Conservation Biology

Contributed Paper

Evaluating and expanding the European Union's protected-area network toward potential post-2020 coverage targets

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Abstract: The Convention on Biological Diversity's (CBD) strategic plan will expire in 2020, but biodiversity loss is ongoing. Scientists call for more ambitious targets in the next agreement. The nature-needs-half movement, for example, has advocated conserving half of Earth to solve the biodiversity crisis, which has been translated to protecting 50% of each ecoregion. We evaluated current protection levels of ecoregions in the territory of one of the CBD's signatories, the European Union (EU). We also explored the possible enlargement of the Natura 2000 network to implement 30% or 50% ecoregion coverage in the EU member states' protected area (PA) network. Based on the most recent land-use data, we examined whether ecoregions have enough natural area left to reach such high coverage targets. We used a spatially explicit mixed integer programing model to estimate the least-cost expansion of the PA network based on 3 scenarios that put different emphasis on total conservation cost, ecological representation of ecosystems, or emphasize an equal share of the burden among member states. To realize 30% and 50% ecoregion coverage, the EU would need to add 6.6% and 24.2%, respectively, of its terrestrial area to its PA network. For all 3 scenarios, the EU would need to designate most recommended new PAs in seminatural forests and other semi- or natural ecosystems. Because 15 ecoregions did not have enough natural area left to implement the ecoregion-coverage targets, some member states would also need to establish new PAs on productive land, allocating the largest share to arable land. Thirty percent ecoregion coverage was met by protecting remaining natural areas in all ecoregions except 3, where productive land would also need to be included. Our results support discussions of higher ecoregions protection targets for post-2020 biodiversity frameworks.

Keywords: Aichi targets, conservation targets, ecological representation, Half-Earth, mixed integer programing, nature-needs-half, protected-area networks, systematic conservation planning

Evaluación y Expansión de la Red de Áreas Protegidas de la Unión Europea hacia Objetivos Potenciales de Cobertura Post 2020

Resumen: El plan estratégico del Convenio sobre la Diversidad Biológica (CBD) expirará en 2020, pero la pérdida de la biodiversidad continúa. Los científicos exigen objetivos más ambiciosos para el siguiente acuerdo. Por ejemplo, la corriente la-naturaleza-necesita-la-mitad ha abogado por la conservación de la mitad del planeta para resolver la crisis de la biodiversidad, lo que se ha traducido a la protección del 50% de cada ecoregión. Evaluamos los niveles actuales de protección de las ecoregiones en el territorio de uno de los signatarios de la CBD, la Unión Europea (UE). También exploramos el posible crecimiento de la red Natura 2000 para implementar una cobertura del 30% o 50% de las ecoregiones en la red de áreas protegidas (AP) de los estados miembros de la UE. Con base

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en los datos más recientes de uso de suelo, examinamos si las ecoregiones todavía tienen suficiente área natural como para alcanzar tales objetivos tan altos de cobertura. Usamos un modelo de programación entera mixta espacialmente explícito para estimar la expansión más asequible de la red de AP con base en tres escenarios que colocan un énfasis diferente sobre el costo total de la conservación, la representación ecológica de los ecosistemas o que enfaticen un porcentaje equitativo de la carga entre los estados miembros. Para alcanzar una cobertura del 30% y 50% de las ecoregiones, la UE necesitaría añadir 6.6% y 24.2%, respectivamente, de su área terrestre a la red de AP. Para los tres escenarios, la UE necesitaría designar la mayoría de las nuevas AP recomendadas en bosques seminaturales y en otros ecosistemas semi- o totalmente naturales. Debido a que 15 ecoregiones no tenían ya suficiente área natural para implementar los objetivos de cobertura de ecoregiones, algunos estados miembros también necesitarían establecer nuevas AP en suelo productivo, asignando la proporción mayor al suelo arable. La cobertura del 30% de las ecoregiones se alcanzó con la protección de las áreas naturales permanecientes en todas las ecoregiones salvo tres, en donde el suelo productivo también necesitaría estar incluido. Nuestros resultados respaldan las discusiones sobre objetivos más altos de protección de ecoregiones para los marcos de trabajo post 2020 para la biodiversidad.

Palabras Clave: la-naturaleza-necesita-la-mitad, Media-Tierra, objetivos de Aichi, objetivos de conservación, planeación sistemática de la conservación, programación entera mixta, redes de áreas protegidas, representación ecológica

摘要: 《生物多样性公约》的战略计划将于 2020 年到期, 但生物多样性丧失仍在继续。科学家们呼吁, 应在下一份协议中制定更宏伟的目标。例如, "自然需要一半" 运动主张保护半个地球以解决生物多样性危机, 这已经转化为保护每个生态区的 50%。本研究评估了《生物多样性公约》签署方之一的欧盟境内目前的生态区保护水平, 并探讨了将 Natura 2000 网络扩大到覆盖欧盟成员国保护区网络中 30% 或 50% 的生态区的可能性。根据最近的土地使用数据, 我们评估了各个生态区是否有足够的自然面积来实现如此之高的覆盖率目标。我们利用空间显式混合整数规划模型, 基于三种分别强调总保护成本、生态系统的生态代表性和成员国之间的责任均分的不同情景, 估计了保护地网络成本最低的扩张情况。为实现 30% 和 50% 的生态区覆盖率, 欧盟分别需要将其陆地面积的 6.6% 和 24.2% 纳入保护地网络中。在三种情景中, 欧盟最好都应在半天然林或其他半自然生态系统中建立新的保护区。由于有 15 个生态区没有足够的自然面积来实现生态区覆盖目标, 一些成员国还需要在生产土地上建立新的保护区, 将最大承担份额分给了耕地。所有生态区都可以通过保护剩余自然区域来实现 30% 的生态区覆盖率, 但有三个生态区除外, 它们仍需要将生产土地纳入保护地。我们的结果支持为 2020 后生物多样性框架制定更高的生态区保护目标的讨论。【**翻译: 胡怡思; 审校: 聂永刚**】

