Supplementary Material

Supplementary information regarding the article "Optimising global conservation, restoration, and agriculture for people and nature",

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1. Additional information on optimisation metrics

Intactness

Beyer et al.[1] define intactness (Q) (Equation 1) as:

$$Q = \frac{\sum_{i=1}^{N}\sum_{j=i}^{N}(w_i w_j)^z \exp(-\beta d_{ij})}{\sum_{i=1}^{N}\sum_{j=i}^{N}\exp(-\beta d_{ij})} \tag{1}$$

where d_{ij} is the distance between cells i and j (km), w is a measure of the quality of the cell in the range [0-1], z is an exponent that scales the product of two quality values, and N is the number of cells within a spatial unit such as an ecoregion. The parameter β determines how the combined value of pairs of cells diminishes as a function of the distance between them. The denominator standardised the metric such that the current state is relative to a hypothetical ideal state in which no habitat loss or degradation has occurred (all habitat weights equal one). Without standardisation, the metric would vary according to ecoregion area and shape, thereby diminishing the ability to compare ecoregions.

To include intactness as an explicit objective in linear programming formulated optimisation problem, we needed to quantify the expected change in intactness as a function of restoration of habitat (or loss of habitat) within a cell. However, there is a complex relationship between the change in the quality of a cell and its nearby neighbours to the change in intactness. We adopted an approach whereby we estimate the expected change in the contribution of a cell to intactness as the quality of that cell changes, assuming that the quality of neighbouring cells remains constant. We then updated this estimate following each increment of habitat restoration, thereby accounting for any changes in the quality of neighbouring cells.

Specifically, the contribution of a cell (i) to intactness (Equation 2) is defined as ref.[1]:

$$Q'_i = \frac{\sum_{j \in M_i} (w_i w_j)^z \exp(-\beta d_{ij})}{\sum_{j \in M_i} \exp(-\beta d_{ij})} \tag{2}$$

where *Mi* is defined as the set of cells falling with a specified radius of cell *i*. The rate at which that cells contribution to intactness (*Q′*) increases as restoration occurs, thereby increasing the habitat quality of that cell, is estimated using the equation for the slope of a line (m) (Equation 3):

$$m = (y_2 - y_1)/(x_2 - x_1) \tag{3}$$

where the numerator represents the change in *Q′* following restoration, and the denominator represents the change in habitat quality within cell i (*w*i). Thus, if *δw* is defined as a small value representing the change in habitat quality and wi represents the current habitat quality, then:

$$dQ'_i = \frac{\sum_{j \in M_i} ((w_i + \delta w) w_j)^z \exp(-\beta d_{ij}) - \sum_{j \in M_i} (w_i w_j)^z \exp(-\beta d_{ij})}{\delta w \sum_{j \in M_i} \exp(-\beta d_{ij})} \tag{4}$$

However, the rate of change in habitat quality differs depending on whether pasture or cropland is restored, with the relative rate of increase in quality being 7/4 times greater for cropland than pasture. This arises because Beyer et al.[1] use a transformation of the human footprint index (HFI)[2,3] to estimate the habitat quality of cells. Specifically, *wi = exp(−γHi*), where H is the human footprint score and γ = 0.402. Pasture and agriculture land uses are two of the eight components that constitute the HFI[3], with their relative weights being 4 and 7, respectively, based on estimates of their relative levels of human pressure following Sanderson et al.[2]. Hence, within the linear programming problem dQ' and $exp(-7\gamma)/exp(-4\gamma)dQ' = 3.34dQ'$ are used to represent the expected relative rate of change in intactness following pasture or cropland restoration respectively.

Nature Contributions to People

For water quality regulation, we followed Chaplin-Kramer et al.[4] and modelled nitrogen export via InVEST Nutrient Delivery Ratio model[5]. We then use these outputs along with data on rural populations (which we assume to have lower access to water treatment) to determine people's needs and nature's contributions as a realised service. The InVEST model maps nutrient sources from watersheds and their transport to the stream. Nutrient loads (sources) are determined based on the land-use/cover map and associated loads and were set accordingly with the 2050 Shared Socioeconomic 3 scenario (SSP3). Each pixel's load is modified to account for the local runoff potential, with SSP3 precipitation serving as a proxy for this runoff potential. Last, the nitrogen retention capacity for a given vegetation type is expressed as a proportion of the amount of nutrient retained from upstream sources by each land use/cover class[4].

Based on the InVEST Coastal Vulnerability Model[5], and modifications made by Chaplin-Kramer et al.[4], we modelled the contribution of coastal natural habitats to mitigating coastal risk in terms of the difference in this risk with and without that habitat present. The risk is assessed through a ranked index based on bio-geophysical variables such as wind exposure, wave exposure, natural habitats, and sea level change. For the latter, we use the sea level rise projected by IPCC for the period 1986–2005 to 2081–2100 for RCP 6.0 of the SSP3 scenario. In addition, we used information on populations along coastlines and living less than 10 metres above sea level to determine the realised benefit. We presented the relative values between optimised scenarios and SSP3 impacts for coastal protection and water quality regulation because lack of calibration precludes an interpretation of absolute values.

