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Approaches to identify terrestrial priority areas for achieving the 30% and 10% protection target in the EU

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Executive summary

A key component of the EU Biodiversity Strategy is the development of a truly coherent and resilient Trans-European Nature Network (TEN-N), defined as 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''* (European Environment Agency 2020).

The realisation of the TEN-N will depend on national and sub-national initiatives for designations of protected areas and recognition of Other Effective Area-Based conservation measures, but its benefits for biodiversity will depend on how individual elements contribute to addressing protection gaps of under-protected habitats and species at the EU level.

This report provides a blueprint for developing and exploring scenarios for expansion of terrestrial protected areas in the EU and aims to address the following questions selected for their prevalence within science-policy dialogues between the ETC-BE, the EEA, the European Commission and representatives of EU Member States in the context of the Biogeographical Process:

- What are the implications of considering different sets of existing protected areas as a baseline?
- What are the implications of different burden-sharing among EU Member States in achieving the 30% protection targets?
- How sensitive are conservation priorities to the consideration of socio-economic costs and constraints?

This report does not analyse the connectivity of the current protected area network, climate change resilience, or priorities for the establishment of ecological corridors for terrestrial and freshwater ecosystems, which is an important element of TEN-N planning and will be the subject of future ETC-BE work.

The report describes a process of translating Target 1 and 2 of the EU Biodiversity Strategy in a generic analytical problem, with alternative parameters that can be adapted to explore the implications of different choices at the discretion of planning authorities, such as the emphasis put on achieving protection targets at national or European level.

We found that, on average, 30% of the species suitable habitat range is protected by all protected designations, and 23% of the range in average, is protected in Natura 2000 areas. Habitats listed in Annex I of the Habitats Directive, have on average 37% of their distributions within all protected area designations, and 29% when only considering Natura 2000 sites. Several habitats and species of EU conservation concern have <10% of their suitable habitat protected.

Closing these protection gaps can be achieved more or less efficiently depending on the level of coordination and burden-sharing agreed between Member States. Our results suggest that strategic placement of additional designations can more than double the protection level of habitats and species in the EU, and almost triple that of habitats and species endemic to the EU, compared to the current protection level afforded by the Natura 2000 network.

When expanding on Natura 2000 sites only, the terrestrial protected area network expands by an additional ~11% of the land area, as opposed to ~4% when all National designations are assumed to contribute to Target 1 of the EU Biodiversity Strategy. Priorities that expand on Natura 2000 sites only would achieve the average representation of 61% of habitat distributions and 45% of species distributions; while expanding on both Natura 2000 sites and nationally designated areas achieve the average representation of 54% of habitat distributions, and 41% of species distributions. This suggests that careful scrutiny should be placed in identifying which nationally designated areas contribute to the coherence of the network as expressed in Target 1 of the EU Biodiversity Strategy depending on the value of the site for their conservation.

European-wide planning of further designations can achieve a higher level of species and habitat representation for the same extent of protected areas than uncoordinated planning within EU Member States, even when each country limits its protection effort to 30% of its land area. This is because accounting for the full pan-European distribution of habitats and species allows protection efforts to be focused on habitats and species that are threatened and under-protected at the EU level as opposed to country level. Allowing for a small deviation from a maximum 30% at country level and setting a protected area coverage target at the biogeographic level, further increases the mean level of protection.

Our exploratory analyses suggest that there is scope for a large expansion of strictly protected areas in the EU if the baseline level of strict protection is only protected areas that are considered under IUCN management category I and II, which collectively account for ~3% of the EU land area.

While socio-economic acceptability is an important element of protected area planning, our results suggest that restricting designations of new strictly protected areas to sites already under some form of protection and avoiding areas of high existing or potential revenue for agriculture, forestry, or infrastructure development, severely limits the opportunity to address conservation gaps for species and habitats threatened with extinction or in an unfavourable conservation status. We conclude that some areas of high potential economic value will require protection without compromises, in order to achieve EU conservation targets.

This report demonstrates an approach to produce a pan-European analyses of conservation priorities that spatially reflect the ambition of Targets 1, 2 and 4 of the EU Biodiversity Strategy across all Member States. It illustrates how Member States and the European Commission can make use of TEN-N scenarios such as those proposed here, to enable an iterative process of identification and designations of protected areas of Community importance. A comparison of EU-wide priorities and national priorities can provide insights into the coherence of national spatially explicit strategies for future designations, highlighting which unprotected regions of pan-European importance could be included into national strategies and action plans for future designations.

1. Introduction and objectives

1.1. European Union Protected Area Targets

The EU 2030 Biodiversity Strategy aims to put biodiversity on the path to recovery by 2030, as a contribution to the EU Green Deal goal of preserving and restoring Europe's natural capital and placing Europe in a leadership position in the Post-2020 CBD Framework. A key component of the EU Biodiversity Strategy is the development of a truly coherent and resilient Trans-European Nature Network (TEN-N), defined as 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*'' (European Environment Agency 2020). The TEN-N is expected to bring added coherence to the existing network of Natura 2000 sites and other nationally designated protected areas, by not only addressing gaps in the coverage of priority habitats and species, but also enhancing the diversity, functioning and resilience of all species and ecosystems. Broadening the scope of conservation actions beyond listed species and towards preserving the broader structure and functioning of ecosystems is critical given the context of global changes. The TEN-N should legally protect at least 30% of the land, including inland waters, and 30% of the sea in the EU (EU Biodiversity Strategy Target 1), of which at least one third under strict protection, including all remaining primary and old-growth forests (EU Biodiversity Strategy Target 2, see Table 1.1 for an overview of EU Biodiversity Strategy Targets connected to this report).

Member States (MS) will be responsible for designating the additional protected areas either by expanding Natura 2000 or by using national protection schemes. The TEN-N should create a functionally connected system with ecological corridors through Green and Blue Infrastructure (GBI[1]) including in cities and other intensively managed systems, to address genetic isolation, allow for species migration, and maintain healthy ecosystems that not only are resilient to climate change but also provide Nature Based Solutions (NBS) for climate to help mitigating emissions.

These goals and objectives of the TEN-N, as defined in the EU Biodiversity Strategy and in the European Commission Staff Working Document on the Guidance on the implementation of EU Protected Area Targets (European Commission 2022), can be translated into criteria to identify spatially explicit conservation priorities to reach Target 1 and 2 of the EU Biodiversity Strategy (section 2.1). The resulting priority maps can then inform us about the benefits of alternative protected area configurations, *e.g.* in terms of the closure of gaps in the coverage of under-protected habitats and species of EU conservation concern.

[1] The GBI is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas (Estreguil, C., Dige, G., Kleeschulte, S., Carrao, H., Raynal, J. and Teller, A 2019).

1.2. Objectives of this report

This report provides the blueprint of how to develop and explore scenarios for expansion of terrestrial protected areas in the EU and aims to address the following questions:

- What is the implication of considering different sets of existing protected areas as a baseline?
- What is the implication of different burden-sharing among EU MS in achieving the 30% protection targets?
- How sensitive are conservation priorities to the consideration of socio-economic costs and constraints?

The report starts with an introduction of the use of decision-science to support conservation decision-making, with a focus on area-based conservation measures which falls under the realm of Systematic Conservation Planning (Margules & Pressey 2000; Moilanen et al. 2009b; Wilson et al. 2009). Systematic Conservation Planning (SCP) provides the methodological framework to apply decision-making principles in spatially explicit ways, ensuring that protected area networks are ecologically representative, adequate, resilient and efficient (Kukkala & Moilanen 2013). The remainder of the introduction describes the analytical framework and analyses presented here. The methods section describes the process of translating Target 1 and 2 of the EU Biodiversity Strategy in a generic mathematical problem, with alternative parameters that can be adapted to explore the implications of different choices at the discretion of planning authorities, such as the emphasis put on achieving protection targets at national or European level. The methods section further describes the data used for a worked example of protected area expansion scenarios for the EU, and the parameters and assumptions used in these scenarios. Section three presents some example results of pan-EU spatial conservation priorities designed to realise the first two targets of the EU Biodiversity Strategy in ways that best contribute to Target 4, i.e. the recovery of species and habitats of conservation concern.

It is worth noting that the analyses presented in this report and the associated results and maps are purely illustrative and aimed at describing a replicable workflow for setting conservation priorities and demonstrating its benefits to investigate several practical questions about the implementation of EU and national area-based conservation strategies. The resulting maps should not be taken as spatially precise recommendations for protected area designations but as broad areas which are likely to contain areas of conservation significance that are unique and irreplaceable at the European level. The analyses are based on species and habitats of EU conservation concern for which expert-based or modelled distribution was available, and the exact location of conservation priorities is sensitive to the input data used. We highlight additional desirable data and parameters that should be included in any analysis that is intended to inform decision-makers on actual spatial configurations considered for implementation (section 4). Nevertheless, the analyses presented here help to answer the key questions outlined above and demonstrate the usage of systematic conservation planning approaches to investigate several others.

The approach presented here to set spatial conservation priorities can be adapted to other decision contexts and works across all spatial scales. While these analyses are only focussing on terrestrial ecosystems, the principles and analytical approach illustrated here can also apply to marine ecosystems, and several marine conservation planning examples exist in the scientific and grey literature that document its applications (Beger et al. 2015; Jumin et al. 2018; Virtanen et al. 2018; Virtanen & Moilanen 2023 p. 202).

Table 1.1 Overview of the targets of the EU Biodiversity Strategy connected to this report

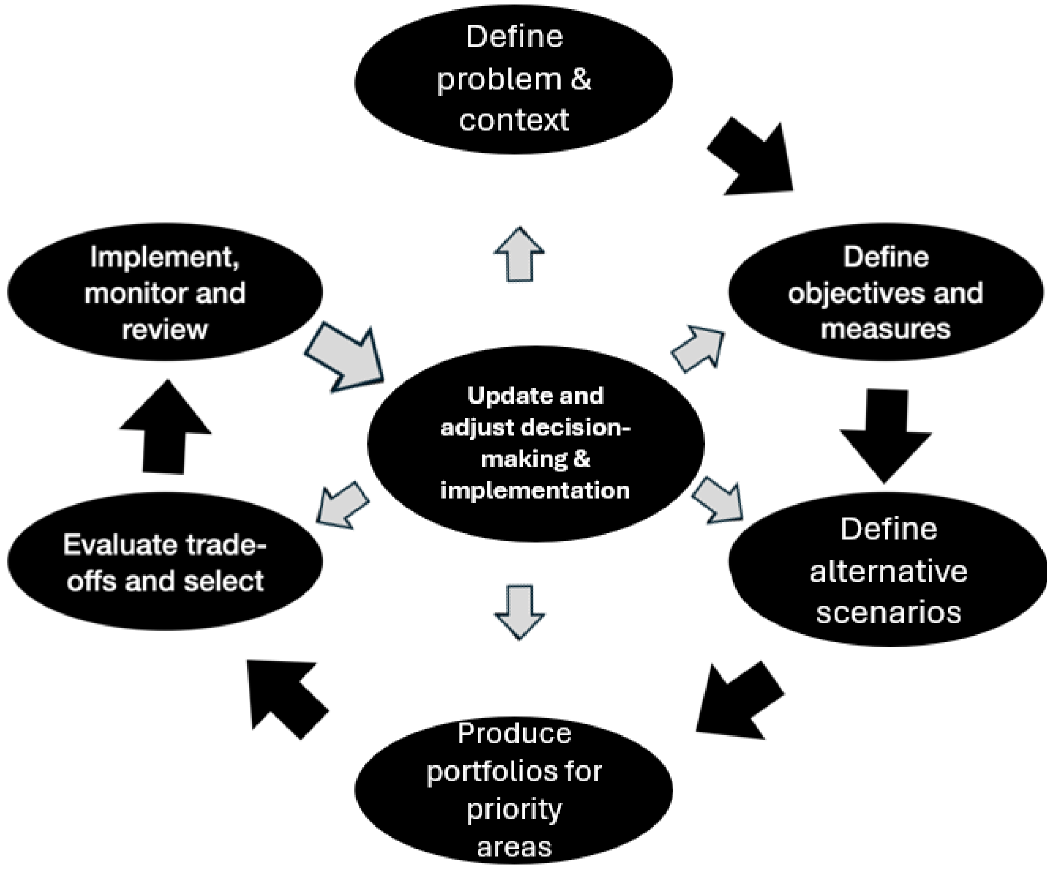
Target 1: Legally protect a minimum of 30% of the EU land area and a minimum of 30% of the EU sea area, and integrate ecological corridors, as part of a true Trans-European Nature Network.
Target 2: Strictly protect at least a third of the EU's protected areas, including all remaining EU primary and old-growth forests.
Target 4: Habitats & species show no deterioration in conservation trends and status; at least 30% reach favourable conservation status or show a positive trend.
Target 5: The decline of pollinators is reversed.

