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# 1 Complementary biodiversity metrics are essential to adequately 2 evaluate no net loss

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18  
19 Keywords: Ecosystem condition, extinction risk, corporate impacts, mean species abundance (MSA), LIFE score,  
20 STAR

## 21 **Abstract**

22 Business and finance sector actors have the potential to contribute substantially to bending  
23 the curve of biodiversity loss, in the context of a global nature positive agenda. The scope of  
24 application of the mitigation hierarchy – avoiding and reducing negative impacts on nature, and  
25 compensating for the residual ones – is being extended, from localised impacts to potentially  
26 diffuse ones at the level of corporate value chains, to achieve at least no net loss (NNL) of  
27 biodiversity. This poses a need to define and quantify the equivalence of biodiversity losses and  
28 gains, which may depend on the metric(s) used to measure them. Here we evaluate and compare  
29 three biodiversity metrics in a global NNL context, using an optimization approach to identify  
30 the minimum area to be restored in order to compensate for biodiversity losses from corporate  
31 activities. The three metrics are Mean Species Abundance (MSA), the Land-cover Change  
32 Impacts on Future Extinctions (LIFE) score and the Species Threat Abatement and Restoration  
33 (STAR) metric. We also investigate how spatial scale constraints imposed on restoration affect  
34 the achievement of NNL across metrics. We observe cases for all metrics where NNL cannot  
35 be achieved within strict spatial scale constraints. We also find that NNL for one metric does  
36 not guarantee NNL for the others, and that differences in the nature of the metrics (MSA,  
37 compared to LIFE/STAR) influences the overall area restored to achieve NNL. The results  
38 highlight how outcomes for biodiversity will be more satisfactory if using two or more  
39 complementary metrics for value-chain level NNL assessments, and how avoiding and  
40 minimizing losses is key, as compensation within certain spatial constraints is not always  
41 possible.

## 42 1. Introduction

43 In the face of the current biodiversity crisis, bending the curve of biodiversity loss is  
44 increasingly urgent (IPBES, 2019). Business and finance sector actors, among others, have the  
45 potential to contribute substantially to this goal (Mace et al., 2018). Target 15 of the Kunming-  
46 Montreal Global Biodiversity Framework (GBF) specifically aims to reduce the negative and  
47 increase the positive impacts of business on biodiversity and to encourage more sustainable  
48 production (Convention on Biological Diversity, 2022). Stemming corporate losses of  
49 biodiversity is linked to the concept of “no net loss” (NNL) (Robertson, 2000), frequently  
50 referred to in development projects (Maron et al., 2018). According to the mitigation hierarchy,  
51 adverse impacts on biodiversity should first be avoided as much as possible, then minimised;  
52 restoration should then be implemented for the biodiversity that has been impacted, and  
53 remaining residual impacts should be offset in order to achieve (at least) NNL (BBOP, 2012).

54 In practice, current offsetting – whether regulatory, required by funders or voluntary (Bull  
55 and Strange, 2018) – focuses on impacts of direct operations on a defined set of priority  
56 biodiversity features. Approaches to dimensioning the offsets differ, but often include both  
57 overall ecosystem area and condition (Gardner et al., 2013), as well as priority features (species  
58 and/or threatened/distinctive ecosystems) considering irreplaceability and vulnerability  
59 (Gonçalves et al., 2015). For example, the International Finance Corporation's (IFC's)  
60 Performance Standard 6 includes provisions for both natural habitats and critical habitats, *e.g.*  
61 that include highly threatened species or constitute unique ecosystems (IFC, 2012). The  
62 DEFRA Biodiversity Metric, for measuring compulsory biodiversity net gain of developments  
63 in the UK, accounts for habitat area, quality, distinctiveness and its local strategic significance  
64 (DEFRA, 2024). Offsets involve equivalence requirements, with limited fungibility between  
65 losses and gains of different biodiversity features (Gardner et al., 2013). Measuring outcomes  
66 directly at the sites of impact instead of through indirect techniques is recommended (Gardner  
67 et al., 2013). Dimensioning of offsets depends on the metrics used for measuring losses and  
68 gains: in an Uzbek region, offset requirements for oil and gas infrastructure varied by up to an  
69 order of magnitude, and did not always lead to NNL, across a range of species- or habitat-based  
70 methods used for calculating the required gain (Bull et al., 2014). Similarly, Marshall et al.  
71 (2022) found different offset requirements and outcomes for simulated developments in  
72 Australia depending on the habitat- or species-based biodiversity metric employed.

73 However, attention of business and finance is now moving beyond direct operations to the  
74 value chain; reducing and compensating impacts up- and downstream, with commitments to  
75 achieve NNL and even a net positive impact (NPI) at the corporate level (Rainey et al., 2015;  
76 Silva et al., 2019; zu Ermgassen et al., 2022), in the context of nature positive approaches  
77 (Business for Nature, 2022; ICMM, 2024; Locke et al., 2021; Milner-Gulland, 2022). Here,  
78 loss-gain accounting is much less clear-cut with regard to assessing both impacts and gains  
79 expected from the compensation actions, as well as the equivalence of the two (Maron et al.,  
80 2023), since measures of biodiversity are contingent on the scale of the analysis and the metrics  
81 chosen (McGill et al., 2015). For example, evaluating the risk of vertebrate biodiversity loss  
82 from soy production in Brazil, Argentina and Paraguay, Molotoks et al. (2023) found different  
83 hotspots of threat dependent on the group of species selected (threatened, endemic, affiliated to  
84 forest habitat, or all species). Countries identified as having higher consumption-based  
85 biodiversity footprints differ when calculated with metrics of alpha or gamma diversity  
86 (Marquardt et al., 2019). Each metric of biodiversity is a proxy for one or several component(s)  
87 of biodiversity's complexity. Corporates may choose metrics that can track prioritised  
88 components of biodiversity and also support value-chain measurements, potentially across the  
89 globe. Dimensioning and measuring achievement of NNL at the value-chain level implies some  
90 level of aggregation of dispersed and dissimilar impacts – on different ecosystems, species, *etc.*

91 – into a single assessment. In many cases, incomplete knowledge of the exact location of a  
92 corporate’s impacts creates a further complication. The feasibility of demonstrating NNL at  
93 value-chain level likely is influenced both by the choice of loss-gain metric(s) and the scale at  
94 which they are aggregated and/or considered fungible. However, quantification of this influence  
95 for metrics that are already being used to track biodiversity impacts in corporate contexts has  
96 yet to be fully explored.