Nutrition provided by wild pollinators on each planning unit (pixel of the maps) of agricultural land is calculated according to pollinator habitat sufficiency and the pollination-dependent nutrient production[4]. Pollination sufficiency is based on the pollinator habitat area around the farmland (using a 2km radius). We account for different levels of pollination-dependency of each crop, that is, the percent by which yields are reduced for each crop with inadequate pollination. We assumed the current crop mix in the optimised scenarios, even though the full restoration land cover scenario contained no agriculture (lacking a fully dynamic optimisation). Also, crop content of critical macro and micronutrients (KJ energy/10g, IU Vitamin A/100g and mcg Folate/100g) is used to derive pollination-dependent nutrient production. We normalised these nutrient production values dividing each layer of pollination-dependent nutrient production by the recommended weighted-averaged annual dietary intake for each nutrient calculated using global demographics data. Then, we averaged their normalised values per pixel to calculate the equivalent number of people fed through pollination[4].

Variable uncertainties and sensitivities

In this work, we used systematic uncertainties, as the solution of a linear programming optimisation problem is a set of exact numbers estimating the amount of restoration and agriculture expansion in each planning unit (pixel). The systematic uncertainties of the carbon and opportunity cost layers are described in Strassburg et al.[6] work.

For the extinction risk layer, we derived the uncertainty (δ_{BD} - Equation 5) assuming a variation of ±0.1 on the power parameter z[6]. Hence, the uncertainty on the aggregated final value of total extinction risk is computed using a quadratic propagation of individual (j) uncertainties of extinction risk (e):

$$\delta_{\mathrm{BD}} = \sqrt{\sum_j \left(\frac{\partial e_j}{\partial z}\right)^2 \delta_z^2} \quad (5)$$

The ecosystem´s collapse risk definition is similar to the species extinction risk, therefore its uncertainty (δ_{EC} - Equation 6) is determined analogously:

$$\delta_{\mathrm{EC}} = \sqrt{\sum_j \left(\frac{\partial c_j}{\partial z}\right)^2 \delta_z^2} \quad (6)$$

As described in the Intactness section of this document, there are three relevant parameters for the intactness index: z, γ and β. The value of each one is chosen to meet the criteria described in Beyer et al.[1]. We assumed as a systematic uncertainty of the intactness index (δ_{IT} - Equation 7) the difference of its aggregated value when all these three parameters vary within 10% of its original values:

$$\delta_{\mathrm{IT}} = \sqrt{\left(\frac{\partial \mathrm{IT}}{\partial z}\right)^2 \delta_z^2 + \left(\frac{\partial \mathrm{IT}}{\partial \gamma}\right)^2 \delta_\gamma^2 + \left(\frac{\partial \mathrm{IT}}{\partial \beta}\right)^2 \delta_\beta^2} \quad (7)$$

In the case of water quality regulation, the InVEST NDR model has been shown to be fairly robust, even when not calibrated, when evaluating relative values[4]. At this coarse scale, the greatest sensitivity of the model is to land use/cover data sets (and their corresponding nutrient loads/retention values). The modelled absolute values could show increasing error when using these coarse resolution inputs. However, the relative magnitude of differences between catchments and scenarios, which we chose to present in this work, is more consistent. For pollination and coastal protection, our models had the same uncertainties and sensitivities that Chaplin-Kramer et al.[4] work.

2. Multicriteria optimisation algorithm

The algorithm

We performed spatially explicit multi criteria optimisation based on linear programming[7] when selecting areas for restoration and agriculture expansion. Conservation actions are also being optimised by selecting natural ecosystems not to be converted to agriculture. For each planning unit, the algorithm first calculates the cost-effectiveness of restoration or agriculture expansion actions, using a subset or all metrics depending on the scenario's set-up. We then compute the area to be restored to natural ecosystems or converted to agriculture, based on an objective function (Equation 8) and respective scenario constraints (Equations 9-13) following the equations:

$$\max \sum_{i}^{Np} x_i \left(\frac{w^{b1} b_i^1 + \ldots + w^{bn} b_i^n}{w^{c1} c_i^1 + w^{c2} c_i^2} \right) \tag{8}$$

subject to

$$\sum_{i}^{Np} x_i a_i \leq T \tag{9}$$

$$\sum_{ik}^{Npk} x_{ik} d_{ik} a_{ik} \leq D_k \tag{10}$$

$$\sum_{ik}^{Npk} x_{ik} g_{ik} a_{ik} \leq G_k \tag{11}$$

$$\begin{gathered} -lb_{ik} \leq x_{ik} \leq 0 \\ (\text{if } D_k + G_k \leq 0) \end{gathered} \tag{12}$$

$$\begin{gathered} 0 < x_{ik} \leq ub_{ik} \\ (\text{if } D_k + G_k > 0) \end{gathered} \tag{13}$$

where x is the decision variable indicating the proportion of the planning unit *i* that should be restored to natural ecosystems (positive values of x) or converted to agriculture (negative values of x). The components of the fraction in the objective function (equation 8) represent the metrics being optimised, b for benefits or c for costs, and their respective weight (w). Np is the total number of planning units. The global constraint (equation 9) limits the total net area to be restored (T, in km^2), in which a_i is the planning unit area (in km^2). The following two constraints (equations 10 and 11) limit the total amount (km^2) of agricultural area (D for croplands and G for cultivated grasslands) in country k that can be restored to natural ecosystems (positive values of D and/or G) or need to be converted to agriculture (negative values of D and/or G). The parameters d and g represent the proportion of the decision variable x corresponding to croplands or cultivated grasslands, respectively, being restored to natural ecosystems or converted to agriculture. The value of x can vary between zero and the proportion of natural area of a planning unit (lb), in countries that need agriculture expansion (equation 12), or the proportion of agricultural areas of a planning unit (ub) in countries that can restore (equation 13). Hence, the algorithm indicates optimal areas for restoration - the planning units with the highest gains for benefits and lower costs - and optimal areas for agricultural expansion - the planning units with the lowest losses for benefits and higher opportunity cost.