1.3. The importance of a transparent and rigorous framework for setting conservation priorities

Achieving biodiversity conservation goals under global and EU strategies and policies in a densely populated continent like Europe is inherently challenging. In fact, domestic and foreign demand for food, feed, timber and other natural resources from Europe is expected to increase, as well as infrastructure development, and this is at odds with expanding protected areas to conserve and restore important areas for biodiversity across Europe (Visconti et al. 2024). Therefore, developing spatial plans that integrate competing land-use objectives is key for avoiding societal conflict and increasing the likelihood that the implementation of conservation plans not only goes ahead but is also met with the high rates of compliance and acceptance needed to make it work. Integrated spatial planning is not only a scientific discipline but has been applied successfully in many applications in a variety of contexts to deliver benefits for biodiversity through marine or terrestrial protected area planning, or reduce negative impacts during development (Kremen et al., 2008; Virtanen et al., 2018; Whitehead, Kujala, & Wintle, 2017).

The scientific discipline of decision science provides evidence of the usefulness of a clear process with key components when seeking solutions to complex problems (Hammond et al. 2002; Gregory et al. 2012). Knowledge of specific criteria that should be addressed in each decision-making phase due to their importance in decision-making equips decision-makers with a transparent plan to navigate complex problem contexts (Figure 1.1).

Figure 1.1 Schematic diagram of individual steps within decision-making processes, adapted for site selection for conservation in systematic conservation planning, starting with the clarification of the decision context, adapted from Gregory et al., 2012.



Note: In the original structured decision-making diagram, step 3 is called "defining alternative actions" and step 4 "estimating consequences". The circle can also be re-entered for iterative decisions with new insights gathered from monitoring after implementation, for example in Adaptive Management contexts.

Neglecting different steps during the decision-making process can lead to unintended consequences, and the risk of failure increases (Game et al. 2013; Bode et al. 2015; Renwick et al. 2015; Devillers et al. 2015; Hervé et al. 2016). For example, the lack of meaningful objectives (Bond et al. 2008; Game et al. 2013), lack of a theory of change that links actions to threats (Kuempel et al. 2019), not acknowledging constraints such as costs or feasibility (Symes et al. 2016), or lacking an evaluation of uncertainty (Mazor et al. 2014; Sutton & Armsworth 2014; Larson et al. 2016; Runge et al. 2016) have been found to lead to suboptimal or counter-productive decision outcomes.

The individual steps in a structured decision-making process usually cover the distinct thematic sections of scoping the decision context, developing clear objectives and related metrics, identifying possible alternative solutions, and estimating consequences for each possible solution based on the developed metrics, followed by an assessment of trade-offs and selection of the preferred solution.

These steps are presented sequentially in the following sections, but they are strongly interlinked and these feedback loops may require iterating a given step multiple times.

It is important to note that decision support frameworks and tools, as well as modelling and scientific data, can only support decision-makers in identifying their preferences and understanding the implications of different options but cannot take the burden of making the decision from them. Applied examples of protected area planning always include close collaboration with decision-makers and stakeholders (Lewis et al. 2003; Fernandes et al. 2005; Lehtomäki et al. 2009; Bignoli et al. 2016; Jumin et al. 2018). However, sound decisions can only be made when decision-makers have access to the most important values and motivations that underpin the decisions and provide the motivation to act (Keeney 1992). Even though this seems simple, understanding core values and translating them into useful objectives and metrics is an often overlooked and undervalued part of decision-making despite being a key driver of any prioritisation process (Bond et al. 2008). The following sections provide more details on each step's key components.

1.3.1. Defining the conservation problem and the context

The first step consists of reviewing all relevant policy goals, the key actors, the decision-making process involved in addressing these goals and the information needs of these actors. Below we provide the context for the two protected area targets of the EU.

By the end of 2021, terrestrial protected areas covered 26% of EU land, with 18.6% of the EU land area designated as Natura 2000 sites and 7.4% as other national designations therefore falling short of the 30% protection target in the EU Biodiversity Strategy (EEA 2023). All Natura 2000 sites should satisfy the three criteria necessary to contribute to Target 1, namely:

- the area is covered by a national or international legislative or administrative act or a contractual arrangement aiming to achieve long-term conservation outcomes;
- conservation objectives and measures are in place; and
- effective management and monitoring of the biodiversity in the area is in place.

Unfortunately, despite being a requirement, a recent assessment uncovered that many protected area management plans are insufficient, with many protected areas lacking objectives and measures, and ongoing challenges to implement management and monitoring (Naumann et al. 2021). All Natura 2000 areas are expected to count towards the 30%, even though not all of them are effectively managed (Naumann et al. 2021), because it is expected that these shortcomings will be addressed for these sites to continue being considered in the Union List. However, not all Nationally designated areas and Other Effective Area-Based Conservation measures (OECMs) satisfy these conditions (European Commission 2022). Member States are required to identify which designation types and individual OECMs satisfy these conditions and should be counted towards addressing EU Biodiversity Strategy Target 1 in their pledges and in upcoming protected area reporting. At the time of writing, only a few pledges are available, and therefore, the baseline level of contribution towards 30% remains uncertain. In this report we explore alternative prioritisations to evaluate the implications of considering different sets of protected areas as a baseline for the 30% (section 2.4.2).

Strictly protected areas are generally understood as areas where biodiversity conservation objectives take absolute priority over other socio-economic objectives (European Commission 2022). Globally, strictly protected areas are typically understood as IUCN protected area management categories I and II, where human activity is limited, and extractive activities are prohibited, often in large areas where natural processes dominate (Cazzolla Gatti et al. 2023). Specific guidance has been provided to the European Commission for the identification of additional strictly protected areas (European Commission 2022). The document states that strictly protected areas are expected to include all identified primary and old-growth forest and should include areas ''*designated to conserve and/or restore the integrity of biodiversity-rich natural areas with their underlying ecological structure and supporting natural environmental processes. Natural processes are therefore left essentially undisturbed*''. However, strictly protected areas may also exceptionally include active management in the cases where there are habitats and species present in a location that depend on specific management actions (e.g. low intensity grazing or fire management). Irrespective of the specific purpose and definition of strict protection, human activities are generally more regulated in strictly protected areas than elsewhere which implies that there are socio-economic costs involved in designating protected areas, especially strictly protected ones. Evidence from protected area planning shows that cost estimates can be quite impactful in driving conservation priorities (Adams 2024), making it necessary to evaluate the trade-offs between minimising costs and maximising biodiversity benefits from strict protection (section 2.4.3).

Previous work has demonstrated that a prioritisation on a European scale leads to better outcomes for biodiversity (Kukkala et al. 2016). Yet, this needs to be balanced with a fair sharing of conservation areas across administrative boundaries. The Kunming-Montreal Global Biodiversity Framework has set the target of protecting 30% of land and sea areas globally and some countries may need to designate more than 30% nationally (Woodley et al. 2022; Shen et al. 2023). In fact, several EU MS have already designated more than 30% of their terrestrial land as protected areas.

The EU Biodiversity Strategy to 2030 suggests that the 30% should be achieved at the level of biogeographic regions. Meanwhile, some countries are aiming to reach the 30% target on a national scale, in line with the notion of burden sharing, where efforts towards achieving conservation targets (such as the 30%) should be evenly distributed among countries. Choices in how the 30% is to be distributed across geographic regions and countries is likely to have important consequences in terms of the placement of new protected areas and especially in terms of conservation effectiveness for biodiversity (Kukkala et al., 2016). In this report, we investigate this trade-off between burden sharing and biodiversity benefits.

1.3.2. Defining relevant objectives and performance metrics

The second step in conservation planning is to translate policy goals into quantitative objectives, performance metrics, sites that achieve these objectives and asses the performance of alternative protected area configurations. In the EU context, further guidance is available to interpret and operationalize the EU Biodiversity Strategy Protected Area targets.

In this context, protected area extent is not the only, nor the most meaningful indicator of progress towards EU Biodiversity Strategy Target 1. Target 1 stresses the need for the protected area network to be *coherent and resilient*. The European Commission Staff Working Document on Guidance for protected area designations (hereafter EC SWD) highlights the priority for improved coherence: '*The completion of the Natura 2000 network, based on the criteria in Annex III of the Habitats Directive for special areas of* *conservation and on the IBA criteria or similarly robust ornithological criteria for special protection areas under the Birds Directive, should be done first and foremost by addressing the identified gaps in site designations'.* (European Commission 2022)*.* The document further adds that '*It is expected, however, 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'.* Finally, the document highlights the need to protect habitat for wild pollinators, as an important functional group for natural and semi-natural ecosystems.

The concept of coherence as intended in EU nature legislation includes the concept of Ecological Representativeness or Comprehensiveness, that is, the conservation network should address the conservation needs of all habitats and species requiring area-based conservation measures. The EC SWD also highlights the fact that many protected areas are 'too small or disconnected from one another to be effective'. Coherence as intended in EU nature legislation is also related to the concept of Adequacy, that is, sites should be sufficiently large, replicated and well connected ''*to help prevent genetic isolation, allow for species migration, facilitate adaptation to climate change and more generally, maintain and enhance healthy ecosystems* (European Commission 2022).''

The concept of coherence, as well as that of adequacy, are also included in the Marine Strategy Framework Directive, for what concerns Marine Protected Areas and other measures, especially for what concerns coordination (coherence in actions) between MSDF (sub)-regions (European Commission 2018).

Comprehensiveness and Adequacy are two key principles widely adopted in conservation planning to describe desirable properties of conservation networks (Kukkala & Moilanen 2013). They are often accompanied by other principles such as resilience and effectiveness of reserve networks, sometimes to form the acronym CARE (Possingham et al. 2006; Sarkar et al. 2006; Kukkala & Moilanen 2013; Agnesi et al. 2017). The specific definition of these principles vary in the literature and their usage is described in Kukkala and Moilanen (2013), below we provide a short definition that we consider most relevant for the achievement of the EU protected area targets.

Comprehensiveness: A comprehensive network of conserved areas is one that includes a portion of every biodiversity feature. More broadly the notion of comprehensiveness in conservation prioritisation implies sampling the full range of biodiversity taking into account composition (e.g. species and genetic diversity), structure (e.g. habitat types), and function (e.g. biotic interactions, recruitment and dispersal processes) (Wilson et al. 2009; Kukkala & Moilanen 2013). Studies have shown that a narrow focus on a subset of species leads to suboptimal outcomes, and instead, comprehensiveness is key to ensure biodiversity recovery across all facets, including more common species that might be population depleted (O'Connor et al. 2021; Virtanen & Moilanen 2023). Including a comprehensive set of taxa is crucial as all species interact with one another and the interactions that sustain them are also at risk (Valiente-Banuet et al. 2015; O'Connor et al. 2024); many non-listed species and habitats could be in urgent need of conservation given ongoing and future climate changes; and previously common species (such as the hedgehog, or farmland birds) are also strongly declining (Rigal et al. 2023).

Adequacy: An adequate network of conserved area is one whose protected areas are sufficiently large, intact, connected and well replicated to ensure the long-term survival and evolutionary potential of the species for which it is designated, that captures significant ecological variations of the habitat/species as well as supporting the structure and function of habitats for which those protected areas are designated.

This definition is a small adaption from Kukkala and Moilanen (2013) to take into consideration requirements from the Habitats Directive that the natural ecological variation of habitat and species is safeguarded within protected areas (European Commission 2006; DG Environment 2017).

Resilience: The notion of Resilience is often referred to in association to the Trans-European Nature Network, referred to in Target 1 of the EU Biodiversity Strategy definition and accompanying text. Resilience is here defined as an *ecosystem's ability to recover its original structure and function after a perturbation, which could be a natural disturbance or anthropogenic damage such as fire, flooding, droughts, heatwaves, pest invasion, timber harvest, etc.* Studies have suggested that almost two thirds of the species of conservation concern occurring in Natura 2000 areas may be exposed to unsuitable climate conditions within protected areas by 2080 under most scenarios of projected climate change (Araújo et al. 2011). As climate change is expected to intensify, it is critical to strategically place new protected areas in a way that accounts for the projected effects of climate change on the biogeography of species and habitats, so that protected area networks may effectively conserve biodiversity both in the present and future climates (Kujala et al. 2013; Fordham et al. 2013; Triviño et al. 2018).

Efficiency: Efficiency in conservation can be understood as maximizing biodiversity representation or benefits within constrained resources, such as limited land area, or by limiting socio-economic costs of conservation. Well-placed and managed protected areas generate conservation benefits as well as societal benefits (Waldron et al. 2020), but also incur costs, in particular opportunity costs, by limiting certain human activities such as intensive agriculture, forestry, mining and infrastructure development (Carwardine et al. 2008). Therefore, selecting putative areas for protection has, either explicitly or implicitly the goal of maximising biodiversity benefits for a given socio-economic cost, or minimising the costs of achieving a stated conservation objective. This leads to the concept of efficiency, the attempt to maximise the benefit/cost ratio of a set of priority areas for conservation.

1.3.3. Defining alternative scenario analyses

Often biodiversity strategies include multiple objectives and EU protected area targets are exemplary of this, listing several criteria for designations, including for instance the protection of carbon-rich ecosystems as well as under-protected habitats and species of EU conservation significance. There are therefore multiple spatial configurations of TEN-N possible, depending on the particular emphasis given to specific objectives. These configurations can be realized with the aid of spatial prioritization algorithms (see next section). One advantage of using algorithms is that they allow planners to delineate explicit "rules" that mimic preferences or the relative importance of different objectives, which allows assessing alternative portfolios of conservation areas by making changes to these rules (Beyer et al. 2018).