97 To address this, we examine the degree with which a restoration plan designed to achieve  
98 NNL when using a given biodiversity metric also achieves NNL as measured with alternative  
99 biodiversity metrics. We also examine how spatial scale constraints on restoration (related to  
100 either administrative or ecological boundaries) influence the area requirements for NNL and  
101 whether it can be achieved. To do this, we develop and apply a framework to assess required  
102 NNL actions for activities inducing biodiversity loss in different locations (*e.g.*, for value chains)  
103 in relation to the choice of the metric used to measure biodiversity losses and gains, and to the  
104 scale at which NNL is defined. For fictitious value-chain biodiversity losses we compare  
105 restoration requirements to achieve NNL for three metrics and three geographical constraints:  
106 anywhere globally (no constraint), within the countries of the losses (economically and  
107 politically relevant scale), and within the ecoregions of the losses (ecologically relevant scale).

108 The metrics assessed are Mean Species Abundance (MSA), the Land-cover change Impacts  
109 on Future Extinctions (LIFE) metric and the Species Threat Abatement and Restoration (STAR)  
110 metric. MSA is a measure of ecosystem condition, quantifying local biodiversity intactness at  
111 the assemblage level (Alkemade et al., 2009), while LIFE and STAR are species-level metrics  
112 of extinction risk. LIFE measures the effect of land-use change on the extinction probability of  
113 species, relative to a historic baseline using a non-linear persistence score (Durán et al., 2020;  
114 Eyres et al., 2024). STAR quantifies the potential contribution of habitat restoration and/or  
115 threat abatement to the reduction of species’ extinction risk through a linear relationship (Mair  
116 et al., 2021). These are three of many available biodiversity metrics, that were chosen since  
117 MSA and STAR are both cited in the TNFD’s assessment approach (TNFD, 2023), as well as  
118 in the GBF, as complementary indicators for goal A (MSA), and targets 4 and 15 (STAR). LIFE  
119 scores are expected to be made publicly available and appear promising for a range of  
120 applications, in particular as the metric enables assessment of both continued corporate impacts  
121 and gains from restoration (Eyres et al., 2024). All three are therefore candidate metrics for  
122 assessing losses and gains in the context of nature-positive approaches.

## 123 **2. Methods**

### 124 **2.1 Overview of the approach**

125 We consider a number of hypothetical loss simulations, each consisting of a set of localised  
126 impacts with corresponding biodiversity loss, mimicking the multiple impacts of a value-chain  
127 (see section 2.3 for details). Per simulation, we identify the minimum localised area to restore  
128 to achieve NNL using one of the three metrics as target. We then calculate the percentage of  
129 NNL achieved as measured by the other metrics, for restoration over the same localised area.  
130 This computation is done under three different spatial scale constraints (global *i.e.*  
131 unconstrained; country; ecoregion), defining the geographic scale at which NNL is defined, *i.e.*,  
132 the scale at which losses are aggregated and where restoration can occur. We repeat the exercise  
133 changing the metric used as a target in the restoration problem, leading to nine cases: three  
134 target metrics combined with three spatial scale constraints. The following sections describe  
135 the methodology in detail.

### 136 **2.2 Defining equivalence of losses and gains for each metric**

137 For each metric we define equivalence of losses and gains of biodiversity for terrestrial  
 138 ecosystems. Metric data are available at a grid cell level. We consider multiple losses and gains,  
 139 each occurring in distinct grid cells. Losses are assumed to arise from corporate activities  
 140 leading to a total destruction of habitat and biodiversity. Gains are assumed to arise immediately  
 141 and completely from habitat restoration via land-use or land cover change, restoring a set of  
 142 habitats to their original state before human intervention. Details on the definitions of the  
 143 metrics are provided in sections 2.2.1-2.2.3 below and in Supplementary Material 1.

#### 144 2.2.1 Mean Species Abundance (MSA)

145 Mean Species Abundance (MSA) is an assemblage-level measure of local biodiversity  
 146 intactness (0-1, dimensionless) (Alkemade et al., 2009). Under the assumption that given  
 147 corporate activities result in a complete loss of the remaining biodiversity in grid cells  $i$ , the  
 148 loss of MSA can be quantified as:

$$MSA_{loss} = \sum_i MSA_i \cdot A_i \cdot f_{loss,i} \quad \text{Eq. 1}$$

149 where  $MSA_{loss}$  is the total loss of biodiversity ( $>0$ , expressed in MSA.km<sup>2</sup>);  $MSA_i$  is the  
 150 biodiversity in cell  $i$  prior to the impact (0-1, MSA);  $A_i$  is the area of cell  $i$  (km<sup>2</sup>); and  $f_{loss,i}$  is  
 151 the fraction of cell  $i$  where the impact is occurring (0-1, dimensionless).