Weight definition

The metrics' nature and database could represent different responses in the optimisation process. In the case of optimising multiple variables at once, this characteristic could generate an ambalancing between the metrics results. Therefore, we analysed the response of each variable to avoid biases caused by differences between the distribution of the considered criteria. This analysis showed that only the species' extinction risk had poor performance when evaluated along with the other two biodiversity metrics. To balance the response to the species' extinction risk, we defined a higher weight for this metric than the others.

3. Additional discussions

Contribution of each ecosystem type

When comparing the area proportions of each natural ecosystem type between their current (2015) distribution and the area restored in each optimised scenario, we found that wetlands and forests are of the highest relative importance for biodiversity and NCPs metrics, respectively, while forests are of the highest absolute importance for both (Figure S3). Similarly to previous studies[6], a higher proportion of wetlands was restored when the optimisations included the biodiversity metrics than expected if this restoration followed the proportions of original natural land covers (Figure S3), reinforcing the importance of wetland ecosystems in reducing species extinction risks[6]. When optimisation focused on maximising outcomes for NCPs metrics, restoration actions were concentrated in landscapes that originally were forest ecosystems (Figure S3), primarily reflecting their role in sequestering carbon and providing other contributions to human livelihoods.

Accordingly, when the goal is to maximise biodiversity and NCP outcomes, optimal areas for restoration concentrate on both wetland and forest classes, located mainly in Southeast Asia, Africa and Central and South America, as well as in temperate climates such as eastern regions of Europe, United States and Canada (Figure 3 in the manuscript). On the other hand, arid ecosystems had less area selected than expected if restoration were planned following current land cover proportions in all scenarios. This is explained not only because these systems have fewer threatened species[8] and lower outcomes for other benefit metrics but also because, in our scenarios, several countries that have large arid regions converted these natural ecosystems into agricultural land to guarantee food security.

Limitations

Some limitations were presented throughout the main text and are complemented in this section:

- We fully acknowledge that effective and equitable conservation and restoration actions must be rooted in participatory and inclusive processes at local scales. Still, global spatial optimisation provides relevant inputs and contributions to conservation-related decisions[9,10]. This study has limitations in representing specific local contexts, mainly because it requires inadequate assumptions at the global level scale related to social aspects, relational values, and stakeholder preferences[9]. For instance, we based our discussions on scenarios with local constraints, accounting for reconciling food production with restoration actions at the local level, even though this premise does not avoid the real risk of displacing people.

- Although we recognise that restoring partially degraded lands can also provide substantial benefits to biodiversity and people[11], our approach only considers restoration of fully agricultural land to entirely natural vegetation, because the costs and benefits of restoring degraded natural ecosystems are poorly quantified[6].

- Due to the challenges in implementing a dynamic approach, we did not consider the positive feedback of carbon sequestration from restoration actions on the other benefit metrics, especially those that incorporate climate change impacts.

- We do not consider the impacts of different agricultural intensification practices on biodiversity and NCP metrics. Depending on the approach and starting point, there are likely negative externalities on biodiversity and NCP, especially due to increases in fertilisers, pesticides, and other chemical inputs. However, we reinforce the necessity to advocate for the best intensification practices in the international agendas, public policies, and implementation actions.

- Carbon stock was estimated using the current land-use maps that Strassburg et al[12] updated. However, as in Strassburg et al.[6], we assumed a constant value for aboveground carbon stock (6 tC ha^{-1}) for all agricultural land. This stock can vary considerably across land uses, e.g., up to 97 tC ha^{-1} in Indonesian agricultural lands with high tree cover[13,14]. However, as Strassburg et al.[12] showed, different values of carbon stock have an impact of less than 8.6% on carbon sequestration results when applied in planning units containing mosaic and agroforestry landscapes.

- We recognise that our opportunity cost metric considers only one dimension of the loss of potential gains from other alternatives. We have not considered some aspects that might change these costs, such as the reliability of a diversity of crops and land uses, subsistence production not accounted for in commodity prices, political and economic forces, and effects on cultural identities associated with agricultural landscapes, among others[9,15]. For instance, the opportunity costs for cultivated grasslands only account for cattle to produce beef and, therefore, miss other products (e.g., milk) and other ruminants (e.g., sheep and goats). On the other hand, we have also not considered a variety of benefits that people derive from natural areas that, if lost, can have disproportionate impacts on local communities, including relational values.

- We do not account for subsistence farming due to a lack of spatially explicit data at global level. Hence, our approach only considers agricultural areas used for commodities production. For instance, this limitation impacts the restoration actions allocated in India, overestimating them. Although global spatial optimisations are important inputs to conservation-related decisions, this limitation reinforces that effective and equitable conservation and restoration actions must be based on participatory and inclusive processes at local scales[16].

- The highest increases in pasture and cropland production across the five SSPs scenarios are observed in SSP3[17]. To meet these high agricultural demands, the fractions of yield gap closure proposed in this study should be in addition to the yield intensification already projected in the SSP3 scenario. A limitation of this work is that we do not directly project the yield gap for the 2050 SSP3 scenario due to a lack of data. Nonetheless, the projected agricultural intensification in the SSP3 scenario is low compared to other SSPs[17]. Also, we considered conservative the assumption of meeting 2050 agricultural production only with yield gap closure, as by 2050, people will see more food production technologies emerging, which will have a much smaller land footprint.