Additionally, most data and parameters benefit from an exploration of associated uncertainty; scenarios with altered parameters (e.g. representation targets, socio-economic costs, connectivity criteria) or alternative datasets can be useful to explore the magnitude of sensitivity of the exact locations of priority areas to these uncertainties (Langford et al. 2009).

In the context of conservation planning and the TEN-N, alternative portfolios are configurations of the TEN-N that are based on different interpretations of protected area targets for the EU and a different emphasis is given to different sub-targets (e.g. improving the network coherence for species or habitats), especially when not all of them can be realized within the constraint of other land-use needs. In section 2.4, we describe a selection of scenarios that are relevant to address the key questions posed in this report.

1.3.4. Producing portfolios of priority areas for conservation

Once the criteria to set conservation priorities are defined, an analytical procedure to identify them spatially needs to be implemented.

Over the years, several scoring approaches have been developed that rank individual candidate sites based on a set of criteria, typically added or multiplied (Butchart et al. 2012; Dinerstein et al. 2017, 2020). However, these approaches rely on the aggregate metrics of species or ecosystem richness, rarity or endemism, which risks overlooking many areas of importance to biodiversity that are irreplaceable, complementary, and home to under-protected species or habitats (Pressey & Nicholls 1989; Justus & Sarkar 2002; Cowling et al. 2003; Game et al. 2013; Ribeiro et al. 2017). Complementarity-based algorithms for area-based conservation prioritization have been independently developed since the 90s of the last century (Justus & Sarkar 2002; Pressey 2002) to address the limits of scoring-based methods for conservation prioritization. Complementarity *measures the extent to which an area, or set of areas, contributes to protecting under protected biodiversity features (e.g. habitats and species) to an existing area or set of areas* (Margules & Pressey 2000). The usage of complementarity has since been aided by several standalone software and packages in commonly used programming languages (Moilanen et al. 2009b; Hanson et al. 2019; Silvestro et al. 2022).

Many protected area expansion plans have been aided by decision support software for conservation planning. Priority areas identified using Zonation software were used for expanding the protection of forests on state-owned land in Finland (Lehtomäki et al. 2009). In the marine realm, priority areas identified by Virtanen et al. (2018) were incorporated into the Finnish Maritime Spatial Plan which guides sea use planning and development of new infrastructure. Outside of Europe, different SCP software informed the zoning of the Great Barrier Reef Marine Park in Australia (Great Barrier Reef Marine Park Authority 2004; Fernandes et al. 2005); the upgrade of protected areas to IUCN I & II in Australia (Whitehead et al. 2017); the designation of new protected areas in Madagascar (Kremen et al. 2008); the expansion of the Mongolian Protected Area Network (Mongolian government & TNC 2013); the additional designation of protected areas in Maputaland, a biodiversity hotspot in Africa (Smith et al. 2008); and zoning in a marine protected area in Malaysia (Jumin et al. 2018).

These decision-supporting software programs not only indicate which subsets of all potential candidate sites for protection satisfy the CARE criteria, they also provide some indices of importance for each candidate site. One common index is irreplaceability, which measures how essential is the protection of a given candidate site for achieving a set of conservation targets. An irreplaceability of 1 (the maximum value) means that no other site could replace that site in achieving conservation targets (Ferrier et al. 2000). This index has been used for example in a participatory and interactive process to identify forest stands to be protected and those where timber extraction was allowed in New South Wales (Ferrier et al. 2000). Other indices have been produced that provide similar rankings, such as selection frequency (Ball et al. 2009), and replacement costs (Moilanen et al. 2009a).

The choice of the algorithm and the software depends on the user needs and we refer to other literature for more guidance on this choice (Ferrier & Wintle 2009; Moilanen et al. 2009b). In this study we choose to use an integer programming algorithm in R (see methods), due to its versatility, that allowed to mimic the real-world conservation goals as closely as possible, and its speed, which facilitated the usage of as many biodiversity features as relevant and needed, the production of a sufficient number of spatial configurations (one for each scenario analysis), as well as keeping a sufficiently fine spatial resolution of the analyses.

1.3.5. Exploring solutions and trade-offs

Once the different configurations of protected area networks have been produced, each reflecting alternative criteria for priority setting, quantitative benefits and costs based on performance metrics (see 1.3.2) can be extracted for each configuration and their performance compared. This process typically includes multiple iterations that involve planners and all relevant decision makers to reduce the number of alternative configurations based on their expected benefits and costs (see also section 4.3 for further detail). These iterations can also involve re-analyses to refine the spatial priorities, based on better data and manual corrections, reflecting for example local information on the feasibility of protection due to ecological condition and socio-economic factors (Pressey et al. 2013). The process can continue until only one or very few configurations are retained, and these are used to produce recommendations, e.g. for legal designations.

National and EU-wide priorities are likely to differ due to different sources or quality of the biodiversity data (e.g. using national atlases based on systematic surveys, rather than continent-wide expert-based ranges or modelled distributions) but also due to different goals, such as focus on nationally threatened habitats and species and accounting for the national socio-economic context (Kukkala et al. 2016). Therefore, there are likely to be compromises to be made between achieving national and EU-wide objectives when spatial priorities do not align. This is one of the examples of trade-offs that are common to conservation decision-making, given scarce resources and sometimes mutually exclusive objectives. The explicit exploration of these trade-offs with the aid of decision-support tools and scenario building processes is a necessary step to be able to navigate them and find acceptable compromises. In this report, we explore some trade-offs documented in spatial prioritization conducted elsewhere that we expect to apply to the implementation of the EU Biodiversity Strategy Targets 1 and 2:

- Focus on achieving network coherence at the EU level without limits to the maximum amount of protection of any country *versus* sharing the burden of protection equally across countries.
- Focus on maximizing the baseline level of protection through considering all nationally designated areas as contributing towards the 30% protection target *versus* focusing on network coherence, thereby counting only Natura 2000 sites and selected protected areas that are most complementary to them.
- Focussing on ecologically coherent areas *versus* areas of higher socio-economic feasibility (e.g. lower opportunity costs for agriculture and forestry).

This is a non-exhaustive list of trade-offs that are faced by authorities charged with identifying and designating protected areas in Europe, that helps in illustrating the process of applying structured decision processes aided by decision support tools for area-based conservation.

1.4. From the EU strategy to National implementation

In the context of the TEN-N, both the planning and implementation of new protected areas are distributed across several national and sub-national government agencies, and the level of coordination is limited, especially at the international level, with the exceptions of Sites of Community Importance (SCI) which are part of the Natura 2000 network. For SCIs, the Habitats Directive establishes a process of selection by Member States of proposed sites, to be reviewed by the European Commission for what concerns their coherence following criteria established in Annex 3 of the Habitats Directive. The list of proposed sites can be reviewed at this stage and the process iterated until adoption by the Commission, and designation by the MS as a Special Area of Conservation (SAC).

As established earlier, the TEN-N will include more than SACs, and the coherence of the network goes beyond the criteria established in Annex 3 of the HD. A voluntary pledging process and review of the proposed national approaches towards achieving Target 1 and 2 of the EU Biodiversity Strategy is ongoing to favour coordination at biogeographical level and ensure that future designations increase the coherence and resilience of the network.

It is hoped that this report can illustrate how EU Member States and the European Commission can make use of EU-wide TEN-N scenarios such as those proposed here, to enable an iterative process of identification and designations of protected areas of community importance. A comparison of EU-wide priorities and national priorities provides insights into the coherence of national spatially explicit strategies for future designations, highlighting which unprotected regions of pan-European importance could be included into national strategies and action plans for future designations. This process can also help revising EU-wide analyses, for instance with more recent and higher quality national biodiversity data when they exist, or by excluding areas where protection is deemed unfeasible or unnecessary based on local data and knowledge.

2. Materials and methods

2.1 Problem formulation

Here, we identify ways in which strategic placement of additional protected areas, including one third strictly protected (Targets 1 and 2 of the EU Biodiversity Strategy) can best contribute to the recovery of habitat and species of EU conservation concern as stated in Target 4 of the EU Biodiversity Strategy: "*Habitats and species show no deterioration in conservation trends and status; and at least 30% reach favourable conservation status or at least show a positive trend*" and promote the recovery of pollinator species as stated in Target 5.

We translate this problem into a mathematical formulation that can be solved with the aid of optimisation algorithms that addresses the principles of coherence and efficiency via use of complementarity. We create and solve the conservation planning problem as a linear programming problem using the 'prioritizr' R-package (Hanson et al. 2019). We used the Gurobi solver for fast identification of the optimal solution (Gurobi Optimization 2024).

The formulas below include several parameters that are adapted to explore the implication of different prioritisation scenarios. Parameters and variables are described in Table 2.1.

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

subject to:

$$\sum_{p}^{P}\sum_{p}^{P} x_{p,z}c_{p,z} \le B_z \quad (2)$$

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

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

$$d_{p,z} \le x_{p,z} \le 1 \quad (5)$$

Equation 1 is called the objective function, which states the mathematical goal to be achieved. In this case, it is to minimise the overall distance between a stated protection target for each biodiversity feature (habitat or species) t_f and the protection achieved by a given protected area configuration $r_{f,p}k_{f,z}x_{p,z}$. This distance is termed *target shortfall* in 'prioritzr'. This function mimics Target 4 of the EU Biodiversity Strategy, as it aims to achieve a sufficient amount of protection to each habitat and species of EU conservation concern to bring them to a desirable conservation state, *e.g.* a non-threatened or favourable conservation status.

The quantity that is minimised in equation 1 (target shortfall), is the result of the summation across all management zones *z* which in these analyses are strictly protected areas and other protected areas, as well as all biodiversity features (habitats and species) and all candidate sites for protection (a uniform grid of 10x10 km^2). Because not all species and habitat area targets might be met within 30% of EU land area, and some trade-offs will be necessary, a weighting parameter is included in equation 1, that allows to give higher priority to achieve protection targets to habitats and species considered of higher importance, such as those in an unfavourable conservation status according to Habitats Directive reporting, or listed as threatened with extinction by the IUCN Red List. Testing alternative weighting schemes is something amenable to sensitivity analyses through different scenarios (see 1.3.3) but was not pursued in this study as it is not related to the questions this study wishes to address.

Equation 2 states that the total amount of area that is included in each management zone (strict protection or any protection), should not exceed a given value *B.* These values are set to 10% of EU land area for strict protection, and 30% for any protected area. Equation 2 is also used to explore the implications of different burden sharing between countries, that is, contrasting scenarios in which every country protects 30% of their land, with a scenario where priority areas are selected where they most contribute towards achieving species and habitat protection targets even if this meant exceeding a 30% protected area coverage threshold in a given country. A third option explored is to achieve 30% protected area coverage for each bioregion, with unequal burden-sharing among countries.

Equation 3, states that for each 10x10 km^2 planning unit p, the fraction that is assigned to a given zone z is denoted as $x_{p,z}$ and varies continuously between 0 and 1.

Equation 4 states that not all zones contribute equally to achieving protection targets for all habitats and species. For example, species that are particularly sensitive to disturbance during the breeding season may require strict protection regimes, including restrictions to access, in this case the value $k_{f,z}$ would be 0 for conventional protection, and 1 for strict protection.

Equation 5 states that as well as being bounded between 0 and 1, the fraction assigned to a given management zone (strict protection or any protection) should be at least the fraction covered by existing designations. We also include all remaining old-growth and primary forests in Europe alongside existing protected areas, in line with EU policy guidance indicating that they should be strictly protected. In the prioritisation scenarios aiming to achieve the 30% protected area coverage in Europe expanding on Natura 2000 sites, we ensure that all Natura 2000 sites are always protected, hence the minimum value of x in a planning unit is the fraction that is already covered by the Natura 2000 network. We also test the implication of building a network up to 30% when including both Natura 2000 sites and national designations from the Nationally designated areas (NatDa). Similarly, for the 10%, we ensure that all protected areas falling under IUCN protected area management categories I and II are always protected. Equation 5 also provides the geographic scope of the analysis, the European Union, and provide the flexibility to introduce country-specific expansion scenarios, for instance by considering protected area pledges. This was not done in this specific report, but it would be an important step of the iterative process referred to in section 1.3.5.

Table 2.1 Parameters used in the analysis and their purpose

Parameter Name	Symbol	Purpose
Planning unit	$p \in P$	Identifies the specific planning unit in what the action is applied.
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)
Area	A	The amount of area of a current or future landcover state.
Target	T	A specific 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*
Budget	B	The total amount that can be spent on a given management zone, in this analysis the budget is set in km^2 and is 10% of EU land area for the strict protection management zone, and 30% for all protected areas.
Cost	c	A specific cost specified for a given planning unit *p* and zone *z*. In this case the cost is km^2.
Contribution	k	The contribution $k_{z,f}$ is a zone *z* specific parameter that defines the contribution that zone *z* has to achieving the target for a given feature *f*
Decision	x	A constant stating the total share of the planning *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*
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).

2.2 Data sources

Study area and resolution. The study area covered the spatial extent of the European Union (EU). A spatial resolution of 10x10 km^2 was chosen for this analysis, supported by the spatial data for the distributions of habitats and species.