关键词: 爱知目标, 保护目标, 生态代表性, 半个地球, 混合整数规划, "自然需要一半", 保护地网络, 系统保护规划

Introduction

The Convention on Biological Diversity's (CBD) Strategic Plan for Biodiversity 2011–2020 will soon expire. However, the international community has not reached its goal of halting biodiversity loss. At COP14, the CBD's signatories discussed the global post-2020 biodiversity framework and considered the strategic expansion of protected areas (PAs) as an essential measure toward the 2050 biodiversity vision to live "in harmony with nature" (UNEP 2011).

Current PA-coverage targets of Aichi target 11 (i.e., protecting 17% of the global terrestrial area and 10% of the marine area by 2020) are too low for adequate long-term protection of biodiversity (Baillie & Zhang 2018). Proposals for the CBD's next strategic plan range from conserving 100% of all remaining intact ecosystems (Watson et al. 2018) to protecting 30% of all land and ocean areas until 2030 and 50% until 2050 (Baillie & Zhang 2018). The nature-needs-half or Half-Earth movement argues that 85% of the species on Earth could be sustained if half the planet is set aside as "inviolable natural reserves" (Wilson 2016), a goal that has been translated to protecting 50% of each of the world's ecoregions (Dinerstein et al. 2017*a*). There has been much support for this vision among the conservation science community (Cafaro et al. 2017; Watson & Venter 2017; Kopnina et al. 2018), and some researchers have examined its systematic implementation and possible trade-offs with other land-uses on the global level (Mehrabi et al. 2018; Pimm et al. 2018). However, other scientists warn there is not yet enough scientific evidence to back the Half-Earth vision (Sleep et al. 2017) or challenge its feasibility (Büscher et al. 2017). One unquestionable strength of Half-Earth is its simplicity, transferring a clear goal that is similar to the 2°C target of the Paris Agreement to limit climate change. Formulating a similar target for biodiversity protection could facilitate and stimulate more ambitious actions (Mace et al. 2018). Because signatories explicitly call for scenarios and models on different spatial scales to inform the development of post-2020 targets (CBD 2018), we undertook a detailed assessment for the European Union (EU) as one of the signatories of the CBD.

Europe has a high population density, a long history of human land-use, and little wilderness left (McCloskey & Spalding 1989). With 22.7% of the 11,260 European species on the IUCN Red List classified as threatened (IUCN 2017), the EU will fail to stop biodiversity loss by 2020 (Hochkirch et al. 2013). Despite missing the overall target, the EU made substantial progress in achieving some of CBD's Aichi targets. The EU created the world's largest network of protected areas, Natura 2000, in an exemplary effort (Campagnaro et al. 2019). With 18.2% of the terrestrial area under formal protection, Natura 2000 exceeds the 17% PA-coverage target of Aichi target 11 (European Commission 2018). Considering also nationally designated PAs that are not part of Natura 2000, more than 26.3% of the EU's terrestrial area is already protected (UNEP-WCMC and IUCN 2019). Therefore, the EU considers its terrestrial Natura 2000 network nearly complete (Orlikowska et al. 2016). However, neither the EU's terrestrial (Müller et al. 2018) nor the marine (European Environment Agency 2018*b*) PA network is fully ecologically representative, and visions such as Half-Earth would require adopting more ambitious PA-coverage targets. Furthermore, many sites lack appropriate management (Hochkirch et al. 2013) and include land under intense human pressure, which leads to an overestimation of the actual level of protection (Jones et al. 2018). Other challenges that hamper successful biodiversity protection in the EU are small PA size and landscape fragmentation, extinction debts, and climate change (Gaston et al. 2008).

We aimed to evaluate the current amount of ecoregions protected in the entire terrestrial PA estate of the EU's member states and to assess how the EU could fill potential gaps toward more ambitious 30% and 50% ecoregion coverage targets. First, we determined which ecoregions have not reached such targets yet. Second, we used the latest European land-cover data to analyze whether there would be enough natural areas left to protect 30% and 50% of the ecoregions or whether the inclusion of productive land (arable land, productive grassland, and production forest) would be necessary. Third, we simulated how the EU could expand its terrestrial Natura 2000 network cost-effectively to implement the 30% or 50% ecoregion-coverage target within its member states' entire network of PAs. Finally, we tested 2 further scenarios to account additionally for the ecological representation of ecosystems and for sharing the burden of PA designation more equally among member states.

Methods

Study region and Data Sources for Modeling

We examined the terrestrial area of all 28 EU member states, excluding territories outside the Palearctic realm. We also excluded the Azores and Madeira because of data deficiencies.