- The modeling of 'unidirectional' objectives in each country, i.e., restore natural ecosystems or convert to agriculture, but not a mix of the two, was a necessary simplification within our approach to identifying where each country would meet its 2050 agriculture production. However, it misses national complexities, especially for large and heterogeneous countries, with potential impacts on our results, especially for the NCPs with local/regional benefits and to small-range species.

- Our results are only illustrative of the potential of spatial optimisation. Since many land parcels entering the optimisation are nearly identical, countless alternative solutions are very similar in their optimality, which is also true for the spatial allocation of agricultural productions[18]. Therefore, we are not suggesting that the spatial solutions coming out of our analysis should be the only guidance on implementation. We use linear programming and present only one solution for each scenario constellation: the upper bound of efficiency gain given SSP3 baseline conditions. This has important policy implications as there is much more flexibility to implement spatial solutions in landscapes, countries, and globally. When it comes to implementing restoration and conservation planning, it is important to take a scientific co-creation approach, where stakeholders will be able to negotiate over many alternative implementation scenarios, which are more or less outcome neutral but very different in political acceptability[19,20]. Such flexibility will allow for efficient implementation mechanisms, compensating coalitions of the willing for their environmental performance using a bottom-up approach that top-down optimisation models support. The main purpose of these models is to suggest numerous implementation options that allow stakeholders to negotiate.

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Supplementary Tables

Table S1 - **The performance of the biodiversity metrics and carbon after optimal spatial allocation of restoration, conservation and agriculture.** It considers low, intermediate and high efforts to increase the world's natural areas, closing yield gaps and without local constraints. Scenarios vary depending on the combination of optimisation metrics used: biodiversity (optimisation using all biodiversity metrics simultaneously), NCPs (optimisation using all NCPs metrics simultaneously), benefits (optimisation using all biodiversity and NCPs metrics simultaneously), and costs (optimisation using opportunity and implementation costs). We did not show values for the other NCPs as we could not ensure that every landscape subjected to restoration actions would have some agricultural land serving as sources of fertilisers (for water quality regulation) and/or receiving pollination service.

Global effort	**Scenario**	**Net CO_2 sequestration after SSP3 2015-2050 impacts being mitigated and/or compensated ($GtCO_2$)**	**Reduction in ecoregions' vulnerability after SSP3 2015-2050 impacts being mitigated and/or compensated (%)**	**Reduction in the SSP3 2015-2050 impacts on ecosystems structural integrity (%)**	**Reduction in the SSP3 2015-2050 impacts on species' extinction risk (%)**
Low	Benefits	226	34	25	78
Low	Benefits and Costs	198	27	28	65
Low	NCPs	240	28	19	58
Low	NCPs and Costs	205	23	24	49
Low	Biodiversity	135	37	35	87
Low	Biodiversity and Costs	115	30	36	72
Low	Costs	87	21	31	40

Intermediate	Benefits	286	41	27	86
Intermediate	Benefits and Costs	252	34	32	73
Intermediate	NCPs	300	36	20	67
Intermediate	NCPs and Costs	257	30	27	58
Intermediate	Biodiversity	184	44	38	97
Intermediate	Biodiversity and Costs	159	36	39	80
Intermediate	Costs	131	26	34	49
High	Benefits	368	51	32	97
High	Benefits and Costs	320	43	37	84
High	NCPs	378	47	24	81
High	NCPs and Costs	327	40	32	69
High	Biodiversity	260	53	43	100
High	Biodiversity and Costs	221	44	42	90
High	Costs	200	38	37	64

Table S2 - **Percentage increase of species' extinction risk under the SSP3 RCP7.0 scenario, considering 9 different global climate models**. The results were divided by the percentage of increase due to the project climate and land use changes. These estimates were obtained using the intersection between IUCN RedList data and the climate models ("with intersection") and using only the climate models ("without intersection") when generating species' ranges (see Methods for more details). Global climate models: bc = BCC-CSM2-MR; ca = CanESM5; cm = CNRM-CM6-1; cn = CNRM-ESM2-1; gf = GFDL-ESM4; ip = IPSL-CM6A-LR, ms = MIROC-ES2L; mi = MIROC6; mr = MRI-ESM2-0.

Intersection	**GCM**	**bc**	**ca**	**cm**	**cn**	**gf**	**ip**	**mi**	**mr**	**ms**
with intersection	**Total increase (%)**	59	152	59	59	60	67	35	44	47
	Increase due to projected climate change (%)	44	138	45	45	46	53	21	30	32
	Increase due to projected land use change (%)	15	14	15	14	14	14	15	14	15
without intersection	**Total increase (%)**	21	95	23	23	23	27	3	8	12
	Increase due to projected climate change (%)	9	84	11	11	11	16	-9*	-3*	0
	Increase due to projected land use change (%)	12	11	12	12	12	11	12	11	12

* These values represent the reduction of species extinction risk compared to the current situation due to climate change, as in the "without intersection" scenarios species would be able to migrate to any future suitable habitat.