152 The global data layer available for MSA evaluates remaining biodiversity by decomposing the  
 153 effect of several pressures. Restoration here is assumed to only lead to gains through land-use  
 154 changes, since other pressures such as climate change can continue to affect biodiversity even  
 155 after habitat restoration. Thus, equivalence assumes that a loss and a gain can be expressed as  
 156  $MSA_{gain} = MSA_{loss}$ , with:

$$MSA_{gain} = \sum_j \frac{1 - MSA_{j,LU}}{\sum_x (1 - MSA_{j,x})} (1 - MSA_j) \cdot A_j' \cdot f_{gain,j} \quad \text{Eq. 2}$$

157 where  $MSA_{gain}$  is the total gain in biodiversity ( $>0$ , expressed in MSA.km<sup>2</sup>);  $MSA_{j,LU}$  is the  
 158 remaining biodiversity in relation to the land-use pressure in cell  $j$ ;  $x$  designates all pressures  
 159 affecting MSA;  $MSA_j$  is the biodiversity in cell  $j$  prior to the restoration (0-1, MSA);  $A_j'$  is the  
 160 maximum restorable area in cell  $j$  (km<sup>2</sup>); and  $f_{gain,j}$  is the fraction of restorable area in cell  $j$   
 161 that is restored (0-1, dimensionless).

162 Losses and gains are expressed in MSA.km<sup>2</sup> to account for the area that is affected by  
 163 impacts/restoration actions.

#### 164 2.2.2 Land-cover change Impacts on Future Extinctions (LIFE)

165 The Land-cover change Impacts on Future Extinctions (LIFE) metric is based on the  
 166 persistence score (P), which reflects the likelihood that a species will persist as a function of its  
 167 area of habitat (AOH) (Durán et al., 2020; Eyres et al., 2024). Thus, losses ( $\Delta P < 0$ ) or gains  
 168 of persistence ( $\Delta P > 0$ ) can be calculated based on losses or gains in AOH. Summed across all  
 169 species, this provides biodiversity losses, quantified using the LIFE score (Eyres et al., 2024)  
 170 in the following way:

$$LIFE_{loss} = \sum_i \sum_s \Delta P_{i,s} \cdot f_{loss,i} \quad \text{Eq. 3}$$

171 where  $LIFE_{loss}$  is the total loss ( $<0$ , dimensionless) of species persistence probability (P);  
 172  $\Delta P_{i,s}$  is the marginal change in P for species  $s$  when cell  $i$  is completely destroyed ( $<0$ ,

173 dimensionless), independently of all other cells; and  $f_{loss,i}$  is the fraction of cell  $i$  where the  
 174 impact is occurring (0-1, dimensionless).

175 Persistence is calculated as the remaining proportion of a species AOH raised to a given  
 176 exponent, taken as 0.25 in the present study and in previous ones (Durán et al., 2020; Eyres et  
 177 al., 2024). A discussion on the impact of choosing a different exponent is provided by Eyres et  
 178 al. (2024).

179 Equivalence of a loss and a gain can be expressed as  $LIFE_{gain} = |LIFE_{loss}|$ , with:

$$LIFE_{gain} = \sum_j \sum_s \Delta P_{j,s} \cdot f_{gain,j} \quad Eq. 4$$

180 where  $LIFE_{gain}$  is the total gain (dimensionless) of species persistence probability;  $\Delta P_{j,s}$  is the  
 181 marginal change in P for species  $s$  when all restorable area in cell  $j$  is restored independently  
 182 of all other cells (dimensionless); and  $f_{gain,j}$  is the fraction of restorable area in cell  $j$  that is  
 183 restored (0-1, dimensionless).

184 Note that in practice  $\Delta P_{j,s}$  can be negative or positive, *i.e.*, restoration can lead to a marginal  
 185 loss or a gain of persistence, depending on the species' habitat needs. Restoration can lead to  
 186 losses in very species poor areas (*e.g.* deserts) where agricultural expansion has led to increases  
 187 in biodiversity; restoring therefore leads to a loss. However, for NNL to be achieved,  $\sum_j \sum_s \Delta P_{j,s}$   
 188 ensuing from restoration activities must be positive.

189 The calculation provided in Eq. 3 and Eq. 4 is an approximation, as the marginal persistence  
 190 changes are determined assuming that each cell is destroyed independently from others,  
 191 whereas in our simulation more than one cell may be destroyed. The scalability of LIFE scores  
 192 is discussed by Eyres et al. (2024), and this approximation is not expected to affect the overall  
 193 conclusions.

194 LIFE scores intrinsically account for area affected within  $\Delta P$ .

### 195 2.2.3 Species Threat Abatement and Restoration (STAR)

196 The Species Threat Abatement and Restoration (STAR) approach captures, in two distinct  
 197 metrics, the potential contribution of threat reduction in remaining natural habitat (STAR<sub>T</sub>) and  
 198 habitat restoration (with threat abatement within the restored habitat) (STAR<sub>R</sub>) to the reduction  
 199 of species extinction risk (Mair et al., 2021). Using STAR<sub>T</sub>, a loss can be expressed as:

$$STAR_{loss} = \sum_i \sum_s \sum_t Q_{i,s} W_s C_{s,t} \cdot f_{loss,i} \quad Eq. 5$$

200 where  $STAR_{loss}$  is the total loss of dimensionless STAR<sub>T</sub> units (>0, dimensionless) including  
 201 all threats in the different cells  $i$  impacted;  $Q_{i,s}$  is the current AOH of each species  $s$  within cell  
 202  $i$  (% of global current AOH for  $s$ );  $W_s$  is the IUCN Red List Category weight of species  $s$  (Least  
 203 Concern = 0, Near threatened = 1, Vulnerable = 2, Endangered = 3, Critically Endangered = 4  
 204 (Butchart et al., 2007, 2004));  $C_{s,t}$  is the relative contribution of threat  $t$  to species  $s$  extinction  
 205 risk (0-1, dimensionless); and  $f_{loss,i}$  is the fraction of cell  $i$  where the impact is occurring (0-1,  
 206 dimensionless).