We considered 41 ecoregions (Figs. 1 & 2) from the Ecoregions 2017 Resolve map (Dinerstein et al. 2017*b*) to assess the representation of these broad but ecologically distinct regions as primary biodiversity surrogates for the EU's PA network. To evaluate how much natural area is left to fill gaps in ecoregion coverage, we used the latest CORINE land-cover assessment (European Environment Agency 2018*a*). We excluded marine and anthropogenic land-cover classes and reclassified the remaining into semi- or natural ecosystems and productive land (Supporting Information). We refined the 3 CORINE forest classes (3.1.1. broad-leafed, 3.1.2 coniferous, and 3.1.3 mixed) with data from the Forest Management Map of European Forests (Hengeveld et al. 2012). We considered the classes nature reserve, close to nature, and combined objective as seminatural forests. Even-aged forestry and short-rotation forestry were considered intensively managed production forests. We split each CORINE forest class into 2, containing production forests and seminatural forests. In total, semi- or natural ecosystems included 18 land-use classes, which we grouped into seminatural forest, natural grassland, and other semi- or natural ecosystems for reporting our results. Productive land included 14 land-use classes, which we divided into production forests, productive grassland, and arable land. To further enhance ecological representation, we used the semi- or natural ecosystems as secondary biodiversity surrogates in our expansion exercise.

We took into account data on Natura 2000 sites (DG ENV 2017) and nationally designated PAs from the World Database on Protected Areas (UNEP-WCMC and IUCN 2019). We prepared the WDPA data set according to the guidelines of the UN Environment Program - World Conservation Monitoring Centre (UNEP-WCMC 2019). We used both data sets to calculate PA coverage of ecoregions, semi- or natural ecosystems, and productive land categories within the EU.

We used land opportunity costs as the best available proxies for conservation costs. Systematic conservation planning exercises need to include all relevant costs of conservation to find cost-efficient solutions (Naidoo et al. 2006). However, costs on reserve establishment and management of PAs are currently not available at the EU level, and it is not straightforward to estimate them from existing data (Kotiaho & Moilanen 2015). We estimated land opportunity costs based on agricultural-land rent data on NUTS-2 level (Farm Accountancy Data Network 2018). We calculated arithmetic means from annual data from 2009 to 2015 (Supporting Information). We created the 499 planning units (PUs) used in the modeling system by intersecting ecoregions and NUTS-2 regions.

Representation Metrics

To evaluate ecological representation in the PA network, we applied the metrics mean target achievement (MTA) (Jantke et al. 2019) and protection equality (PE) (Chauvenet et al. 2017). The MTA metric showed to which degree ecoregions already meet the 30% or 50%