Table S3 - **Percent reduction in the SSP3 2015-2050 impacts on species' extinction risk, considering 9 different global climate models**. The results are per global effort of increasing the world's natural areas through restoration actions and closing yield gaps, per scenario with different combinations of benefits and costs metrics, and with or without restrictions of restoration at the local level (see main text for more details). Global climate models: bc = BCC-CSM2-MR; ca = CanESM5; cm = CNRM-CM6-1; cn = CNRM-ESM2-1; gf = GFDL-ESM4; ip = IPSL-CM6A-LR, ms = MIROC-ES2L; mi = MIROC6; mr = MRI-ESM2-0.

Global effort	Scenario	Local constraints	bc	ca	cm	cn	gf	ip	mi	mr	ms
Low	Benefits	no	78%	28%	78%	77%	77%	67%	100% (+11%)*	100% (+2%)*	99%
Low	Benefits and Costs	no	65%	23%	65%	65%	64%	56%	100% (+4%)*	87%	82%
Low	NCPs	no	58%	20%	58%	58%	57%	49%	99%	78%	74%
Low	NCPs and Costs	no	50%	17%	49%	49%	48%	42%	84%	66%	63%
Low	Biodiversity	no	88%	31%	87%	87%	86%	75%	100% (+17%)*	100% (+8%)*	100% (+5%)*
Low	Biodiversity and Costs	no	73%	26%	72%	72%	71%	62%	100% (+8%)*	97%	92%
Low	Costs	no	41%	15%	40%	40%	41%	35%	70%	55%	52%
Low	Benefits	yes	64%	23%	64%	64%	63%	55%	100% (+3%)*	86%	82%
Low	Benefits and Costs	yes	55%	19%	54%	54%	54%	47%	93%	73%	70%
Low	NCPs	yes	57%	20%	57%	57%	56%	49%	97%	76%	73%
Low	NCPs and Costs	yes	48%	17%	48%	48%	47%	41%	82%	64%	61%
Low	Biodiversity	yes	68%	24%	68%	68%	67%	58%	100% (+6%)*	91%	87%
Low	Biodiversity and Costs	yes	56%	20%	56%	56%	55%	48%	96%	75%	71%
Low	Costs	yes	46%	16%	45%	45%	45%	38%	78%	61%	58%
Intermediate	Benefits	no	87%	31%	86%	86%	85%	74%	100% (+16%)*	100% (+7%)*	100% (+4%)*
Intermediate	Benefits and Costs	no	74%	26%	73%	73%	72%	63%	100% (+9%)*	98%	93%
Intermediate	NCPs	no	68%	24%	67%	67%	66%	57%	100% (+5%)*	91%	86%
Intermediate	NCPs and Costs	no	59%	21%	58%	58%	58%	50%	100%	78%	75%
Intermediate	Biodiversity	no	97%	35%	97%	97%	96%	83%	100% (+23%)*	100% (+13%)*	100% (+11%)*

Intermediate	Biodiversity and Costs	no	81%	29%	80%	80%	79%	69%	100% (+13%)*	100% (+3%)*	100% (+1%)*
Intermediate	Costs	no	50%	17%	49%	49%	49%	42%	84%	66%	63%
Intermediate	Benefits	yes	75%	26%	74%	74%	73%	64%	100% (+9%)*	100%	94%
Intermediate	Benefits and Costs	yes	64%	22%	63%	63%	62%	54%	100% (+3%)*	84%	80%
Intermediate	NCPs	yes	66%	23%	66%	65%	65%	56%	100% (+4%)*	88%	83%
Intermediate	NCPs and Costs	yes	57%	20%	56%	56%	55%	48%	96%	75%	72%
Intermediate	Biodiversity	yes	79%	28%	79%	79%	78%	67%	100% (+12%)*	100% (+3%)*	100%
Intermediate	Biodiversity and Costs	yes	65%	23%	65%	65%	64%	55%	100% (+4%)*	87%	83%
Intermediate	Costs	yes	50%	18%	49%	49%	49%	42%	86%	67%	64%
High	Benefits	no	98%	35%	97%	97%	96%	84%	100% (+23%)*	100% (+14%)*	100% (+11%)*
High	Benefits and Costs	no	84%	30%	84%	84%	82%	72%	100% (+15%)*	100% (+5%)*	100% (+3%)*
High	NCPs	no	82%	29%	81%	81%	80%	69%	100% (+13%)*	100% (+4%)*	100% (+1%)*
High	NCPs and Costs	no	70%	25%	69%	69%	68%	59%	100% (+6%)*	92%	88%
High	Biodiversity	no	100% (+3%)*	38%	100% (+3%)*	100% (+3%)*	100% (+3%)*	91%	100% (+28%)*	100% (+18%)*	100% (+16%)*
High	Biodiversity and Costs	no	91%	32%	90%	90%	89%	77%	100% (+19%)*	100% (+9%)*	100% (+7%)*
High	Costs	no	64%	23%	64%	63%	63%	55%	100% (+3%)*	86%	82%
High	Benefits	yes	85%	30%	85%	85%	84%	73%	100% (+16%)*	100% (+6%)*	100% (+4%)*
High	Benefits and Costs	yes	77%	27%	76%	76%	75%	65%	100% (+11%)*	100% (+1%)*	97%
High	NCPs	yes	79%	28%	79%	79%	78%	67%	100% (+12%)*	100% (+3%)*	100%
High	NCPs and Costs	yes	70%	25%	70%	69%	69%	59%	100% (+7%)*	93%	88%
High	Biodiversity	yes	88%	31%	88%	88%	87%	75%	100% (+18%)*	100% (+8%)*	100% (+5%)*
High	Biodiversity and Costs	yes	79%	28%	79%	79%	78%	68%	100% (+12%)*	100% (+3%)*	100%
High	Costs	yes	68%	24%	67%	67%	67%	58%	100% (+5%)*	90%	86%

* The value in parenthesis represents the reduction of species extinction risk compared to the current situation, after the impacts of the SSP3 scenario were mitigated and/or compensated.