Protected areas. We identify top priorities for the 30% that expand on existing protected areas: Natura 2000 sites (European Commission 2024), and other nationally designated sites (NatDa, European Environment Agency. 2024). In absence of further information on the distribution of strictly protected areas, we use IUCN protected area management categories I and II which are typically considered the baseline for strict protection (Cazzolla Gatti et al. 2023). This assumption will be addressed when EU protected area reporting will include means to distinguish strictly protected areas.

While the European Commission has clarified that some Other Effective area-based Conservation Measures (OECM) could contribute to achieving EU protected area targets, most EU countries have not yet identified any OECM and is not clear which of the identified OECM have been recognised by MS as contributing to protected area targets. Therefore, we have chosen not to include the few OECM as existing protected areas.

Species distributions. To address the dimension of comprehensiveness, we include all threatened species and habitats in Europe, as well as other ecosystem of conservation relevance. We consider all species listed in the Annexes of Article 12 of the Birds Directive and Article 17 of the Habitats Directive and species listed in the EU Pollinator Initiative for which sufficient point occurrence data were available to derive robust models of species distribution. We further consider all species listed in the European Red Lists of species, as well as any other native species for which suitable data is available and that might benefit from conservation efforts now or in the future. A total of 1041 species were considered in the analyses. This is in accordance with the comprehensiveness principle of SCP, as well as existing policy guidance suggesting 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) and the identification and protection of Key Pollinator Areas as part of the EU Pollinators Initiative.

We primarily focus on terrestrial biodiversity, however freshwater systems (rivers, lakes, wetlands) are also considered through the inclusion of semi-aquatic species (e.g. amphibians, water birds, otters, beavers, desmans). The distribution of species was estimated using an integrated species distribution modelling (iSDM) approach where different best-available data sources (occurrence, preference, expert information) are integrated into one joint prediction (Visconti et al. 2024). We estimated the potential distribution of the species through an ensemble modelling approach (stacked SDM) using state-of-the-art machine learning and Bayesian algorithms that complement each other's strengths, using the integrated modelling framework ibis.iSDM coded for R (Jung, 2022).

Using SDM data over EEA estimates of species distributions provides several advantages. SDM data includes EEA (Article 12 and Article 17) reported data on species distributions as input, but reduces commission errors (i.e. false presences), ensures consistency and a standardised approach across all species, leading to more accurate and consistent estimates of species presence/absence. The integrated SDM also reduce reliance on potentially biased datasets and provide a more comprehensive and objective assessment of species distributions. In particular SDM eliminate the artificial boundaries of national reporting, providing more consistent and comparable estimates across countries. Furthermore, these SDMs include threatened species from the IUCN red list that are not listed in the nature directives and for which therefore there are no distribution data from the EEA. While SDM provide more robust and comprehensive species distribution estimates, they still carry inherent uncertainties due to data limitations, model assumptions, and choice of environmental variables, which are typically addressed through confidence intervals or ensemble models. In these analyses we produced an ensemble of several statistical and machine learning models of species distribution, and we produced a weighted mean ensemble of all model predictions where the weight was based on model accuracy, details are available in (Visconti et al. 2024).

Habitats distributions. For habitat distributions, we extracted the spatial distributions of all non-marine habitats listed in Annex I of the Habitats Directive from reported data in Article 17, at a resolution of 10x10 km². We then created an EU-wide raster for every habitat type by merging national reporting data for each habitat. A total of 222 habitats were included in the analyses.

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 should be placed under strict protection. We use the dataset on European old growth and primary forests from (Sabatini et al., 2018), as well as spatial data on carbon sequestration (Schulp et al., 2008). We ensure that all remaining old-growth and primary forests are included in the solution alongside existing strictly protected areas by design (equation 5).

Accounting for ecoregional diversity. For species and habitats that are not assessed as threatened or U1/U2 at European level, but for which local ranges (national, biogeographic, or a combination of both) are assessed as nationally threatened or locally U1/U2, simply including the entire species or habitat 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 an unfavourable conservation status (U1 and U2) specifically in a biogeographic region or Member State according to Article 17 reporting data. National red lists were extracted from https://archive.nationalredlist.org/. In line with the principle of adequacy, we include them as individual features, and weight them by threat status and geographic endemism (see section on weights), in addition to including the whole distributional range of each species and habitats. In total, this led to an additional 1451 features: 1373 species subpopulations, and 78 habitats regional subranges that are assessed as threatened only nationally or regionally.

Socio-economic costs. To address the aspect of balancing conservation needs with competing socio-economic objectives, we include information on the consequences of designating areas for strict protection in terms of the revenue that is foregone if an area was set-aside for strict protection as opposed to be managed for the most profitable extractive or productive activities, including agriculture, forestry or infrastructure development. These costs are used to explore the implication of avoiding placing strictly protected areas in location of high economic interests. We extracted opportunity costs mapped for Europe from Spencer et al. (2024).

2.3 Feature weights and targets

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). To develop specific metrics that define adequate protection for the individual species and habitats, we set individual weights and targets based on relevant ecological criteria.

Conservation status. The EU Biodiversity Strategy aims to ensure that habitats and species show no deterioration in Conservation status, and that at least 30% reach a favourable conservation status or show positive trends. In line with this, we assign higher weights (Table 2.1 and Equation 1 in section 2.1) to threatened species and ecosystems (Pouzols et al. 2014; Jung et al. 2021). As established before, we consider also pollinator species and threatened species and habitats that are not in the Annexes of the Nature Directives (i.e. the Birds and Habitats Directives), following guidance from the Commission (European Commission 2022) and complying with the principle of comprehensiveness (Pouzols et al. 2014; Jung et al. 2021).

We define a weight for each threatened species or habitat based on their Article 17 assessment in the reporting period 2013-2018 and their Red List status. We associated an assessment as Critically endangered (CR) or bad conservation status (U2) with a weight of 8, Endangered (EN) a weight of 6; Vulnerable (VU) or in an unfavourable 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 (least concern and favourable conservation status) were given a weight of 1. We used the European Red List of Ecosystems for the 222 habitats for which we used the full distribution, as well as the 78 habitat features assessed as locally threatened. We used a crosswalk between the Red List of Ecosystems Classification and the Habitats Classification in Article 17 of the Habitats Directive to retrieve information on the habitats threatened with risk of collapse in Europe. For species, we used all available IUCN Red List of Species assessments at the Global, European and national levels.

For the 1041 species for which we used the full distributions, we obtained the Red List weighting by averaging the value across European and Global Red Lists. For the 1373 threatened species subpopulations (portion of the distribution within a country and/or bioregions where an EU assessment or National Red List indicate a locally threatened status), the Red List weighting was the average value across all three Red List assessments: National Red Lists, European Red List and Global IUCN Red List. For species and habitats in the Habitats Directive, we used the overall Article 17 assessment at the biogeographic level (since the assessment is not reported at the European level); therefore, for species and habitats occurring in more than one biogeographical region, we used the average value associated with the assessment. The final weight assigned to each habitat or species feature was the average value across all relevant Red List and Article 17 assessments.

Biogeographic endemism. We considered the biogeographic endemicity of the threatened subpopulations of species and habitats to assign a higher weight to (near-)endemic species and habitats. This is because, when the distribution of species and habitats is split by bioregion and country, it introduces the risk of attributing equal importance to a species that is endemic of a bioregion or country, and a single subpopulation of a species that is otherwise widespread across multiple bioregions and countries. To correct for this, we add a weight that is equal to the endemism of the species (or habitat), *i.e.* the proportion of the total (European) range size of the species (or habitat) within the region (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. Finally, to combine both the conservation status and biogeographic endemism in the weights for split distributions of species and habitats, we multiplied the weight reflecting endemism with the conservation status weight. To reflect stakeholder preferences in the setting of weights, we collected stakeholder preferences both by means of a survey addressed to the expert group of the Birds and Habitats Directive (NADEG) representatives in summer 2023, and in person to Member State delegates during the biogeographic seminars in 2023 and 2024. 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, we did not consider any additional criteria for species and habitat weighting besides extinction risk and conservation status.

Feature-specific targets

Targets represent the amount of the spatial distribution of each species or habitat that should as a minimum, be protected. They are an important element of the adequacy of protected area networks, and the coherence of TEN-N, as also reflected in Annex III of the Habitats Directive. In accordance with the European Commission guidelines, for all features that are in an unfavourable status (U1 and U2) and/or listed in the IUCN Red List as threatened with extinction, we assign a target of 100% of their distribution (see section 2.2), in order to prevent any further decline. Similarly, we assign a target of 100% of the distribution for all species or habitats that are threatened according to the IUCN Red List assessment. For the split sub-ranges of species and habitats included because they are assessed as locally threatened, the conservation target is set to 100% of the threatened sub-range size.

For other species (non-threatened and in a favourable status), we use species-specific area targets that reflect the amount of area needed for the species (or ecosystem) to be non-threatened. We formulate the target in order to minimise the extinction risk according to the IUCN Red List criteria A and B2. Building on previous work (Jung et al., 2021; Mogg et al., 2019), we formulate the target as follows, 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 non-threatened habitats, we apply a similar approach as for species, formulating the target in order to minimise the risk of ecosystem collapse, based on the IUCN Red List of Ecosystems criteria (IUCN RLE, 2017). 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 km². Therefore, the area target for habitats is:

$$t_h = \min(max(5{,}000\ km^2, 0.7\ R_h)\,, 10^6)$$

2.4 Scenario variants for the expansion of protected areas

In section 1.3.4, we highlighted the importance of producing alternative protected area configurations to test the implications of different choices. Below, we illustrate the scenarios produced in this study. Several more TEN-N configurations could have been simulated, but the focus here has been on a small number of scenarios which shed light on policy-relevant questions that emerged through interactions of the ETC-BE team with the European Environment Agency, Member States and the European Commission.

2.4.1 Variations in burden sharing for the 30%

To understand the implications of different burden-sharing scenarios among EU Member States and biogeographic regions in achieving the 30% protection targets, we created a set of 3 variant EU-wide prioritisations. In each of these scenario variants, conservation targets for habitats and species need to be achieved across all of the EU, and therefore their full distribution is considered in the analyses. The variants however differed in terms of the maximum area that could be protected within a given country or bioregion. We considered: i) an EU-wide scenario that ensures that the 30% of area under protection is achieved at the level of Member States across the EU (national burden sharing), ii) another that ensures that the 30% is achieved at the level of biogeographic regions across the EU (bioregional burden sharing), iii) and a EU-wide coordination scenario that ignores burden sharing, where the 30% could be allocated anywhere in Europe, such that certain countries and regions may have more, or less, than 30% of protected area coverage.

In the prioritisations implementing burden sharing, we set a maximum area budget per administrative unit (Member States, or bioregions), equal to 30% of protected areas per unit. When the proportion of existing protected areas exceeded the budget (e.g. more than 30% of the Alpine bioregion is covered by protected areas), we set the budget to the current amount (meaning that no new protected areas could be added in the country or bioregion). We used linear constraints in prioritizR to distribute equal shares of conservation across EU Member States and bioregions, respectively.

To evaluate the benefits of an EU-wide optimisation (with or without burden sharing) compared with a scenario where each country would produce their own prioritisation, and therefore aim to achieve species and habitats conservation targets exclusively within their borders, we also performed 27 individual national-level prioritisations, with the same data (cropped for each Member State) and planning criteria as the EU-wide prioritisation (Figure 3.4).

We also created a variant of the 27 national prioritisations which incorporated the geographic endemism of nationally split features as weights (see section on weights) that mimics a situation where each country prioritizes species and habitats for conservation for which they have a higher responsibility: that is, a large fraction of the EU-wide distribution of these biodiversity features lies within the respective country (Figure 3.6).

2.4.2 Variations in protected areas used as a baseline for the 30%

To evaluate the implications of considering different sets of protected areas as a baseline, we run 2 sets of variant prioritisations: one that expands on Natura 2000 sites only (currently covering about 18% of the EU land area); the other that expands on the union of Natura 2000 sites and nationally designated areas (currently covering 26% of the EU land area) (Figure 3.5). To expand on existing protected areas, we include the proportion of each 10x10 km² grid cell that is currently protected, as the lower bound of protection in the analyses, to ensure that all existing protected areas are included as a basis to achieve a coherent network of protected areas (Equation 5). The solution thus complements the existing protected areas, completing remaining gaps in the protected area network.

2.4.3 Variations in feasibility constraints for the 10% strict protection

To analyse the trade-offs in including or excluding socio-economic costs and other feasibility constraints, we created two variant scenarios for strict protection: one scenario that optimised only based on species and habitats distributions without any feasibility constraints; and a second scenario where priority areas for strict protection could only be selected within existing (non-strict) protected areas; and with lower opportunity cost, using spatially explicit cost data from Spencer et al. (2024). The opportunity costs, in euros, are applied as linear penalties in the optimization (see https://prioritizr.net/reference/add_linear_penalties.html for further information). These two prioritisations are otherwise equal in biodiversity data and planning criteria.
We did not apply a burden sharing constraint for strict protection, since EU policy guidance indicates that this is a continent-wide area target (in fact, some countries such as Sweden have already pledged to go beyond the 10% target area for strict protection at national level).

Here our objective was to evaluate the implications of including socio-economic costs, so for simplicity we focused only on one dimension for strict protection: we specifically focused on species (or subpopulations) and habitats that are listed as threatened or in a bad or unfavourable conservation status (U1 and U2), assuming that strict protection aims to prevent the loss of these species and habitats. This objective is one possibility among many and was chosen purely to analyse the sensitivity of the outcome to cost data as a demonstration.