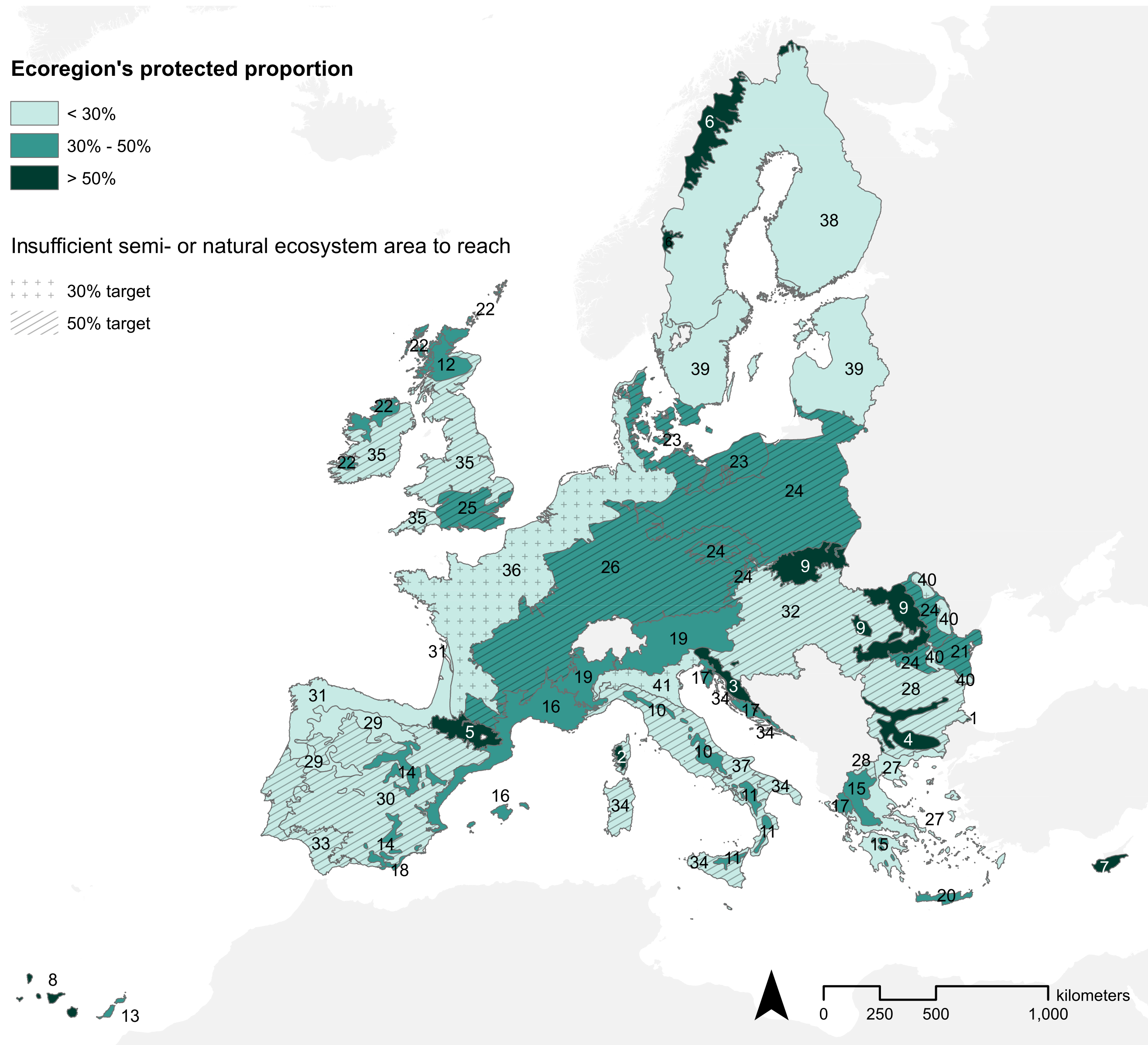

Figure 1. Current ecoregion protection levels in EU member states' protected-area network (ecoregion numbers correspond to Fig. 2).

coverage target. The metric's values range from 0% (no ecoregion is protected) to 100% (all ecoregions fulfill the target). We used the R package ConsTarget to calculate this metric (Jantke et al. 2018). The PE metric explores how homogenously PA networks cover biodiversity features, such as species or habitats. This metric also ranges from 0% (heterogeneous representation of biodiversity features) to 100% (representation of biodiversity features is perfectly homogeneous). We used the R package ProtectEqual (Chauvenet et al. 2015) to calculate how homogenously the PA network represented semi- or natural ecosystems. We computed the same metric to compare how homogenously the PA network covered the member states' territories.

We calculated both metrics for the current PA network and the simulated optimal networks for the 30% and 50% ecoregion-coverage target and each scenario.

Scenarios

To compare how different emphasis on total cost of conservation, ecosystem representation, or member state equity could change the designated additional conservation areas of the modeled network expansion, we developed 3 scenarios. In the first scenario, cost only, we simulated a least-cost network expansion that only fulfilled an ecoregions' coverage target. In the second scenario, ecosystem equity, we simulated a least-cost

