or ideas for the question of burden sharing regarding the 10% strict protection than for the 30% targets?
35	National conservation strategy 10% target: Do you think your country could pledge to provide more than 10% of its area to the 10% target?
36	National conservation strategy 10% target: Do you think your country could pledge to provide less than 10% of its area to the 10% target?
37	Should we produce maps for new protected areas to reach the 10% target across Europe that use specific criteria to account for a fair distribution of conservation efforts per Member state and/or biogeographical region? We could produce maps and figures that show the difference in the network configuration between different strategies.
38	Do you have a preference or idea for a specific criteria that should determine how much countries contribute to the overall 10%?
39	Do you know who or which entity is doing the technical work and develops maps for the new designated areas in your Member State?
40	Would you like to stay in contact with NaturaConnect and be updated on our work? If you want, provide your email address here and you will receive our bi-annual newsletter
41	What other information could NaturaConnect produce that would be helpful for your work regarding the designation of new protected areas to reach the 30% protection and 10% strict protection target? Any comments or feedback is welcome here

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More information about the project:

NaturaConnect has 22 partner institutions: International Institute for Applied System Analysis (project lead; Austria); German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig (project co-lead; Germany); Associacao Biopolis (Portugal); BirdLife Europe (Netherlands); Birdlife International (United Kingdom); Centre National De La Recherche Scientifique (France); Doñana Research Station - Agencia Estatal Consejo Superior De Ivestigaciones Cientificas (Spain); Europarc Federation (Germany); Finnish Environment Institute (Finland); Humboldt-University of Berlin (Germany); Institute for European Environmental Policy (Belgium); Netherlands Environmental Assessment Agency (Netherlands); Rewilding Europe (Netherlands); University of Evora (Portugal); University of Helsinki (Finland); University of Natural Resources and Life Sciences, Vienna (Austria); University of Rome La Sapienza (Italy); University of Warsaw (Poland); Vrie University of Amsterdam (Netherlands); WWF Central and Eastern Europe (Austria); WWF Romania and WWF Hungary.

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NaturaConnect aims to design and develop a blueprint for a truly coherent **Trans-European Nature Network** (TEN-N) of conserved areas that protect at least 30% of land in the European Union, with at least one third of it under strict protection. Our project unites universities and research institutes, government bodies and non-governmental organizations, working together with key stakeholders to create targeted knowledge and tools, and build the capacity needed to support European Union Member States in realizing an ecologically representative, resilient and well-connected network of conserved areas across Europe.

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