2.5 Analysing the outcomes of prioritisation scenarios

Comparing variant scenarios. We compared the variant prioritisation scenarios in terms of (i) *where* the top priority areas fall across EU 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. To summarise the performance of different scenarios in a meaningful way for the 1041 species and 222 habitats (and 1451 regionally threatened species and habitats) considered in the optimisation, we computed the average representation of species and habitats per group of conservation concern (Red List Status, and Article 17 conservation status assessment).

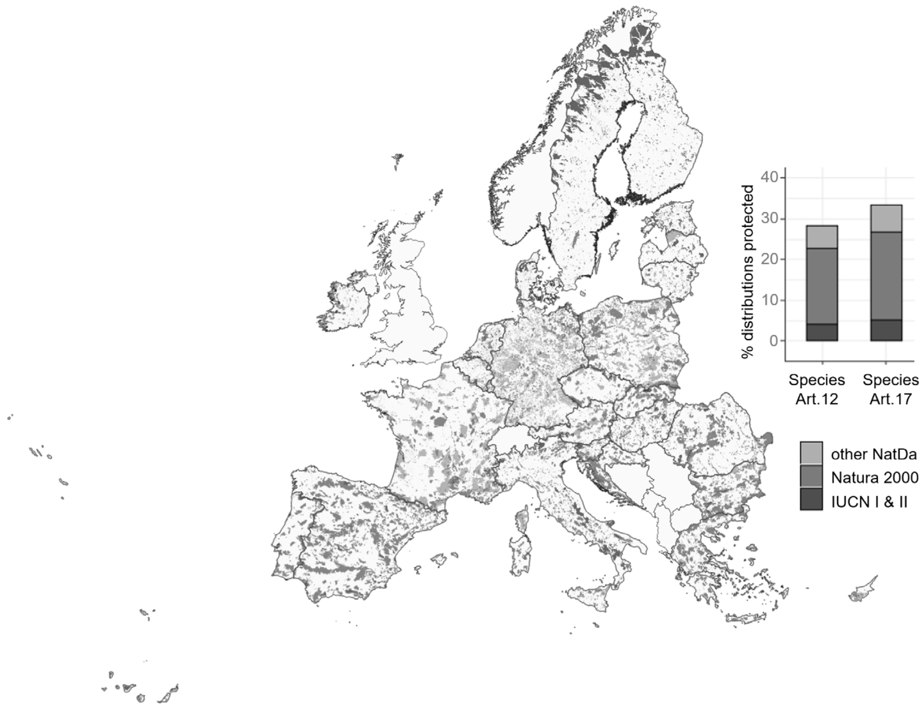
Highlighting valuable nationally designated protected areas. Nationally designated areas that are not Natura 2000 may not all be pledged by countries to count towards the 30%. We can identify which Nationally Designated sites are highly valuable by overlaying them with the top priority areas for the expansion of Natura 2000 areas. We illustrate this with an example scenario (Figure 3.7), noting that it can be done for different prioritisations expanding on Natura 2000.

3. Example results

3.1 Current distribution of protected areas and conservation gaps

Protected areas cover 26% of the EU land area. 19% of EU land is covered by Natura 2000 sites, and 3% by strictly protected areas (IUCN management categories I and II which we assumed to be the baseline for strictly protected areas) (Figure 3.1).

Figure 3.1 Current spatial distribution and conservation gaps of terrestrial protected areas in the EU.

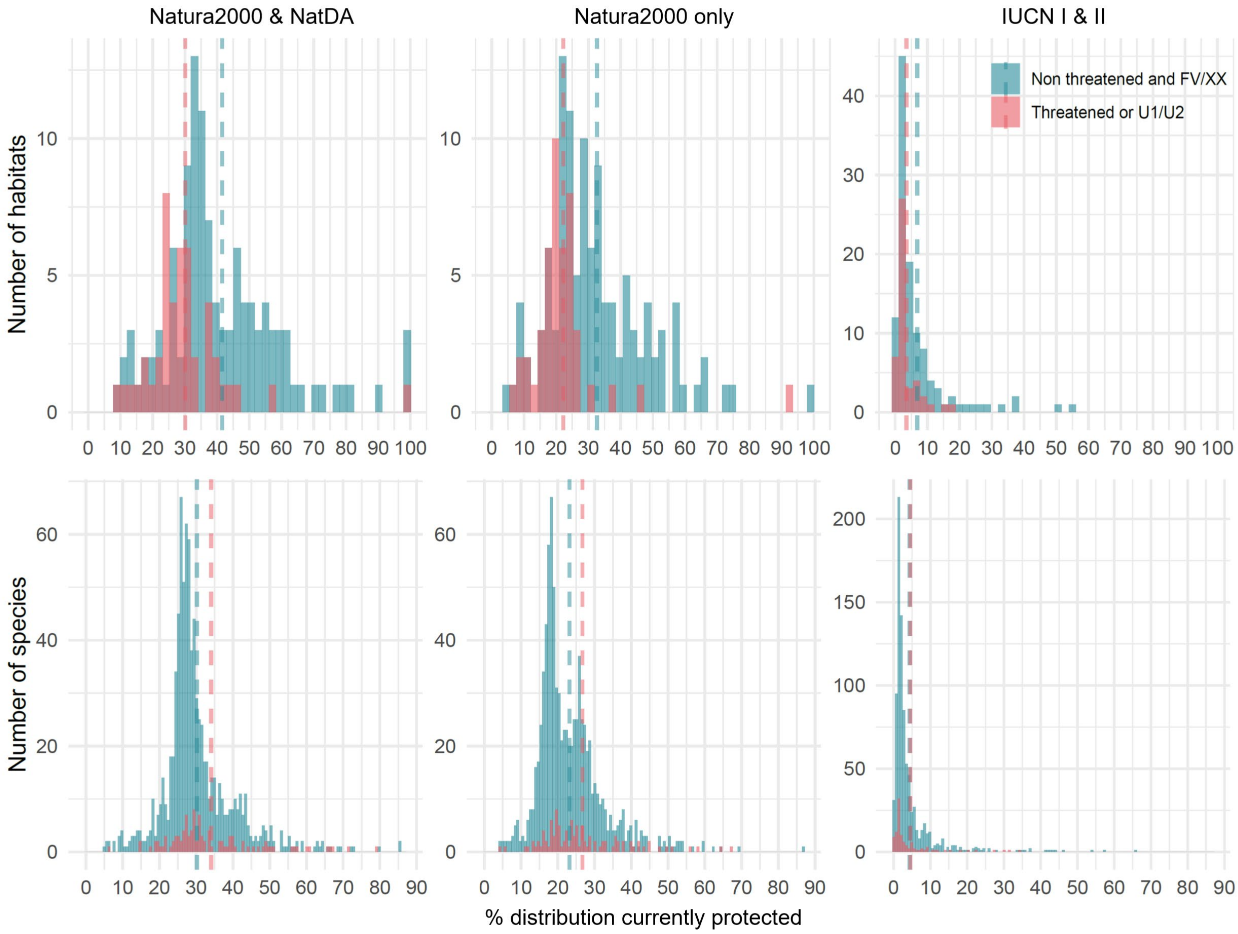


Note: The map shows current protected areas in Europe, across all designations: IUCN I and II, Natura 2000, and other Nationally Designated areas). The bar plot shows the percentage of species distributions in the Nature Directives, that are protected across the three categories of protected areas.

On average, 30% of any given species range is protected by all protected designations and 23% of a range in average, is protected in Natura 2000 areas. Different groups of species show different protection levels: less than 30% of the distributions of bird species listed in Annex I of the Birds Directive are currently protected across all designations, and slightly less than 35% of the distributions of species listed in Annex II of the Habitats Directive. Regarding Article 17 habitats, on average, 37% of their distributions are represented across all protected area designations, and 29% when only considering Natura 2000 sites. This is just an average, and some species and habitats are poorly represented in the network of protected areas within the EU: 19 species[2], and 2 habitats, have less than 10% of their distribution in all protected areas; while 36 species, and 10 habitats, have less than 10% protected in Natura 2000 sites. In fact, habitats that are threatened or in a bad or unfavourable conservation status (U1/U2) tend to be less well represented in protected areas on average, compared with non-threatened habitats (Figure 3.2).

[2] **Note**, that for species we used the potential distribution using Species Distribution Models, (see section 2.2), and therefore it is likely that the actual occupied range is smaller, and the fraction of the range protected is higher than estimated here. For habitats we used Article 17 reports, which may also over-estimate the realized distribution although this data is expected to reflect the best available knowledge on the distribution of these habitats.

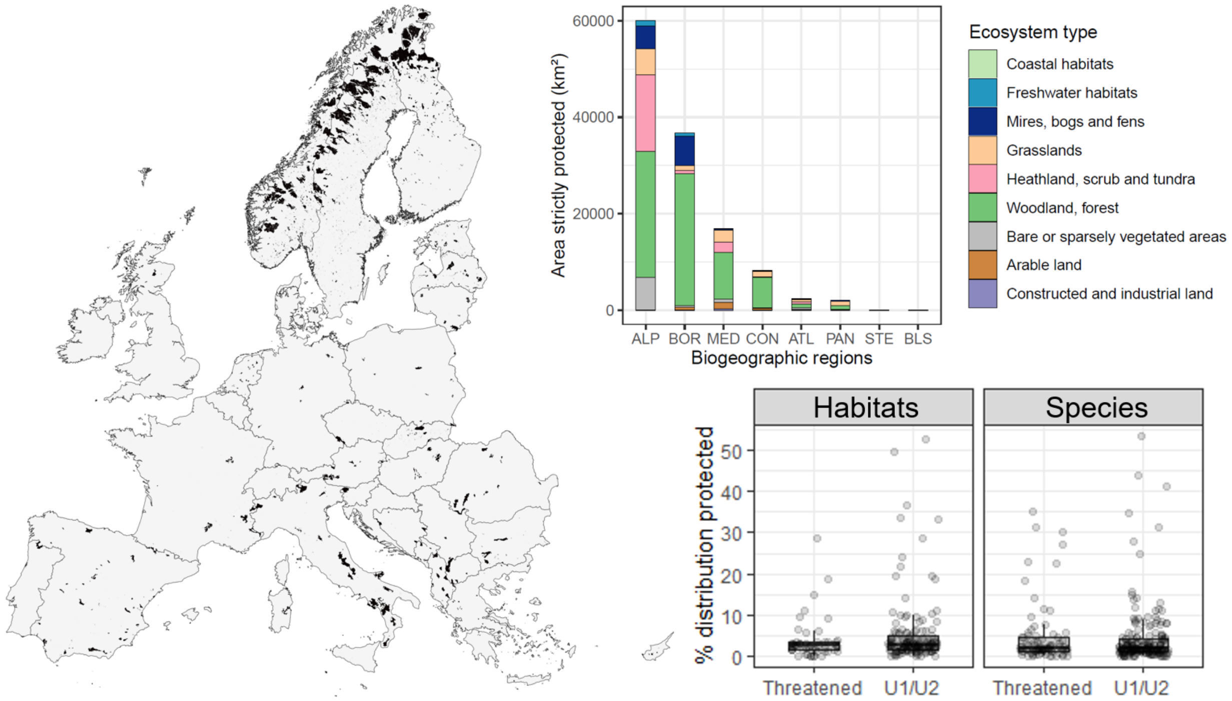
Figure 3.2 Distributions of the gaps in coverage of habitats (top row) and species (bottom row) across the three sets of protected areas in the EU: all protected areas (including Natura 2000 sites and other nationally designated sites), Natura 2000 only, and strictly protected areas (IUCN I & II).



Note: Colours represent the conservation status of species and habitats according to the European Red List assessment and Article 17 reporting: the habitats and species that are assessed as threatened (vulnerable, endangered or critically endangered) in the Red List or in an unfavourable or bad conservation status (U1/U2) in the Article 17 reporting are shown in red; and blue represents all other species and habitats. In each facet, the dashed lines represent the average percentage of distributions protected per group.

If we consider IUCN protected area management categories I and II to be the baseline for strict protection, currently, strictly protected areas cover 3.05% of EU land, and they are predominantly found in the remote and less productive alpine and boreal regions (Figure 3.3). Strictly protected areas primarily consist of forests, followed by heathlands, bogs, and grasslands. Strictly protected areas are not representative of the full variety of EU biodiversity: currently, they protect 2.9% of habitats distributions and 2.0% of species distributions, on average. 157 species, and 24 habitats, have less than 1% of their distribution in strictly protected areas. Threatened or U1/U2 habitats have a lower representation in existing strictly protected areas on average, than non-threatened habitats. While species that are assessed as threatened or U1/U2 tend to be better represented in non-strictly protected areas than non-threatened species, on average, this is not the case for strict protection (Figure 3.2). With many species and habitats still declining, threatened, or in an unfavourable of bad conservation status, there is a need to find priorities for additional protected areas to close conservation gaps, both for the 30% and 10% targets in protected area coverage in Europe.

Figure 3.3 Distribution of strictly protected areas in Europe and current representation of species and habitats.