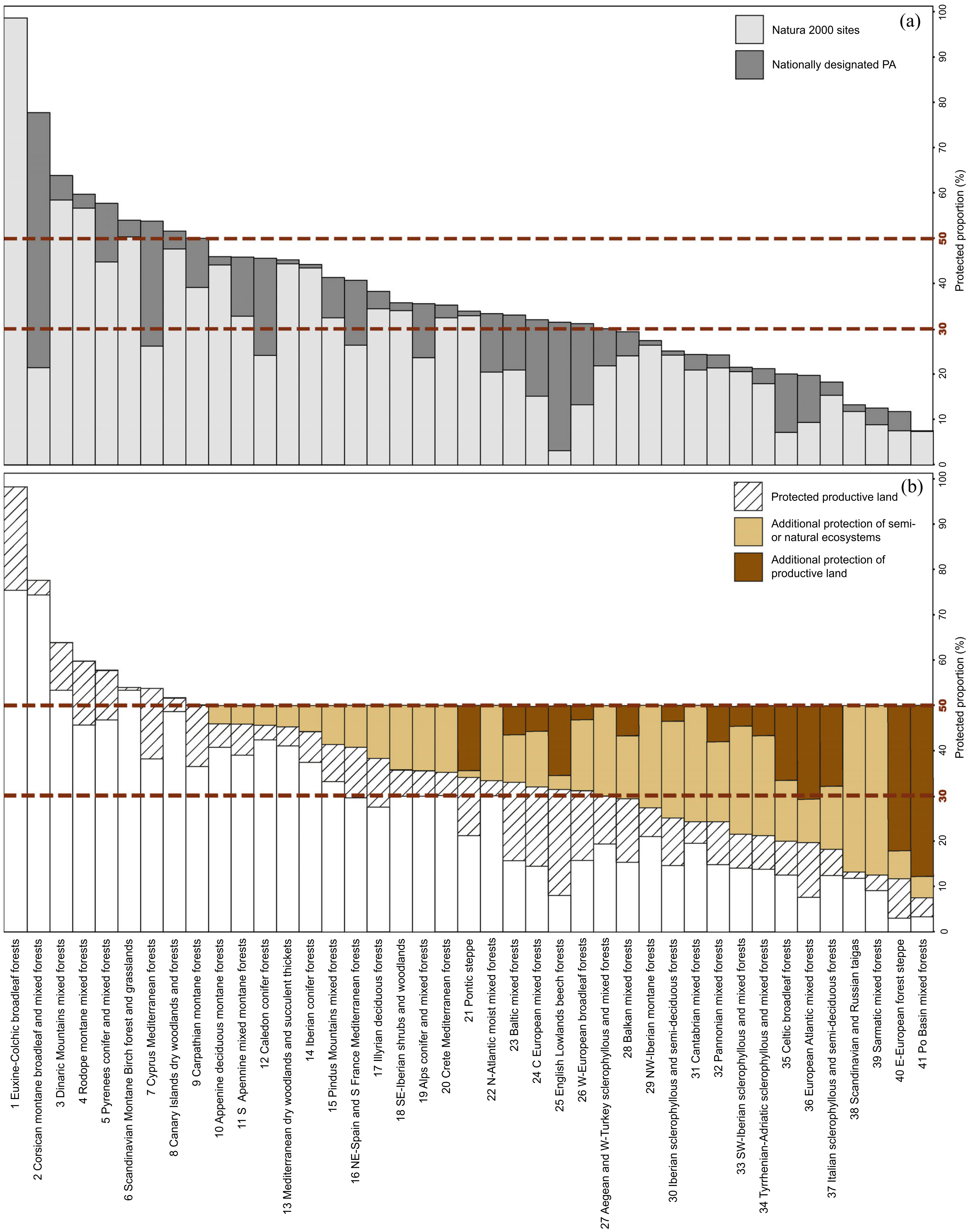

Figure 2. (a) Current ecoregion protection levels in EU member states' protected-area (PA) network and (b) needed additional protection area of semi- or natural ecosystems and production land to reach the 30% or 50% ecoregion-coverage target.

Table 1. Comparison of protection levels, mean target achievement, protection equality of ecosystems and member states, and total conservation cost for the European Unions's current protected-area (PA) network and the 3 PA expansion scenarios.

	Current protected area network	*Network expansion*					
		30%			*50%*		
		cost only	*ecosystem equity*	*member state equity*	*cost only*	*ecosystem equity*	*member state equity*
Protected terrestrial proportion of the EU[a] (%)	26.3		32.6			50.3	
Terrestrial EU[a] area added to the network (km^2)	–		283,902.4 (6.6 %)			1,050,986.0 (24.2%)	
Ecoregion MTA[b] for the 30% target (%)	88.2		100.0			–	
Ecoregion MTA[b] for the 50% target (%)	68.5		–			100.0	
Ecosystem PE[c] (%)	78.0	87.0	88.3	86.9	94.7	97.5	94.6
Member-state PE[c] (%)	76.2	79.4	81.9	85.0	83.0	85.3	95.2
Additional land opportunity cost (billion €/year)	–	2,710.6	3,739.6	3,887.8	12,559.0	13,788.9	14,648.8

[a]*European Union.*
[b]*Mean target achievement.*
[c]*Protection equality.*

expansion to fulfill the ecoregion-coverage target while aligning the protected proportions of semi- or natural ecosystems (serving as a second biodiversity surrogate) as much as possible. For the third scenario, member state equity, we simulated a least-cost network expansion to fulfill the ecoregion-coverage targets while aligning protected proportions of member states as much as possible. We compared total cost, ecosystem protection equality, and member state protection equality for all 3 scenarios.

Simulation of Systematic Network Expansion

We modified the linear programing modeling system from Müller et al. (2018) to estimate the least-cost expansion of the EU member states' PA network to reach 30% and 50% ecoregion-coverage targets. The modeling system consisted of 2 consecutive models that we solved with mixed-integer programing. For the cost-only scenario, we solved only the second model. For the other scenarios, both models were solved consecutively. The first model determined the required additional conservation area for closing coverage gaps in ecoregions while increasing protection equality of semi- or natural ecosystems or member states as much as possible. The second model allocated these additional conservation areas to the cheapest set of PUs. In adjusting the model from Müller et al. (2018) to this study, we changed the following: productive land could be part of the additional conservation areas if and only if an ecoregion did not have sufficient unprotected semi- or natural ecosystem area for meeting a given coverage target. Supporting Information contains a detailed model description.

Results

Current representation of Ecoregions, Land-Cover Classes, and Member States

The EU's current PA network covered 30% of 26 ecoregions. It also covered 50% of 9 ecoregions, but these were typically rather small (Figs. 1 & 2a). Inherently, the protection of many ecoregions in the entire PA network was considerably higher than protection through Natura 2000 sites alone. For example, the United Kingdom designated only a minority of PAs as Natura 2000 sites for the British ecoregion England lowlands beech forests. Iberian coniferous forests, however, received nearly all protection through Natura 2000 sites (Fig. 2a). The MTA metric revealed that the EU is already quite close to reaching the 30% ecoregion-coverage target with its PA network and has also achieved the 50% ecoregion-coverage target by half (Table 1).

Current ecosystem representation levels ranged from 27% for transitional woodland and shrub to 94% for coastal salt marshes (Supporting Information). The high PE value (Table 1) indicated that even though the range between the lowest and highest protection level was large, ecosystem protection levels within the PA network were overall already quite equal. Existing PAs notably also included productive land (Fig. 2b). Land-use intensity on productive land is presumably still high, potentially decreasing PA effectiveness for biodiversity conservation. Although the current PA network also covered member states already quite homogenously (Table 1), Ireland protected only 14% of its terrestrial territory while Cyprus and Slovenia conserved 54%. Together with Luxemburg, these 3 member states established a Half-Earth extent for their national PA networks.

Remaining Natural Area for Implementation of Ecoregion-Coverage Targets

There was not enough semi- or natural ecosystem area left in the EU to reach the coverage targets for all ecoregions (Fig. 2b). Among the ecoregions falling short of 30%, there was not enough semi- or natural ecosystem area to achieve targets in Po Basin mixed forests, East European forest steppe, and European Atlantic mixed forests (Fig. 1). Thus, member states containing part of these ecoregions would need to set productive land aside. Similarly, the EU would need to include productive land in the PA network in 15 ecoregions to implement the 50% ecoregion-coverage target. Notably, the majority of ecoregions with the lowest amount of protection did not have enough semi- or natural ecosystem areas left to implement the protection targets (Fig. 2b). For example, Italy protected only 8% of Po Basin mixed forests, and the remaining natural area would not even be sufficient to raise the protection level to 15%.