Table S4 - **Area (km^2) of ecosystems whose structural integrity was reduced to a low/very low level (< 0.33 on a scale of 0 to 1) or increased to a medium/high level (> 0.33 on a scale of 0 to 1) in the SSP3 scenario compared to the current situation**. We divided the results by the area whose structural integrity changed only because of projected population change and only due to land use changes. Note that their sum does not equal the total change line, as there are ecosystems that are under the influence of both population and land use changes.

	Area where ecosystem structural integrity decreased to low/very low levels (km^2)	**Area where ecosystem structural integrity increased to medium/high levels (km^2)**
Due to land use change only	139,795	6,917
Due to human population change only	2,065,589	139,647
Total	4,286,825	240,130

Table S5 - **Total CO_2 sequestration and emissions compared to the current situation due to the projected land use change in SSP3 and optimised scenarios**. The results are per global effort of increasing the world's natural areas and closing yield gaps, per scenario with different combinations of benefits and costs metrics and with restrictions of restoration at the local level. The sequestration values correspond to the long-term potential of carbon stocks after restoration.

Global effort	Scenario	Sequestration ($GtCO_2$)	Emission ($GtCO_2$)
-	SSP3	19.95	109.04
Low	Benefits	210.43	28.84
Low	Benefits and costs	181.52	33.59
Low	NCP	212.54	26.97
Low	NCP and costs	181.97	32.60
Low	Biodiversity	178.35	47.42
Low	Biodiversity and costs	162.59	49.53
Low	Costs	159.77	50.35
Intermediate	Benefits	264.58	25.67
Intermediate	Benefits and costs	227.12	30.56
Intermediate	NCP	268.37	23.98
Intermediate	NCP and costs	227.99	29.61
Intermediate	Biodiversity	219.19	43.82
Intermediate	Biodiversity and costs	200.63	45.57
Intermediate	Costs	193.63	45.41
High	Benefits	324.39	24.79
High	Benefits and costs	290.08	29.25
High	NCP	326.05	23.17
High	NCP and costs	290.90	28.34
High	Biodiversity	285.12	42.41
High	Biodiversity and costs	271.33	43.79
High	Costs	269.12	43.00

Table S6 - **Results for seven scenarios that consider different metrics with a high level of global efforts to net increase natural areas and intensity agriculture productivity**. The simulations that generated these estimates did not constraint the global efforts at the country level.

Global effort	**Local constraints**	**Scenario**	**Net CO2 sequestration after SSP3 2015-2050 impacts being mitigated and/or compensated (GtCO2)**	**Reduction in ecoregions' vulnerability after SSP3 2015-2050 impacts being mitigated and/or compensated (%)**	**Reduction in the SSP3 2015-2050 impacts on ecosystems' structural integrity (%)**	**Reduction in the SSP3 2015-2050 impacts on water quality regulation (%)**	**Increase in coastal protection after the SSP3 2015-2050 impacts being mitigated and/or compensated (%)**	**Additional number of equivalent people fed through pollination (Billions)**	**Reduction in the SSP3 2015-2050 impacts on species' extinction risk (%)**
High	yes	Benefits	425	61%	99%	-	0.11116%	-	104%
High	yes	Benefits and Costs	366	53%	97%	-	0.11106%	-	93%
High	yes	NCPs	433	54%	98%	-	0.11115%	-	86%
High	yes	NCPs and Costs	372	47%	96%	-	0.11106%	-	82%
High	yes	Biodiversity	282	66%	100% (*+39)	-	0.11113%	-	100%(**+14%)
High	yes	Biodiversity and Costs	309	61%	100% (*+38)	-	0.11108%	-	100%(**+7%)
High	yes	Costs	236	42%	98%	-	0.11106%	-	72%
High	no	Benefits	343	56%	96%	20%	0.11115%	3.5	92%
High	no	Benefits and Costs	290	48%	98%	17%	0.11106%	2.5	84%
High	no	NCPs	348	53%	94%	20%	0.11115%	3.5	82%
High	no	NCPs and Costs	289	44%	97%	17%	0.11107%	2.6	79%
High	no	Biodiversity	278	57%	100% (*+7)	14%	0.11112%	1.6	100%
High	no	Biodiversity and Costs	274	55%	100%(*+10)	12%	0.11109%	1.5	97%
High	no	Costs	249	44%	99%	12%	0.11106%	1.4	75%

* The value in parenthesis represents the net area (Mha) of natural lands whose structural integrity has been increased compared to the current situation, after the impacts of the SSP3 scenario were mitigated and/or compensated. ** The value in parenthesis represents the reduction of species extinction risk compared to the current situation, after the impacts of the SSP3 scenario were mitigated and/or compensated