Note: The map highlights the spatial distribution of strictly protected areas across Europe. The bar plot shows the area coverage in the different biogeographic regions of Europe and their composition in terms of ecosystem types. The boxplot shows the current representation (% of distributions protected) of species and habitats of conservation concern that are found within existing strictly protected areas, illustrating gaps in coverage for species and habitats of conservation concern.

3.2 Implications of different burden-sharing of protected area targets

Our results suggest that EU-wide planning can achieve a higher level of species and habitat representation for the same protected area extent than uncoordinated planning within EU Member States (Figure 3.4 B). This finding is consistent with previous studies (Kukkala et al. 2016) that showed that a EU-wide prioritisation is more efficient for conservation than separate national prioritisations. We found that priority areas designated at the national level, ignoring the distribution of species and habitats outside country borders, tend to cluster around the borders of countries, as highlighted by previous studies (Kukkala et al. 2016) (Figure 3.6, left panel). This is because national prioritisations place a strong focus on species (or habitats) that are nationally rare, even though they may be common elsewhere; and simultaneously neglecting nationally common species that may be near-endemic to that country.

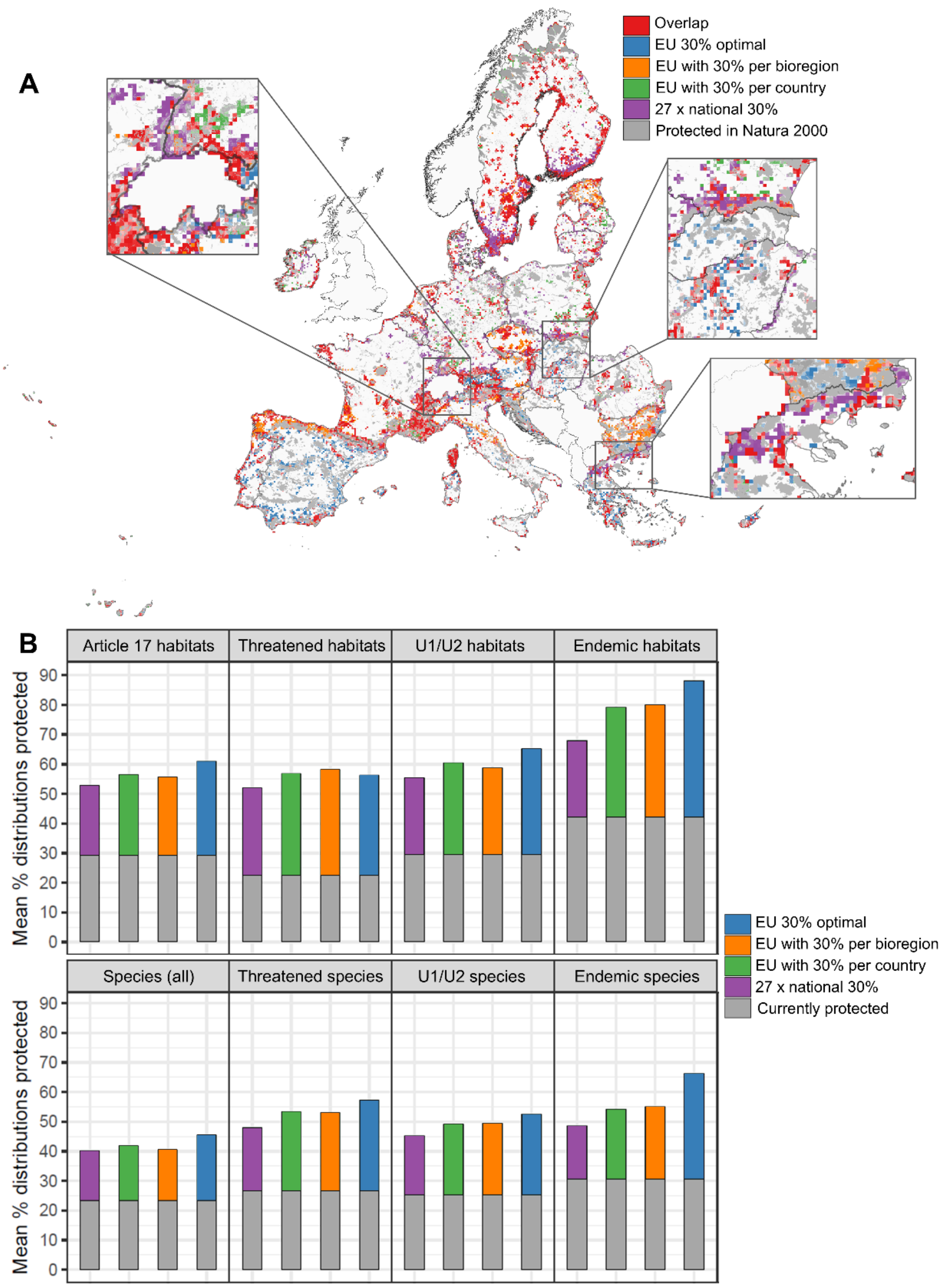
In EU-wide priorities without burden sharing constraints, protecting the priority areas could more than double the amount currently protected for species of policy concern (species listed in the nature directives, listed as threatened by IUCN Red Lists, or assessed with an unfavourable or bad (U1/U2) conservation status), (Figure 3.4). However, the priority areas are unevenly distributed across Member States (for example, more than 30% of the land area in Greece, Cyprus, Croatia, Spain or Portugal are EU-wide priorities when only Natura 2000 sites are considered as baseline towards the 30% target), which raises the question of feasibility.

A prioritisation at the EU level with equal burden sharing of 30% land area within each Member State is almost as efficient as EU-wide priorities without burden sharing constraint (Figure 3.4). This intermediate scenario with burden sharing enables to effectively balance ecological benefits with policy constraints, by maximizing EU-wide coherence of new designations while ensuring equitable sharing of conservation area between Member States. A 30% coverage target for each biogeographic region, as suggested by the European Commission guidance document for Protected Area designations, also improves the coherence of the network, as expressed by the coverage of threatened and endemic habitats (Figure 3.4 B).

The Alpine biogeographic region and Macaronesia emerged as top priorities at EU and national level, due to the high diversity and level of endemism in these regions. The outstanding conservation value of Macaronesia echoes the extraordinary conservation value of many islands in the EU: Cyprus, Corsica, Crete, and the Balearic Islands, among others, stand out as top priority areas for conservation at the EU level (Figure 3.4 A).

By contrast, in the scenario where the 30% was distributed evenly between the different biogeographic regions of Europe, no new sites could be selected in the Alpine, Macaronesian, or Black Sea biogeographic regions (when expanding on Natura 2000 sites), as each of these regions already have more than 30% covered by Natura 2000 protected areas. The fact that no new priorities could be selected in these highly valuable regions may explain the slightly lower performance of this scenario with biogeographical burden sharing for species and habitats overall (compared with the EU-wide scenario with national burden sharing) (Figure 3.4 B). Instead, when the 30% is evenly distributed across Europe's biogeographic regions and only Natura 2000 sites are considered as counting towards protection targets, more priorities were designated in Estonia, Bulgaria and the north coast of the Iberian Peninsula, to address gaps in the coverage of the Boreal, Continental and Atlantic bioregion respectively (Figure 3.4 A and Figure 3.5).

Figure 3.4 (A & B)



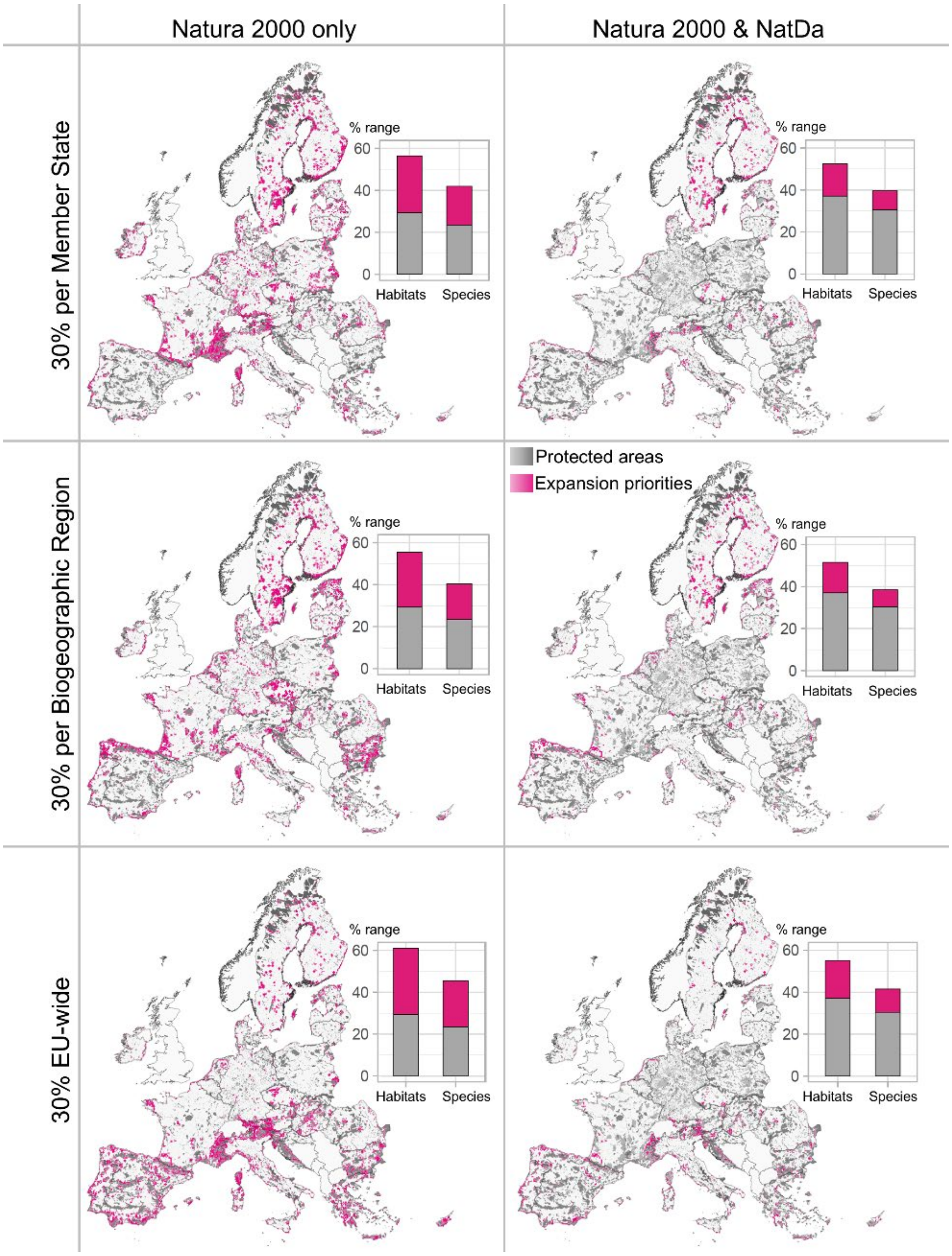
Note: (A) Matches and mismatches between different scenarios expanding on Natura 2000 protected areas (in grey on the map) to reach 30% protected area coverage at the EU level, under different burden sharing scenarios. Expansion priorities differ between all four scenarios. Blue areas show top priorities only in the EU-wide prioritization that ignores burden sharing. Green areas show top priorities only in the EU-wide prioritisation that ensures equal sharing of the 30% between Member States. Purple areas are top priorities identified only at the national level. Orange areas show top priorities only in the EU-wide prioritization that ensures equal sharing of the 30% between biogeographic regions. Red areas show the overlapping priorities between two or more prioritisations. The insets provide a close-up view of three example trans-national border regions. (B) The bar plots show the potential conservation gains in each scenario, for habitats (top row) and species (bottom). The panels from left to right show the different groups of species and habitats of conservation concern. The amount of biodiversity currently protected in Natura 2000 is shown in grey. In purple would be the potential biodiversity gained when planning separately for each of the 27 Member States. In green, the amount of biodiversity that would be gained in the EU-wide prioritisation ensuring 30% of conservation area per Member State. In orange, the amount that would be gained in the EU-wide prioritisation ensuring 30% of conservation area per biogeographic region. In blue, the amount of biodiversity in the optimal EU-wide priorities which does not implement burden sharing constraints.

3.3 Implications of different protected areas baseline

Including nationally designated areas in addition to Natura 2000 led to lower conservation gains overall for species and habitats across all scenarios, because less area was available for selection (4%, instead of 12% of EU land) (Figure 3.5). For instance, optimal priorities expanding on Natura 2000 sites at the EU level would achieve the average representation of 61% of habitats distributions and 45% of species distributions; while expanding on both Natura 2000 sites and nationally designated areas achieve the average representation of 54% of habitats distributions, and 41% of species distributions. This gap in performance between priorities expanding on Natura 2000 only versus all protected area designations suggests that not all nationally designated areas are optimally placed for biodiversity representation and complementarity to Natura 2000 sites.

When the 30% target was applied for each biogeographic region and nationally designated areas were all considered as contributing to it, no new sites could be selected in the Alpine, Black Sea, Continental or Macaronesian biogeographic regions as they already have more than 30% of protected area coverage. Under these scenarios, notable gaps are apparent in the Atlantic and Boreal bioregions, the former were mainly covered in the north coast of the Iberian Peninsula and the Atlantic coast of France, whereas the latter are more distributed across Boreal countries (Figure 3.5).