Scenarios of Network Expansion

Although the EU would need to add only a small fraction of its total territory to the PA network to achieve 30% ecoregion coverage, nearly one-quarter of the EU territory would need to be added to reach 50% ecoregion coverage (Table 1). The 3 scenarios exemplarily visualize potential trade-offs between total conservation cost and the distribution of additional conservation areas across ecosystems and member states.

Not surprisingly, when only minimizing total conservation cost (cost-only scenario), additional conservation areas for a gap ecoregion concentrated on a few PUs with comparably low-cost values (Fig. 3b). Furthermore, this scenario yielded the lowest increases in ecosystem and member state PE (Table 1). Accounting for a distribution of PA that is as even as possible across ecosystems (ecosystem equity scenario) led to higher total conservation cost than the cost-only scenario (Table 1), but yielded higher ecosystem and member state PE values (Table 1) and a more even allocation of additional PAs across PUs (Fig. 3c). Finally, accounting for a distribution of PA that is as even as possible across member states (member state equity scenario) yielded the most expensive network enlargement (Table 1). Although member state equity generated ecosystem PE values similar to the cost-only scenario, it resulted in the highest member state PE values (Table 1). The distribution of PAs across PUs was more concentrated than in the ecosystem equity scenario, indicating that increasing the protected amount of currently underrepresented ecosystems was a stronger constraint to the algorithm than increasing the protection levels of currently less protected member states (Fig. 3d). The PE values did not reach 100% in any scenario because the representation of ecosystems and member states showed a wide range in the current PA network (Supporting Information).

Land-use Category and Member State Contribution

Seminatural forest would contribute most to an extended PA network for both ecoregion-coverage targets and all 3 scenarios, followed by other seminatural ecosystems and arable land (Fig. 4). Although there were only slight differences between the 3 scenarios at the EU level, changes were more apparent on the member state level. For example, the amount of seminatural forest area Sweden would need to set aside differed remarkably for the 3 scenarios, whereas for other member states, such as Germany and France, it stayed roughly the same (Supporting Information). Most member states would need to protect considerable proportions of their natural areas, whereas large parts of productive lands could remain unprotected.

Member state protection levels within the potential future PA network extents varied among the 3 scenarios (Supporting Information), as did the additional protection area in each PU within a member state (Fig. 3 & Supporting Information). For the cost-only scenario, we found very high protection levels in member states with comparably low land rent prices. For example, Slovakia would have to protect 81% of its terrestrial territory for the 50% ecoregion-coverage target. The member state equity scenario, in contrast, forced the algorithm to allocate additional PAs also to member states with relatively high land rents, such as Finland and Denmark.

Discussion

Biodiversity loss in Europe is continuing despite all past conservation efforts, and it will keep continuing unless European countries adopt even more ambitious policies (IPBES 2018). Encouragingly, more than half of all European ecoregions reached 30%, and 9 ecoregions even achieved 50% coverage in the EU member states' current PA network. Furthermore, only a few ecoregions did not have enough unprotected semi- or natural ecosystem areas left to achieve 30% or 50% protection. However, previous studies show that the Natura 2000 network still underrepresents European biodiversity (e.g., narrow-ranged species [Gruber et al. 2012; Abellán & Sánchez-Fernández 2015] and amphibians and reptiles [Maiorano et al. 2015; Sánchez-Fernández & Abellán 2015]). If the EU would systematically expand the Natura 2000 network, additional PAs could not only close the gaps in ecoregion coverage we found, but also increase the size and connectivity of existing PAs, benefitting, for example, insect species (Habel et al. 2019), species with large home ranges (Jantke et al. 2011), and species shifting their distribution due to climate change (Santini et al. 2016).