Supplementary Figures

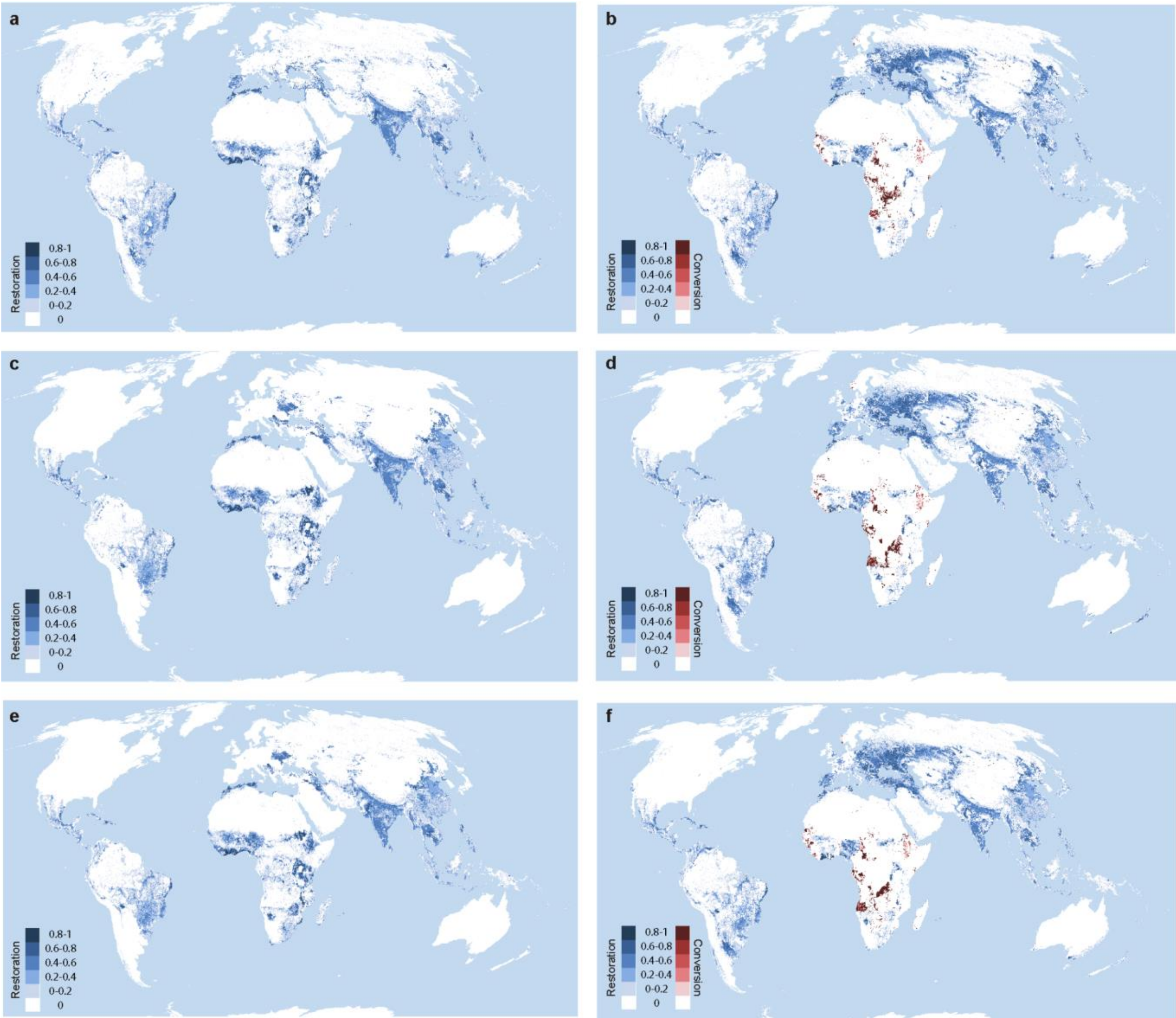

Figure S1 - **Global areas selected for land use change.** They consider the restoration of natural ecosystems (blue) and the conversion to agriculture (red), without (a, c, and e) and with (b, d, f) country-level restrictions, in a situation where high efforts are being made to increase the world's natural areas and close yield gaps. Conservation actions are not illustrated separately but located within the zones where no land use change was projected (0 values). The shades of blue/red represent proportions of each planning unit that were selected to be restored/converted. The optimisations focused on all biodiversity and costs metrics (a and b), all nature's contributions to people and costs metrics (c and d) and all benefits and costs metrics (e and f). All maps consider continuation of local agricultural production, with constraints to restoration actions at the local level