Figure 3.5 Example maps of priorities for protected area expansion given different criteria.



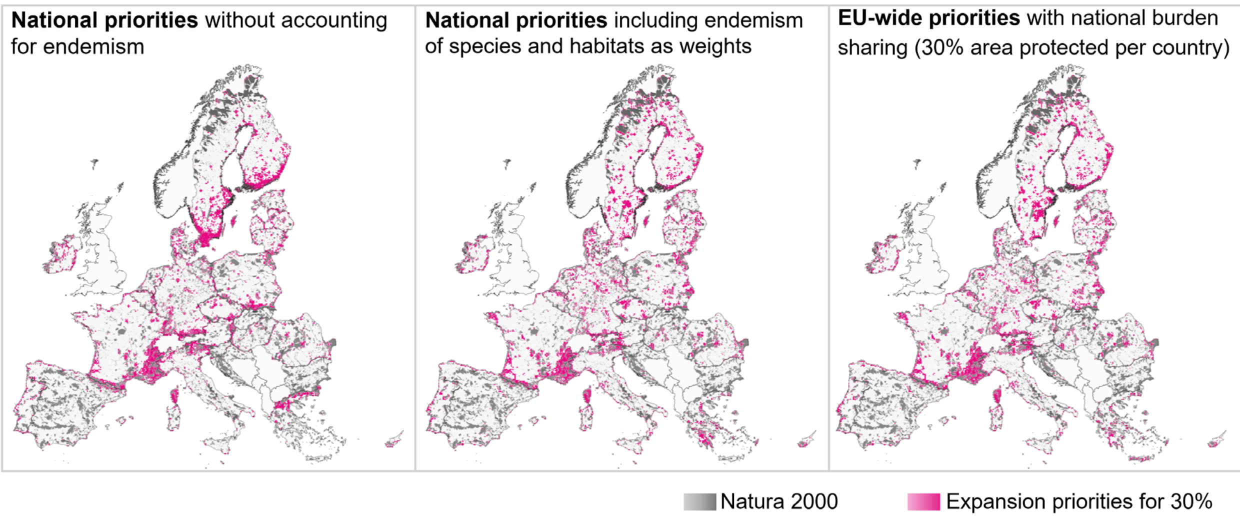
Note: In each map, the priority areas in pink expand on the protected areas in grey. Scenarios vary in the constraints to distribute conservation area equally across EU Member States (top row), biogeographic regions (middle row), or without constraints, i.e., anywhere in Europe (bottom row). Scenarios also vary in the protected areas considered as a starting point: Natura 2000 sites only (left hand column) or all protected areas, including Natura 2000 sites and other Nationally designated areas (NatDa) (right hand column). The maps are purely illustrative, and future TEN-N patterns might differ with better data and more advanced criteria in the planning.

3.4 Improvements in the coherence of National priorities through accounting for geographic endemism

The analysis described above revealed that national-level prioritisations are generally less effective for biodiversity compared to EU-wide approaches (Figure 3.4). However, by adjusting the weights of individual features to account for their level of geographic endemism, the effectiveness of national-level prioritisations can be improved. Specifically, by using a weight calculated as the ratio of the national range size to the total range size of a species (or habitat), the outcomes closely resemble the output of an EU-wide prioritisation (Figure 3.6). This adjustment significantly improves conservation effectiveness by ensuring that species endemic to a particular country receive higher priority, while species that are nationally rare but common elsewhere are weighted less. As a result, resources are more efficiently allocated towards preserving biodiversity at both national and EU levels. This approach improves conservation priorities at the national level by incorporating the responsibility of countries in the conservation of EU-wide biodiversity.

Adjusting weights of species and habitats to account for geographic endemism is a simple and effective way to increase the efficiency and coherence national or regional conservation planning with respect to EU targets.

Figure 3.6 Adjusting the weights for geographic endemism can bring national priorities closer to EU-wide conservation priorities.



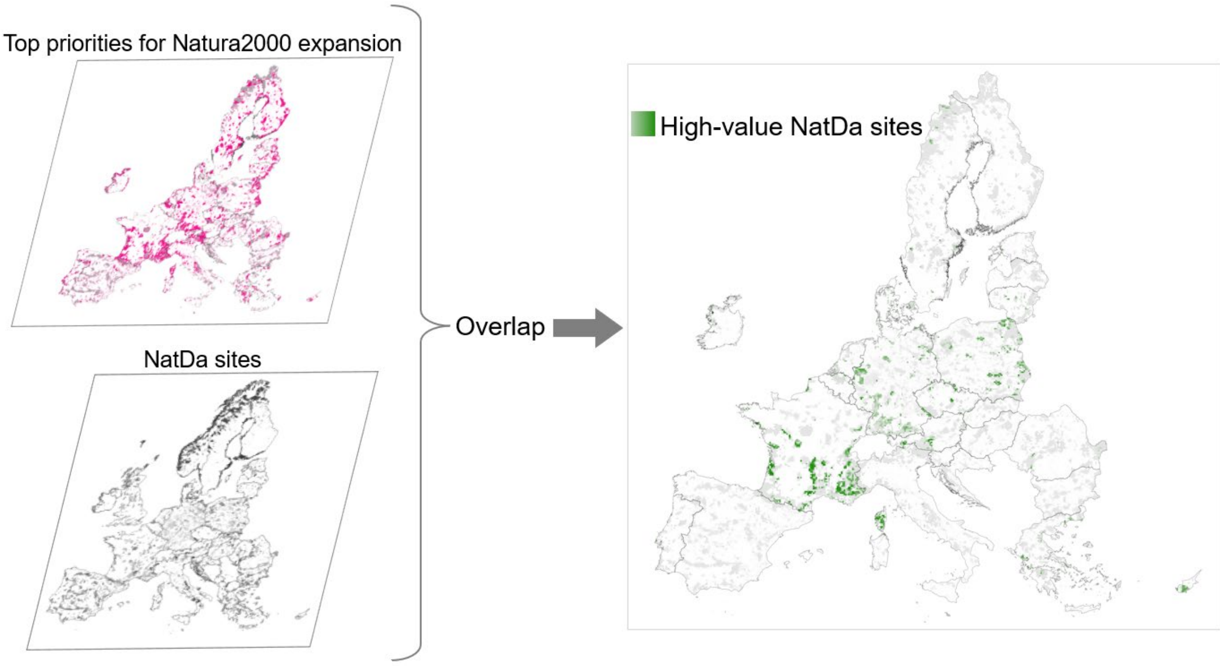
Note: The middle map displays the combined spatial output of 27 separate national prioritisations, accounting for the geographic endemism of species and habitats as weights: each species (or habitat) is weighted by its geographic endemism, calculated as the ratio of its national range size to its total range size. In other words, this weighting scheme incorporates the responsibility of Member States towards the conservation of species and habitats given their European wide distribution. For reference, on the right, the map shows the EU-wide priorities where 30% of conservation efforts are shared equally among countries; and on the left, the map shows the outcome obtained for 27 separate national prioritisations that do not account for the endemism of species and habitats. All other criteria and settings in the prioritisation are equal between all prioritisations.

3.5 Identifying which Nationally designated areas should count towards the 30% targets based on their biodiversity value

EU policy guidance states that all currently established Natura 2000 sites (currently covering a total of 18.6% of the EU land area) should count towards the 30%. However, there are many other nationally designated sites; which of these will count towards the 30% is up to individual Member States to define.

The combined representativeness of Natura 2000 sites and National designations is higher than Natura 2000 alone, suggesting that certain National designations are complementary to Natura 2000 sites and therefore contribute to enhancing the ecological representativeness of the network (Figure 3.1 and Figure 3.5). Our approach can aid in identifying the most valuable nationally designated areas. This can be achieved by overlaying the top priorities for expanding Natura 2000 sites to reach the 30% protected area target – complementary and irreplaceable – with the existing nationally designated areas (Figure 3.7). These nationally designated areas which are also top priorities for conservation of species and habitats of European conservation concern may be strong candidates to be also proposed as Natura 2000 sites.

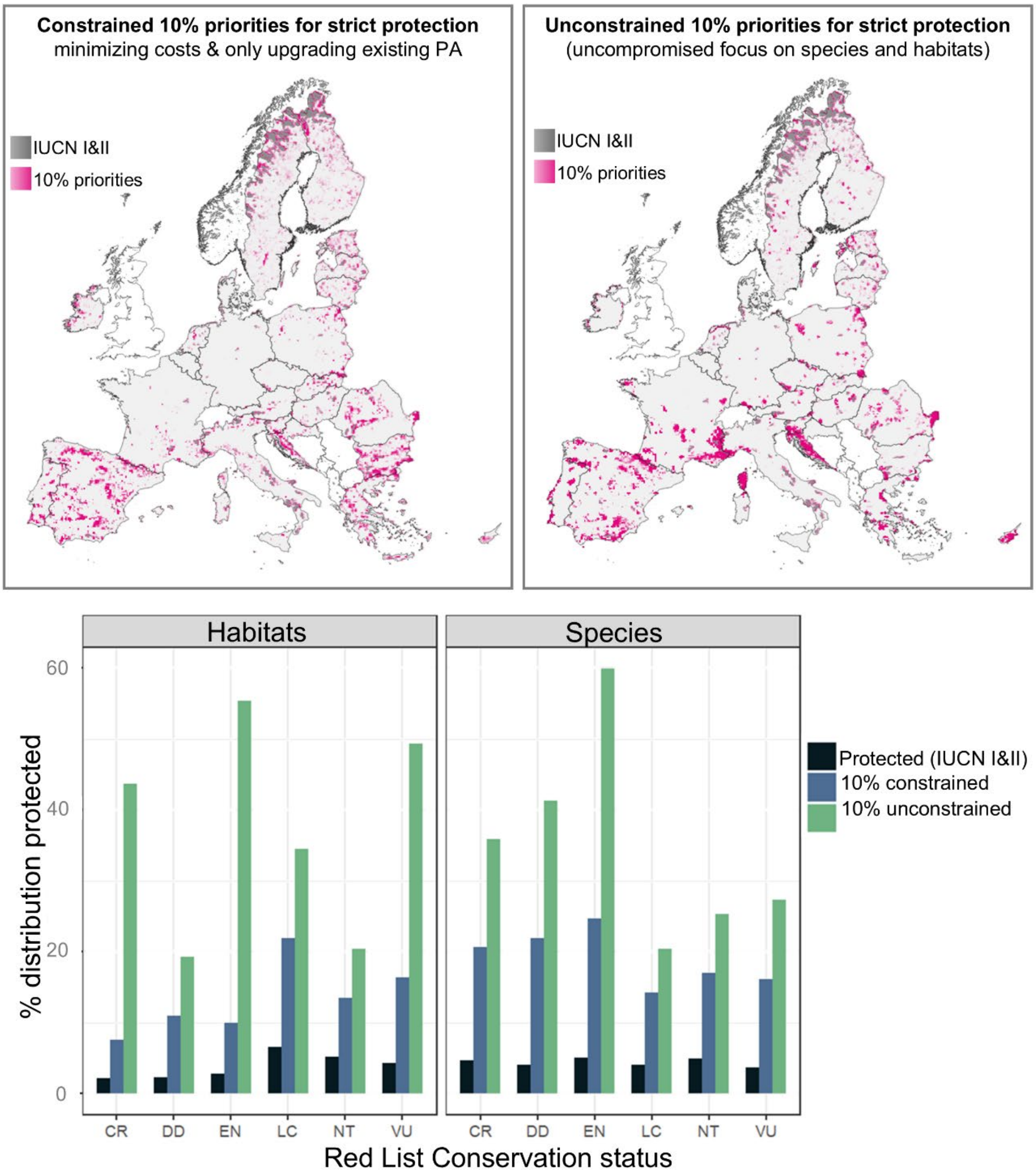
Figure 3.7 Illustrative example for highlighting valuable nationally designated area, which overlap with top priorities for Natura 2000 expansion. These top priority areas have a high conservation value, and they are complementary with Natura 2000 sites.



3.6 Implications of feasibility constraints for 10% strict protection

The representation of species and habitats of European conservation concern in priority areas for strict protection were higher in the 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 3.8). This highlights the question of the trade-off between ecological benefits and feasibility. Under-protected threatened species and habitats would require protection in areas where the opportunity costs of restricting productive and extractive activities are high.

Figure 3.8 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 (bar plot).



Note: The constrained scenarios allow only strict protected area expansion within existing protected areas and aims to minimize opportunity costs, the unconstrained scenario only considers biodiversity features and their weights and targets, and therefore does not compromise ecological gains with feasibility considerations.

4. Discussion

4.1. Priorities for improving the coherence of EU protected area networks

4.1.1. International coordination increases the coherence of the protected area network

The EU Biodiversity Strategy sets EU-wide quantitative targets for protected area coverage, and the strategy itself does not make recommendations about an appropriate distribution of national efforts towards this target. The European Commission Staff Working Document on Protected Area Designation (European Commission 2022) recommends that these targets should be achieved at biogeographical level, which requires some level of coordination between countries within the same bioregion in terms of national level efforts and placement of protected areas, based on the national responsibility towards the protection of shared habitats and species between neighbouring countries. We explored the benefit of this level of coordination, as well as a more extreme one, EU-wide achievement of protection target without lower or upper limits in the share of protection of any single country.