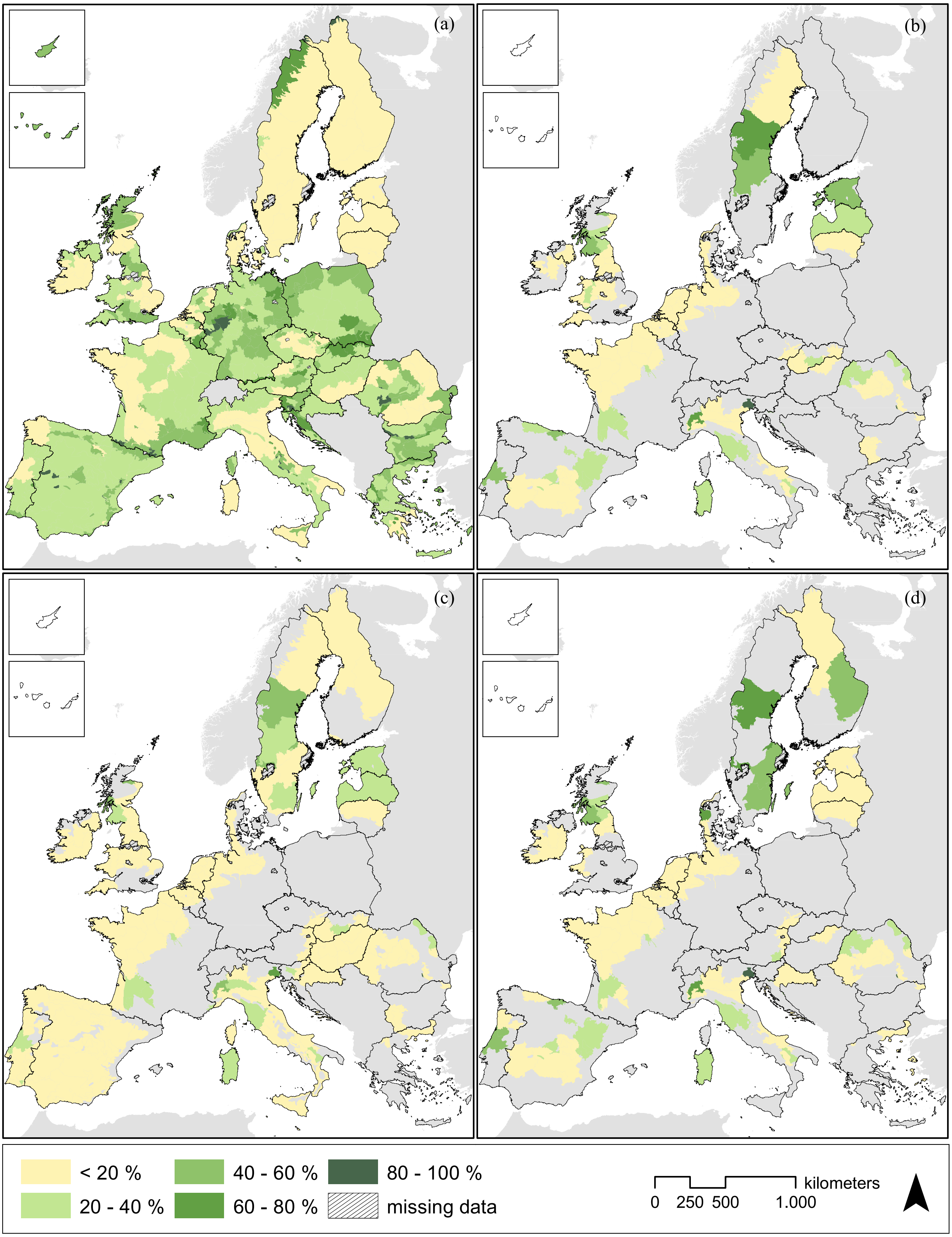

Figure 3. Percent area (a) currently protected in each EU planning unit (excludes CORINE artificial surfaces) and required additional percent protected area for the (b) cost-only, (c) ecosystem-equity, and (d) member-state-equity scenarios for the 30% target for ecoregion coverage.

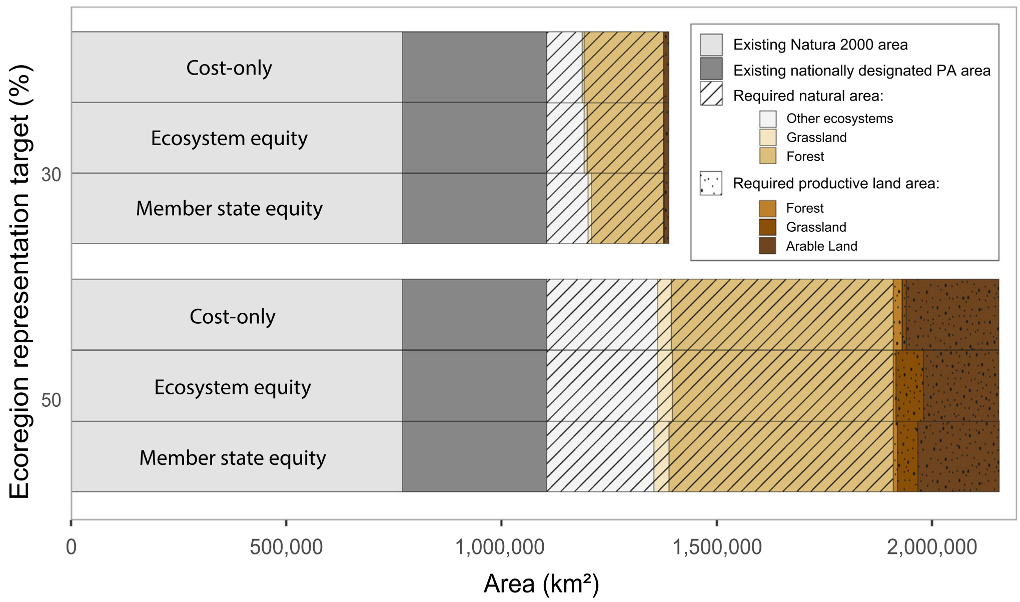

Figure 4. Existing and required protected area (PA) for both EU ecoregion-coverage targets and all 3 scenarios (cost only, ecosystem equity, and member state equity).

The model allocated the majority of additional PAs for all 3 scenarios to seminatural forests, followed by other seminatural ecosystems and arable land. While forests used to be natural, self-sustaining ecosystems in Europe for millennia (Mai 1989), many of the forest types listed on Annex 1 of the Habitats Directive have evolved during the last centuries as extensively used silvicultural systems. Natura 2000 regulations allow continued commercial use of forests, but in many cases restrict this use to close-to-nature forestry (Sotirov 2017). Land users might already manage many forests of our seminatural forest category in compliance with favorable conservation statuses of Natura 2000 forest types. However, a detailed assessment of the economic implications of protecting large forest areas within the EU is needed.