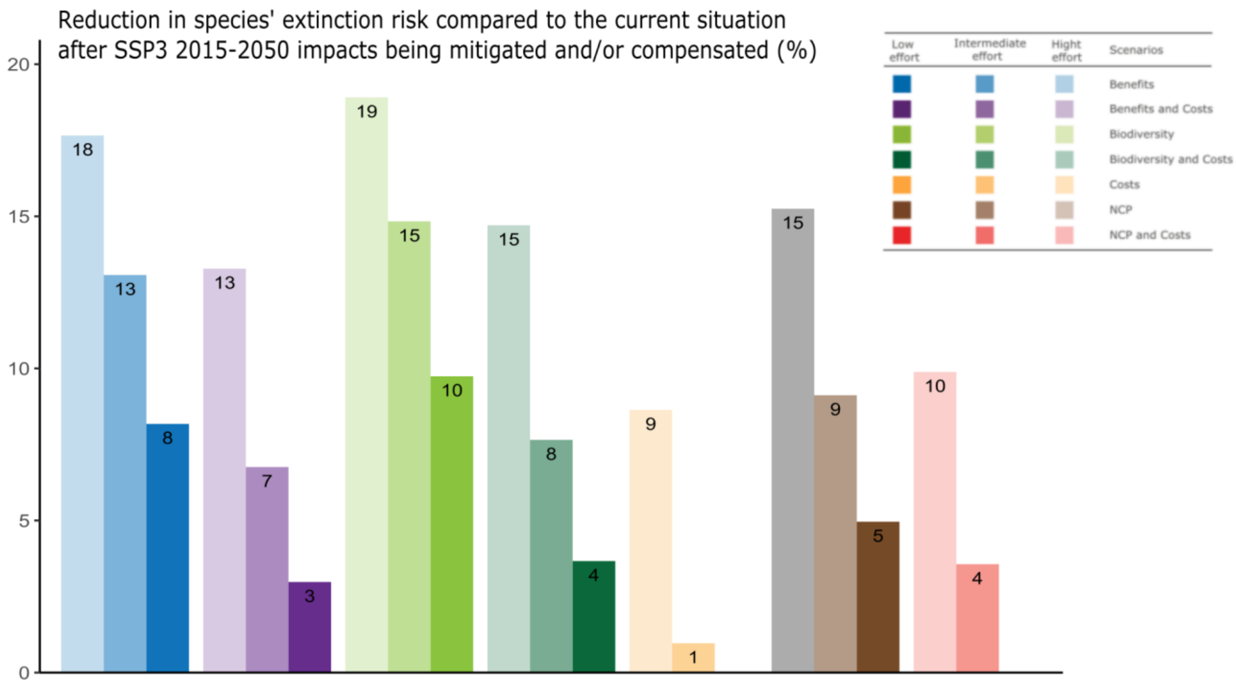

Figure S2 - **Reduction in species' extinction risk, compared to the current (2015) situation.** This result assumes that species can reach all habitats with suitable climate conditions within their current or neighbouring ecoregions until 2050. The results are per global effort of increasing the world's natural areas through restoration actions and closing yield gaps, per scenario with different combinations of benefits and costs metrics, and with restrictions for restoration at the local level (see main text for more details).

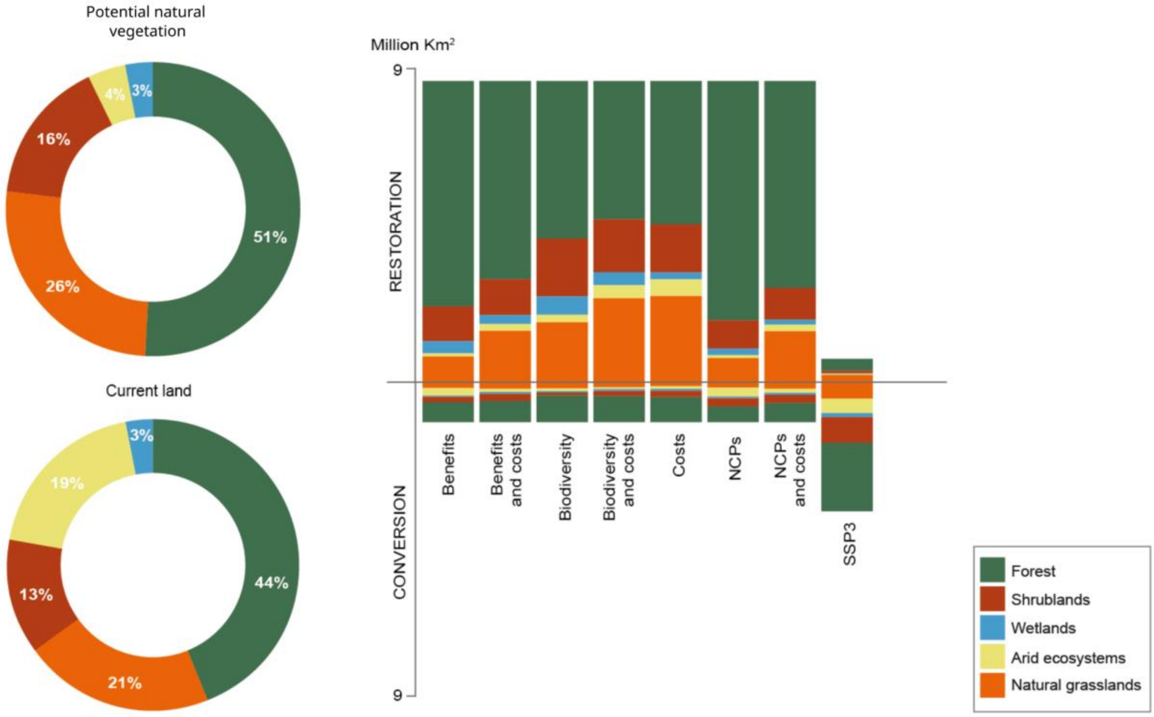

Figure S3 - Percentage of a) the area of each natural land cover type that could be potentially restored and b) the area currently occupied by each natural land cover type: forest (green); shrublands (red); wetlands (blue); arid ecosystems (yellow); and natural grasslands (orange). c) The bars show the proportion of area per natural land cover type to be restored or converted to agriculture in different scenarios: benefits (using all biodiversity and NCPs metrics); benefits and costs (all metrics combined); biodiversity (the three biodiversity metrics); biodiversity and costs; NCPs (all four NCPs metrics); NCPs and costs; costs (opportunity and implementation costs) and the Shared Socioeconomic Pathway 3 (SSP3).