Our analyses confirm that planning for conservation at the EU-wide or biogeographic level ensures far better gains for species and habitats, than when planning within national boundaries (Pouzols et al. 2014; Kukkala et al. 2016; Eckert et al. 2023). Why is EU-wide planning more efficient? When the planning is performed at the national level, it introduces the risk of diverting limited conservation resources to protect species or habitats in a given country at the margin of their range. However, this can mean they are nationally rare but widespread outside the country. If these biodiversity features are prioritised, this comes at the expense of species and habitats that might be nationally common, but continentally threatened or endemic. Coordination between EU Member States for example in the frame of the Biogeographical process is thus key to achieving the best conservation outcomes within the limited additional space that will be afforded protection in the coming years. This will be especially important for connecting protected areas across international borders.

We found that in addition to international coordination, accounting for national responsibility towards the conservation of a biodiversity feature (the fraction the range of the feature that lies within the country) is a simple way to make national or regional conservation planning more efficient and coherent at the EU level. This finding may be relevant for national or subnational authorities tasked with designing protected area networks with national data in a way that contributes to achieve both to national and EU-wide conservation goals, lessening the trade-off between them.

4.1.2. Implications of different baselines

The choice of protected areas considered as the baseline significantly impacts the outcome of the prioritisation to meet the 30% protected area coverage target, both in terms of spatial priorities (Figure 3.5) and biodiversity gains. When expanding only on Natura 2000 sites (covering 18.6% of Europe), an additional 11.4% of land at least must be designated, offering more flexibility and potential for improving the ecological representativeness of the EU protected area network. In contrast, using both Natura 2000 and nationally designated areas (covering a total of 26 of EU land) means only 4% of European land can be designated for additional protection, leaving less room for improvement with fewer benefits for biodiversity. Crucially, accounting for all national designations and setting 30% targets at the biogeographic level, leaves no scope for protected area expansion in the Macaronesian, Continental, Black

Sea and Alpine biogeographic regions, despite European analyses suggest that several habitats and species would require further protection in these regions.

This suggests that careful scrutiny should be placed in identifying which nationally designated areas contribute to the coherence of the network as expressed in Target 1 of the EU Biodiversity Strategy depending on the habitats and species they host and the value of the site for their conservation. The analyses presented here provide a robust approach to assess the European significance of any site for the conservation of species and habitat types of conservation concern and can aid this process of assessment of national designations during the implementation of and reporting against EU protected area targets.

4.1.3. Strict protection: balancing ecological relevance with feasibility

Our exploratory analyses suggest that there is scope for a large expansion of strictly protected areas in the EU if the baseline level of protection is only protected areas that are considered under IUCN management category I and II as assumed here. However, updated protected area reporting standards will allow to identify zones of strict protection within larger designations, and this will result in an increase in the baseline level of strict protection. Further clarification on the definition of strict protection and its adoption by Member States will also result in more existing nationally designated areas being recognised as being under strict protection. This suggests that 3% of the EU land-area could be a substantial underestimate of the current level of strict protection in the EU and future protected area reporting by EU MS should include spatial and tabular information on protected areas, or zones within them, that are considered strictly protected by national authorities.

Notwithstanding the limitations in the assumptions surrounding our definition of strict protection, we found that accounting for opportunity cost data, at least at large scale, can influence the identification of priorities for further strict designations, biasing priorities for strict protection away from ecosystems and species occurring in more productive environments and towards areas of low conflict with forestry, agriculture and infrastructure development (Figure 3.8).

While feasibility is an important element of protected area planning, our results suggest that some areas of high potential opportunity costs for agriculture, forestry or urbanization will require protection without compromises, in order to achieve EU conservation targets.

The definition of strict protection adopted here matches that of IUCN management categories I and II, which would prevent most human activities except for recreation and research, and for which the opportunity costs used here are appropriate, but these cost estimate carry large uncertainties (Armsworth 2014; Adams 2024) and depending on the sectors considered the opportunity costs could vary sensibly (Adams et al. 2010). Furthermore, it is possible that EU countries may adopt criteria for strict protection that are less stringent than the restrictions ascribed to strict protection we assumed here or aimed at achieving different conservation targets than the one tested in this work. These two factors combined suggest that priorities for strict protection may be best assessed first in absence of socio-economic constraints and based exclusively on the location of areas where ecological processes, habitats and species require strict protection regimes. Socio-economic factors could be then accounted to assess the feasibility of proposed strictly protected areas using national or local information.

4.2. Limitations and perspectives

Our analyses were designed to explore specific practical questions for selecting priority areas for designation in the EU to achieve Target 1 and 2 of the EU Biodiversity Strategy. Any attempt to set conservation priorities at national or sub-national level should address some data and modelling assumptions to reach an adequate level of ecological accuracy and policy relevance.

4.2.1. Data resolution and comprehensiveness

Our analyses were at 10x10 km², matching the resolution of the biodiversity data available to us in a gridded layer across the EU. However, given the small average size of Natura 2000 sites and other protected areas in Europe, increasing the spatial resolution to at least 1km² is recommended for more detailed and accurate conservation planning.

To enhance comprehensiveness, a broader set of taxa should be included beyond those listed in the annexes of the two nature directives and on IUCN Red Lists, as well as relevant ecosystem services (e.g. carbon sequestration, flood regulation).

4.2.2. Conservation targets for habitats and species

The adequacy of the proposed protected area network in these analyses were informed by extinction-risk informed targets for both habitats and species. However, the EU has adopted the concept of Favourable Reference Value (for population size, population range, and habitat extent) to assess whether a habitat or species is in a favourable conservation status or not (Bijlsma et al. 2019). If the aim is to expand the network of conserved areas to sustain habitats and species population that are in good condition, the protection target could be set at a relevant Favourable Reference Value, provided that numeric data were available and reliable. Presently there is a high level of missing data in Article 17 reports for FRVs and their usage for conservation planning is not possible.

4.2.3. Future projections of changes in climate and land use

Climate change presents a major challenge to biodiversity and conservation, as regions that currently support species vulnerable to climate change may not guarantee their long-term survival even if protected (Scheffers et al. 2016). This will require species to either adapt to changing local conditions or relocate to more favourable areas (Pecl et al. 2017). Although protected areas play a crucial role in conservation, they may not be optimally situated to support these necessary shifts. Given the projected extent of climate change, many habitats and species may become less represented within protected areas, potentially weakening the ability of fixed conservation sites to mitigate climate-driven ecological changes (Heller & Zavaleta 2009).

Spatial information on climatic risk, such as climate velocity (Loarie et al. 2009; Asamoah et al. 2022) can be used to guide the identification of new protected areas where environmental conditions are shifting slower, giving species and populations more time to respond. In several Finnish protected areas for example, the current temperature conditions are likely to disappear by the end of this century (Heikkinen et al. 2020). This, however, does not inform on the expected impacts on ecosystem functioning as it

ignores the intrinsic resilience of ecosystems, such as their ability to maintain ecological functions despite disturbances, including those whose severity and frequency is increased by climate change.
Research shows that this resilience depends on functional redundancy, where multiple species can perform similar ecological roles (e.g. trophic interactions, nitrogen fixation, habitat provision). Degraded interaction networks are more vulnerable to extinction cascades (Sanders et al. 2018), highlighting the importance of protecting diverse and robust food webs (Tylianakis et al. 2010; Dansereau et al. 2024). Scenarios of protected area expansion and management plans will need to account for these factors to ensure that, if implemented, these protected areas continue to deliver conservation benefits in the future. Furthermore, it is essential to consider ecological connectivity between protected areas, and inherent uncertainties to develop a robust strategy for identifying climate-resilient priority conservation areas across Europe (Jung et al. 2024).

Additionally, future demand for food, feed, fibre, fuel and timber may result in the expansion and intensification of cropland, managed grassland and forests, encroaching on existing protected areas and reducing opportunities for expanding and connecting the network. Accounting for land-use scenarios in the prioritisation process allows to anticipate and account for potential land-use conflicts, explore leakage effects of habitat protection that displaces extractive and productive activities elsewhere, and identify options to minimize the potential negative impact of leakage (Visconti et al. 2015; Chapman et al. 2023).

4.3. From analyses to decisions

Systematic Conservation Planning allows for the exploration of multiple scenarios. This is useful, as it allows to understand the specific implications when different types of objectives or assumptions are used during the prioritisation. However, this also introduces the challenge to compare many, sometimes hundreds of variants and distil a manageable number of alternatives that provide best outcomes for at least one of the main objectives and the best trade-offs for the competing objectives. To provide end users with useful planning products, the results from the prioritisation analysis can be synthesised and developed further with a range of different methods. These include ways to understand the reasons why different areas emerge as priorities, to identify suboptimal or very similar solutions, and to only include and deliberate on these trade-offs that cannot be avoided.

4.3.1. Understanding priority locations

The priority maps produced with workflows like the one presented here are based on spatial data on hundreds of species and habitats and other input information. It is important that decision makers understand the specific reasons why a particular area is highlighted as priority so that this can be communicated to all stakeholders and be used also to inform protected area management plans. This can be achieved through spatial queries of the priority maps for protected area expansion or even the production of interactive maps and dashboards that provide information on the biodiversity features occurring at the site, and those that most contributed to its selection (e.g. those that are least protected in the present network). Further information that can be provided includes other data used in the prioritisation, such as socio-economic costs and constraints, as well as other metrics, not directly used in the prioritisation but of conservation relevance (Burgess et al. 2024).

4.3.2. Options to compare performance across different objectives

When the relationship between some objectives is more interesting to decision-makers than others, additional analyses can help to understand if there are any configurations that deliver the most efficient balance between two different objectives. Both trade-off curves and Pareto frontiers are graphical representations that visualise the performance of different options on two axes, for example, protected range of species versus costs, such as the benefits to biodiversity versus fishery catch losses in the context of MPA planning in Fiji (Gurney et al. 2015) or the size of ecosystems and coverage of species in Australia (Polak et al. 2016). While curves are based on lines, Pareto fronts show a scatter plot of all solutions that allow to identify those that underperform compared to other solutions. When more than two objectives need to be compared, multiple plots can be produced (Driscoll et al. 2016; Law et al. 2017), however this becomes impractical to display and interpret when more than a handful of objectives and associated metrics need to be displayed.

Consensus areas can also be visualised, for example by mapping how often any cell was part of a priority set across different scenarios, this can help to identify which areas are irreplaceable and relevant under a range of considerations (Hammill et al. 2016).

When the number of biodiversity metrics to be evaluated is larger, consequence tables can be used to contrast different putative conservation networks. These tables depict different options as columns and all relevant metrics as rows. Colour coding can help to highlight high performance for any given metric. The method is a standard approach in many applied conservation planning processes and is helpful in creating an overview of different metrics (Failing et al. 2013).

4.3.3. Fundamental considerations during trade-off analysis

Trade-off analysis has the aim of narrowing down options, such as alternative spatial plans, to a manageable number through assessing their performance on the criteria that matter most to stakeholders and decision-makers. Several strategies can help with the screening, some are summarised below, and further options and details are described in Gregory et al. (2012).

Eliminate redundant alternatives and insensitive metrics

When examining alternative spatial priorities for conservation and comparing benefits and costs across environmental, social and economic objectives and their metrics, options that perform worse than others for all important metrics can be discarded, as well as metrics that do not differ across alternative configurations of the TEN-N. If any of the metrics does not differ across the different scenario variants, it can be ignored in the process of selecting between them; for example in the analyses presented here the metric of mean distribution protected averaged across all species was not a good discriminant between alternative scenarios of burden sharing (Figure 3.4 B). This process can simplify the decision by reducing the options and different metrics to consider.

There could be multiple variants that achieve a similar performance but result in quite different spatial configurations, i.e. they select very distinct sets of sites (Linke et al. 2011). Spatial planners may wish to retain a small sample of these equally performing configurations of conservation priorities that are genuinely different so that they can then effectively proceed to refine them through further consultations and negotiations. Multi-variate analyses and clustering algorithms can be used to plot each scenario variant on a dissimilarity dendrogram to analyse at the same time the performance and spatial similarity of alternative sets of conservation priorities and select a small representative sample (Linke et al. 2011).

Comparing pairs of options

Once the clearly inferior or non-relevant results are eliminated, any further elimination based on partial superiority on some of the metrics is driven by value-judgments, and not any longer on technical analysis. Even when objectives and metrics have been developed in group effort, the relative priorities can differ among the stakeholders participating in the decision-making process. It can help to identify and agree on a threshold that is perceived as a “significant” difference in a specific metric. For some cases, already a small percentage of difference might be important, in others a very large one is needed. For example, if variant A provides a 1% larger area for pollination compared to variant B, delivers the same benefits for biodiversity, but is 30% more expensive, it will be most likely unattractive. Once such threshold values have been found, it might be able to eliminate some more options that are clearly worse than others. Every time an option is removed, performance measure can be checked again if they still vary across the remaining options, and if not, can be dropped as well.

When it is more difficult to find an emerging solution, there are a range of quantitative methods that can facilitate further elimination of inferior options. Explicit examples and references for different methods can be found in Gregory et al. (2012).

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