For further seminatural ecosystems (e.g., peatlands, freshwater ecosystems, and heaths), the proposed expansion would be an important step toward conserving remaining ecosystems as called for by Watson et al. (2018). Many of these ecosystems are currently not in good ecological condition in the EU (European Environment Agency 2015). Protecting them might help prevent further damage and facilitate restoration efforts.

High ecoregion-coverage targets would also require the inclusion of arable land in some member state PA networks. Possible management options for these new PAs include traditional restoration approaches to convert arable land into seminatural ecosystems, such as extensively used grasslands (Verhagen et al. 2001). Furthermore, rewilding as a low-cost management strategy for abandoned farmland (Ceaușu et al. 2015) could enable redevelopment into predominantly nature-shaped ecosystems, such as natural forests (Van Uytvanck et al. 2010).

Including not only Natura 2000 sites in our analysis, but also all PA categories reported to the WDPA provided a more realistic picture of the coverage of many ecoregions. However, not all other PA categories strictly aim at biodiversity conservation; thus, their effectiveness to support local biodiversity may be lower than expected. The same constraint may even apply to Natura 2000 areas because not all sites have comprehensive management plans (European Environment Agency 2015). We found a proportion of the current PA network in each ecoregion on productive land, where land-use intensity may be too high for effective biodiversity conservation. For a PA network to effectively protect biodiversity, it does not suffice to create and maintain “paper parks” (Barnes et al. 2018). Thus, the EU member states should adopt adequate restoration and management measures, both for the already existing and for the newly designated PAs.

Despite the urgent need to act on the biodiversity crisis and better safeguard European biodiversity, the EU and its member states would face many challenges if they opted for further expansion of the Natura 2000 network. First, it is still uncertain how high conservation targets would need to be to stop biodiversity loss (Sleep et al. 2017). We, therefore, decided to define 2 potential targets based on Dinerstein et al.’s (2017*a*) operationalization of the Half-Earth vision. These targets are measurable with available metrics and data. Second, a crucial question for the EU and its member states is who would have to protect what. We proposed searching for the optimal solution at the EU level when allocating new PAs, which yields a cost-effective expansion and a systematic increase in the ecoregion and ecosystem representation in the network. However, member states could be affected quite differently depending on the overall strategy the EU adopted, as we visualized by comparing 3 different expansion scenarios. Although the cost-only scenario offered the cheapest solution at EU level to close the gaps in ecoregion coverage, it tended to allocate most additional conservation areas to so-called cheap member states and PUs, a strategy that could be perceived as rather unfair by affected regions or member states. Therefore, the member state equity scenario, aligning the protection levels of member states, yielded a strategy in which member states share the burden of nature protection more equally, but which implies additional costs on the EU level. Third, there is little doubt that the establishment of more PAs may decrease the area for intensive agricultural and forestry production in the EU.

Assessing the economic losses that could result from achieving higher ecoregion-coverage targets was beyond the scope of our study, but should be the subject of future research. Landowners and users have frequently resisted the designation of Natura 2000 sites (Hiedanpää 2002; Welch-Devine 2011; Kati et al. 2015). To raise acceptance for more PA designations among affected stakeholders, positive incentives (Rojas-Briales 2000; Anthon et al. 2010) and bottom-up participatory designation processes (Rauschmayer et al. 2009) could help. Finally, the EU should also scrutinize the effects of higher PA coverage in its territory on global land-use patterns (Lotze-Campen et al. 2018). From a global conservation perspective, there is the danger of saving European biodiversity at the expense of increasing pressure on biodiversity elsewhere on the planet. However, recent studies at European (Zech & Schneider 2019) and global levels (Springmann et al. 2018) indicate substantial environmental benefits if EU citizens would decrease their current consumption levels of agricultural products (e.g., reduce meat consumption).

Our modeling exercise is subject to several limitations. First, our reported land opportunity cost values are only rough estimates of the overall conservation costs and may vary considerably from true costs because we could not include restoration or management cost. Furthermore, we compared ecosystems on a rather broad classification level. Based on CORINE data, we could only include 18 semi- or natural ecosystem classes in our analysis, whereas Annex 1 of the Habitats Directive lists more than 230 habitat types. Although data sets with a finer ecosystem classification, such as the European Red List of habitat types exist, data deficiencies and missing data did not allow us to use them.

Our study provides the first EU-scale assessment on increasing ecoregion-coverage targets toward 30% or even 50% in the PA network. Based on recent land-use data, we identified ecoregions with sufficient natural areas left to reach such high targets theoretically. For all 3 scenarios we explored, our results suggested that most new PAs would need to be designated in seminatural forests, followed by other seminatural ecosystems and arable land. Our results show possible pathways for implementing more ambitious conservation targets in the EU, which should be complemented by a thorough land-use sector analysis to evaluate potential economic implications. With these results, our study provides valuable insights to inform debates for the CBD's and consequently also the EU's post-2020 biodiversity framework.

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Supporting Information

Depiction of all 29 CORINE land-cover classes (Appendix S1), land rent data (Appendix S2), all equations and a description of the modeling system (Appendix S3), details on current and potential protection levels for all EU member states (Appendix S4), detailed allocation of PA to the 6 land-use categories for the 10 largest EU member states (Appendix S5), and a map of the distribution of additional PAs across the PUs for the 50% ecoregion-coverage target (Appendix S6) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than the absence of the material) should be directed to the corresponding author.

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