207 Although the “full” STAR<sub>R</sub> metric assumes abatement for all threats, here we assume, as  
 208 for MSA, that restoration tackles only threats directly related to land cover, *i.e.*, that would  
 209 disappear when habitat is restored. Equivalence of losses and gains can then be expressed as  
 210  $STAR_{gain} = STAR_{loss}$ , with:

$$STAR_{gain} = \sum_j \sum_s \sum_{t,LU} H_{j,s} W_s C_{s,t,LU} M_{j,s} \cdot f_{gain,j} \quad Eq. 6$$

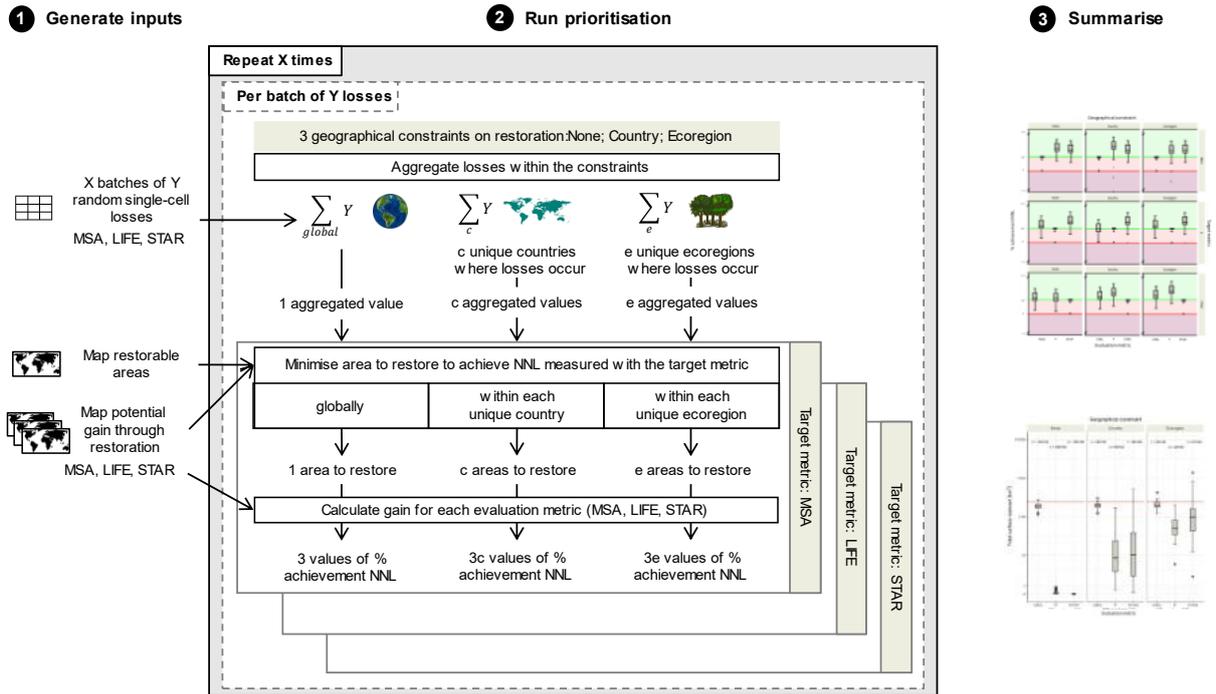
211 where  $STAR_{gain}$  is the total gain of dimensionless  $STAR_R$  units ( $>0$ , dimensionless); gains  
 212 occur in cells  $j$ ;  $H_{j,s}$  is the extent of restorable AOH of each species  $s$  within cell  $j$  (% of global  
 213 current AOH for  $s$ );  $W_s$  is the IUCN Red List Category weight of species  $s$  (Least Concern = 0,  
 214 Near threatened = 1, Vulnerable = 2, Endangered = 3, Critically Endangered = 4 (Butchart et  
 215 al., 2007, 2004));  $C_{s,t,LU}$  is the relative contribution of threat  $t$  to species  $s$  extinction risk,  
 216 restricted to land cover related threats (0-1, dimensionless, see 2.3.2 for the threats covered);  
 217  $M_{j,s}$  is a recovery time discount based on the time elapsed since implementation of the  
 218 restoration actions (10 years in this study, as in (Mair et al., 2021)); and  $f_{gain,j}$  is the fraction  
 219 of restorable area in cell  $j$  that is restored (0-1, dimensionless).

220  $STAR$  scores intrinsically account for area affected within parameters  $Q_{i,s}$  and  $H_{j,s}$ .

## 221 2.3 Simulation design and implementation

### 222 2.3.1 Experimental design

223 We develop and implement a global simulation in R (v4.3.3)(R Core Team, 2024),  
 224 comparing restoration area requirements to achieve NNL for hypothetical biodiversity losses,  
 225 for each of three biodiversity metrics (MSA, LIFE, STAR). The experimental design is  
 226 illustrated in Figure 1.



227  
 228 **Figure 1. Illustration of the experimental design, to compare restoration requirements to achieve NNL**  
 229 **across metrics, for simulated biodiversity loss from corporate activities.** The simulation was implemented to  
 230 run with any number of batches (X) of losses, and any number of losses (Y) within each batch. The target metric  
 231 is the metric for which NNL is sought. The evaluation metrics are those with which achievement of NNL is  
 232 computed.

233 The simulation is designed to replicate any number of corporate loss cases (hereafter  
 234 referred to as batches) and any number of losses per case. One loss corresponds to the  
 235 destruction of all the habitat available in a single cell  $i$  (*i.e.*,  $f_{loss,i} = 1$ ), chosen at random in

236 the terrestrial realm – as mapped by the three metrics – and without replacement, using the  
237 spatSample function from the *terra* package (v1.7-74)(Hijmans, 2024). The magnitude of each  
238 loss is calculated as described in Eq. 1 for MSA, in Eq. 3 for LIFE and in Eq. 5 for STAR. In  
239 our benchmark case, we simulate 200 batches of 10 random losses, but also perform a  
240 sensitivity analysis on both parameters, testing 200 batches of 5 or 20 losses, as well as 100 and  
241 400 batches of 10 losses.

242 For each batch, an optimisation approach is then used to determine the minimum restorable  
243 area to be restored to achieve NNL with respect to the simulated losses measured with each  
244 possible target metric (step 2 in Figure 1). Per target metric, the restored area is potentially  
245 spread across several cells, which are selected from a global raster of restorable areas, excluding  
246 cells where a loss is simulated to occur (losses are assumed irreversible). Three geographical  
247 constraints are simulated. In the unconstrained global simulation, the losses are summed to a  
248 single global loss value for each batch, and optimisation is performed to determine the  
249 minimum area to be restored anywhere globally. For the country and ecoregion constraints, the  
250 losses of a given batch are summed per country or ecoregion, and individual optimisations  
251 performed to determine, within each country or ecoregion, the required area to restore to  
252 achieve NNL. Each optimisation problem is set up using the *prioritizr* package (v8.0.3)(Hanson  
253 et al., 2023) and is solved using the Gurobi solver (Gurobi Optimization, LLC, 2023) – further  
254 details on parameterisation are provided in Supplementary Material 1. Each solution raster  
255 provides the fraction that should be restored per cell to achieve (at least) NNL as measured with  
256 the target metric.

### 257 *2.3.2 Input data collection and processing*

258 We obtained global raster layers of metric values required in calculations of gains and  
259 losses from existing data layers. Specifically, we used the global MSA raster layer produced by  
260 Schipper et al. (2020) covering mammals, birds and terrestrial plants and aggregated over all  
261 pressures included in the underlying GLOBIO model (climate change, land-use, roads,  
262 atmospheric nitrogen deposition, hunting), in combination with a raster of cell area produced  
263 using the cellSize function in the *terra* package, to compute potential loss of biodiversity in  
264 MSA.km<sup>2</sup> according to Eq. 1. We averaged the global raster layers produced by Schipper et al.  
265 (2020) of MSA lost to land-use, for terrestrial plants and warm-blooded vertebrates, and  
266 combined the averaged layer with rasters of cell area and restorable proportion in each cell (see  
267 below) to compute potential gain of biodiversity in MSA.km<sup>2</sup> according to Eq. 2. We summed  
268 across species groups the global LIFE rasters, under total destruction of existing land cover and  
269 when restoring arable or pasture land to natural habitat, produced by Eyres et al. (2024),  
270 covering mammals, birds, reptiles and amphibians. We used this habitat destruction map (resp.  
271 restoration map) for potential loss (resp. gain) expressed with LIFE according to Eq. 3 (resp.  
272 Eq. 4). Finally, we used the global STAR<sub>T</sub> raster layer (all threats) and STAR<sub>R</sub> raster layer  
273 restricted to land cover related threats (based on our expert opinion: threat categories 1, 2.1, 2.2,  
274 2.3, 3.1, 3.2, 5.3, 7.3 and 9.3 in the IUCN Threat Classification Scheme (IUCN, 2023), see  
275 Supplementary Material 1), produced by Mair et al. (2021), covering mammals, birds and  
276 amphibians, for potential loss and gain values expressed with STAR as in Eq. 5 and Eq. 6. A  
277 comparison of the scopes of the three metrics and their underlying data sources is provided in  
278 Table S1 (Supplementary Material 1).

279 We used the raster layer representing the maximum proportion (0-1) of terrestrial areas  
280 currently used for crops or pasture that are available for restoration, from (Strassburg et al.,  
281 2020). We aligned the coordinate reference system and resolution of all other maps to those of  
282 this map of restorable area (Mollweide, 4.96×4.96 km). The cell size for the simulation is  
283 therefore 4.96×4.96 km. For construction of the map of potential gain expressed with LIFE,

284 this harmonization requires the use of the original raster of restorable area used by Eyres et al.  
285 (2024) – please refer to the code provided for further details. The common extent between the  
286 map of restorable area and global vector layers of country and ecoregion boundaries by the  
287 World Bank (2020) and Dinerstein et al. (2017) is used to determine the final extent of all raster  
288 layers used in the simulation ( $x_{min} = -17702327$ ,  $x_{max} = 17876233$ ,  $y_{min} = -6826244$ ,  
289  $y_{max} = 8750095$ ). The vector layers are rasterised to produce rasters containing the  
290 country/ecoregion in which each cell lies (fully or the majority of it).

291 In the simulation, we only consider cells that have data in all raster layers (map of restorable  
292 area, country/ecoregion per cell, metric-specific maps of potential loss and gain) – cells with  
293 NA values (no data) occur for example for oceans or water bodies. For each optimisation, the  
294 planning unit object contains restorable area in km<sup>2</sup> per cell. The target metric map of potential  
295 gain is used as the features object. For optimisations under country/ecoregion constraints, the  
296 maps of restorable area and potential gain expressed with the target metric are cropped to the  
297 appropriate geographical conditions using the country/ecoregion rasters before use.

### 298 *2.3.3 Analysis of the outputs*

299 The total gain from the set of restorations resulting from the optimization problem is  
300 calculated as in Eq. 2, Eq. 4 and Eq. 6 with  $f_{gain,j}$  provided in each solution raster. The gain is  
301 compared to the absolute value of the loss (both expressed with the evaluation metric), to  
302 determine the percentage achievement of NNL for each possible combination of a constraint,  
303 target metric and evaluation metric. In our benchmark simulation with 200 batches of 10  
304 simulated losses, under the global constraint, this yields 200 data points per combination of a  
305 target and evaluation metric, since the 10 losses in each batch are summed to a single overall  
306 loss. Under the country and ecoregion constraints, this yields a number of data points equal to  
307 the number of unique countries or ecoregions per batch – up to 2000 if all 10 losses occur in  
308 unique countries or ecoregions for all 200 batches.

309 Data points corresponding to both a loss and gain of 0 are coerced to 100 % achievement  
310 of NNL. When none of the cells within the geographical constraint contain restorable area, the  
311 gain and area restored are coerced to 0 (and no optimisation performed). When the optimisation  
312 fails because the target (*i.e.* achievement of 100 % NNL for the target metric) cannot be met, a  
313 solution raster is manually created by designating for full restoration all cells, available for  
314 restoration, that have a potential gain through restoration greater than 0, as measured with the  
315 target metric. This leads to partial achievement of NNL for the target metric.

316 The total area restored is also calculated per batch for each possible geographical constraint  
317 and target metric, in the cases where NNL is consistently 100 % achieved within the batch. We  
318 choose to only represent cases with consistent 100% achievement of NNL in a batch for the  
319 target metric, to ensure comparability between batches – a smaller area restored compared to  
320 the others could otherwise be due for example to few cells being available for restoration,  
321 leading to underachievement of NNL.

## 322 **3. Results**

### 323 3.1 Percentage achievement of NNL

324 Our simulations reveal that achieving NNL for one metric does not guarantee this for the  
325 other two (Figure 2, Table 1). Under the global constraint, the restoration requirement to  
326 achieve NNL with MSA as the target metric leads in the majority of cases to overachievement  
327 of NNL as measured with LIFE and STAR. As the geographical constraint is increased to  
328 country then ecoregion, the overall performance for NNL gets worse (Table 1). When

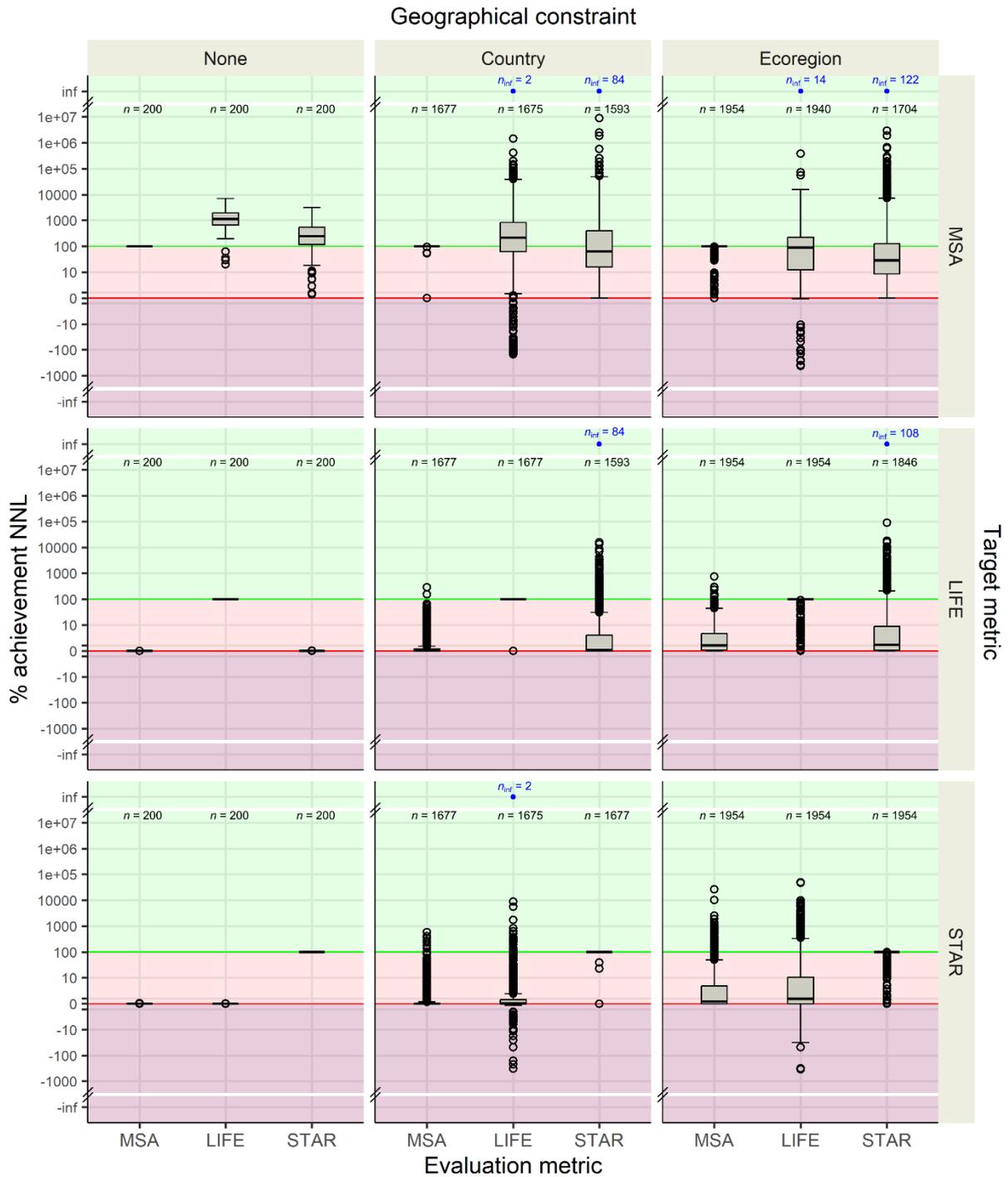
329 achievement of NNL is defined with respect to either LIFE or STAR as target metrics, the  
 330 median percentage achievement of NNL is consistently below 100 % for the other two  
 331 evaluation metrics (MSA and STAR, MSA and LIFE, respectively). Under increasing  
 332 geographical constraints, this failure to achieve NNL is slightly mitigated (Table 1), but  
 333 whatever the target metric for NNL, it is not consistently achieved for the other two metrics.  
 334 The sensitivity analysis suggests that the results are robust to changes in batch number/number  
 335 of losses, which affect the number of outliers but not the general shape of the box plots (Figures  
 336 S1, S3, S5 and S7, Supplementary Material 2).

337 We observe cases where the simulation does not achieve NNL for the target metric. The  
 338 corresponding data points lie at 0 %, or between 0 and 100 % achievement of NNL for identical  
 339 target and evaluation metric pairs (Figure 2). They reflect situations when there is no or not  
 340 enough restorable area or potential gain, respectively, in the geographical constraint's perimeter,  
 341 occurring much more frequently (8.1-10.6 % of cases) under the ecoregion – especially in  
 342 tundra, taiga, desert and shrubland/grassland ecoregions – than the country constraint (Table 2;  
 343 these countries/ecoregions are listed in Tables S2 and S3 in Supplementary Material 2). Points  
 344 at 0 % due to no potential gain occur only for LIFE, where the values of potential gain through  
 345 restoration are based on scores provided in Eyres et al. (2024), obtained using a different map  
 346 of restorable AOH than the one used in this study. For MSA under the country constraint, there  
 347 are many more data points at 0 % achievement NNL than for LIFE and STAR. These all occur  
 348 in Greenland, where losses for LIFE and STAR metrics are mostly measured at 0 and have thus  
 349 been coerced to 100 % achievement of NNL (see Methods section 2.3.3).

350 **Table 1. Summary of the median percentage achievement of NNL per case represented in Figure 2.**

Geographical constraint									Target metric
None	Country	Ecoregion	None	Country	Ecoregion	None	Country	Ecoregion	
100	100	100	1.14E+03	214	89.0	248	63.3	28.4	MSA
6.59E-03	0.151	1.15	100	100	100	6.59E-03	0.151	1.15	LIFE
3.65E-04	5.93E-03	0.393	8.63E-06	0.0471	0.917	100	100	100	STAR
MSA			LIFE			STAR			
Evaluation metric									

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**Figure 2. Percentage achievement of NNL expressed per evaluation metric, depending on the target metric and geographical constraint.** None: per batch, the losses were summed, and optimisation performed to determine the restored area anywhere globally. Country/Ecoregion: per batch, the losses were summed within each unique country/ecoregion and individual optimisations performed to determine, within each country and ecoregion, the required area to restore.  $n$  = number of data points contributing to the boxplots.  $n_{inf}$  = number of data points at infinity (no loss as measured with the evaluation metric), represented for visualisation but not contributing to the boxplots. Hollow points represent outliers (included in the box plots) and blue points represent infinite values (not included in the boxplots). The box delineates the 1<sup>st</sup> and 3<sup>rd</sup> quartiles, and the median. The bottom and top whiskers extend to the data point that are at most at a distance of 1.5 times the interquartile range from the bottom or top hinge, respectively. Green (100 %) and red lines (0%) indicate NNL and a net loss equal to the initial loss,

363 respectively. Green, red and purple shading indicate a net gain, a net loss smaller than the initial loss, and a net  
 364 loss greater than the initial loss, respectively.

365 **Table 2. Summary of the number of data points in Figure 2 for which there is 0 % or strictly between 0 and**  
 366 **100 % achievement of NNL for the target metric.**  $n$  = number of data points contributing to the boxplots.  $n_0$ ,  
 367  $n_{\text{partial}}$  = number of data points (included in the total  $n$ ) for which there was 0 % or strictly between 0 and 100 %  
 368 achievement of NNL for the target metric, respectively. In brackets: the proportion (%) of  $n$  that this represents.  
 369 For LIFE,  $n_0$  is split between points for which the cause is no restorable area (73 points) or insufficient potential  
 370 gain (44 points).

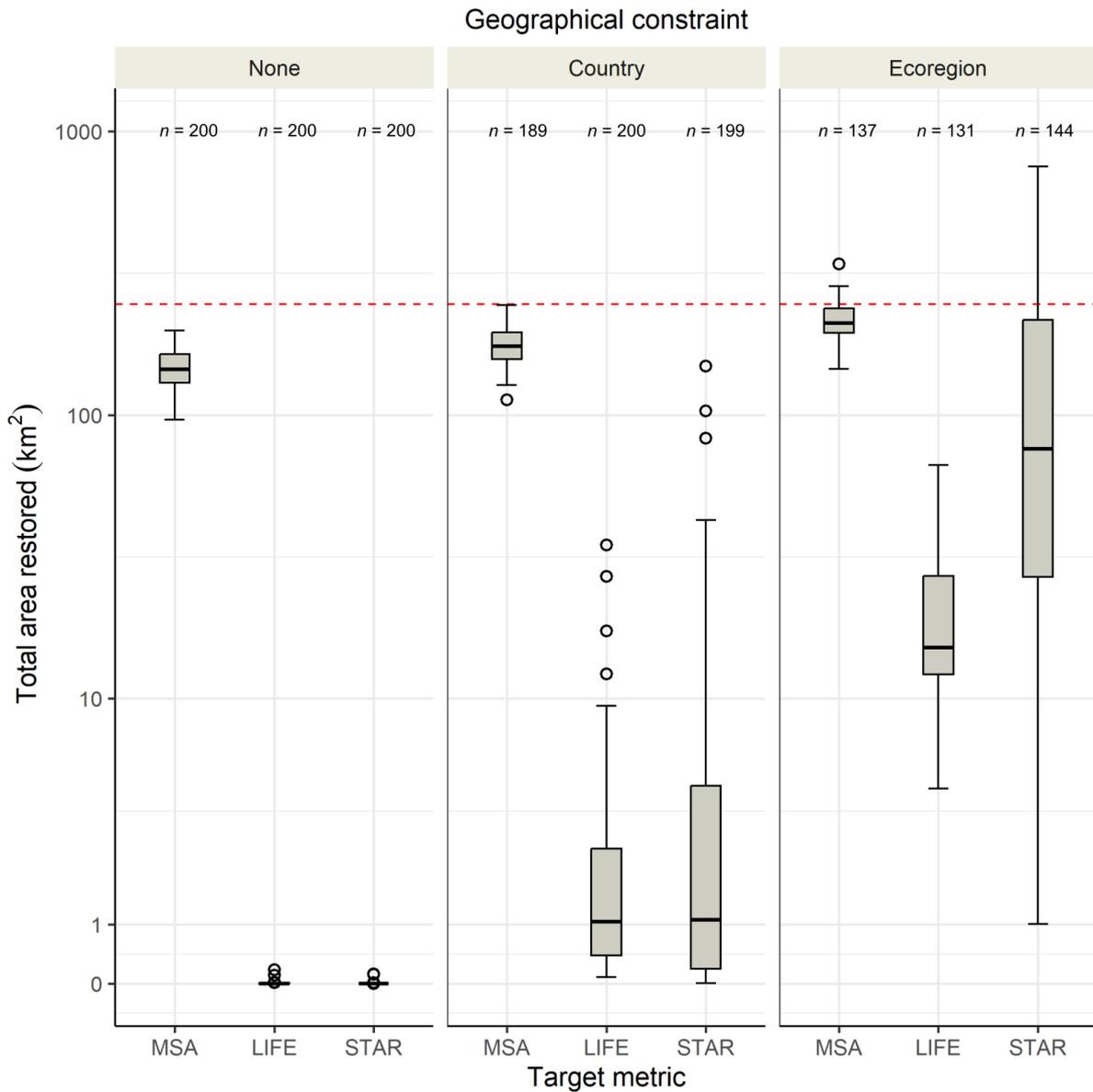
Geographical constraint						
	Country	Ecoregion	Country	Ecoregion	Country	Ecoregion
$n$	1677	1954	1677	1954	1677	1954
$n_0$	20 (1.2 %)	76 (3.9 %)	4 (0.24 %)	73 + 44 (6.0 %)	1 (0.060 %)	76 (3.9 %)
$n_{\text{partial}}$	3 (0.18 %)	100 (5.1 %)	0 (0 %)	90 (4.6 %)	2 (0.12 %)	83 (4.2 %)
	MSA		LIFE		STAR	
	Target metric = Evaluation metric					

371

372 When the target and evaluation metric differ, we observe some data points at 0 %  
 373 achievement of NNL as measured with the evaluation metric (Figure 2). These occur either  
 374 when (a) there is no restorable area within the constraints perimeter despite a loss measured  
 375 with the evaluation metric; (b) there is no gain as measured with the evaluation metric; or (c)  
 376 when there is no loss as measured with the target metric, *i.e.*, the randomly chosen cell in which  
 377 the loss occurs has a value of 0 for the target metric, so nothing needs to be restored, but the  
 378 loss is greater than 0 for the evaluation metric. When LIFE is the evaluation metric (but not for  
 379 MSA or STAR), restoration can occasionally lead to losses, because the restored habitat is  
 380 unsuitable for one or more species that have thrived in a human modified habitat. This results  
 381 in a percentage achievement of NNL below 0 (Figure 2), *i.e.*, a net loss of biodiversity that is  
 382 greater than the initial loss simulated.

### 383 3.2 Area restored to achieve NNL

384 Across all three geographical constraints tested, NNL is overall achieved at the batch  
 385 level with a smaller median area restored (in km<sup>2</sup>) when the target metric driving the restoration  
 386 prioritisation is LIFE or STAR, rather than MSA (Figure 3). For both the LIFE and STAR  
 387 metrics, adding a geographical constraint substantially increases both the median area restored  
 388 to achieve NNL across the entire batch of losses, and the overall spread of areas restored (Figure  
 389 3). Median restored area is around an order of magnitude greater for the ecoregion than the  
 390 country constraint. The ecoregion constraint also drastically reduces the number of batches  
 391 within which NNL is consistently achieved (see sample sizes in Figure 3). For MSA, the  
 392 geographical constraints only slightly increase the median area restored and do not seem to  
 393 affect the spread of areas restored across the different batches. The red dashed line in Figure 3  
 394 represents the maximum total area of habitat destroyed per batch (number of losses per batch  
 395 multiplied by cell area). The area effectively destroyed per batch is likely smaller than this  
 396 maximum value. Across all three constraints, the median area restored when MSA is the target  
 397 metric is of the same order of magnitude as the maximum possible area lost. For LIFE and  
 398 STAR, it is consistently smaller. As for the percentage achievement of NNL, the results appear  
 399 robust to changes in batch number/number of losses, with the same general trends and spreads  
 400 (Supplementary Material 2: Figures S2, S4, S6 and S8).



401  
 402 **Figure 3. Total area restored per batch, target metric and geographical constraint, for 200 batches of 10**  
 403 **losses, in the cases where NNL is consistently 100 % achieved within the batch (with the relevant grouping**  
 404 **from the constraint).** None: per batch, the losses were summed, and optimisation performed to determine the  
 405 restored area anywhere globally. Country/Ecoregion: per batch, the losses were summed within each unique  
 406 country/ecoregion and individual optimisations performed to determine, within each country and ecoregion, the  
 407 required area to restore.  $n$  = number of batches where NNL is 100 % achieved for all losses, i.e., number of data  
 408 points contributing to the box plot. The horizontal dashed red line indicates the maximum total area destroyed per  
 409 batch. The box delineates the 1st and 3rd quartiles, and the median. The bottom and top whiskers extend to the  
 410 data point that is at most at a distance of 1.5 times the interquartile range from the bottom or top hinge, respectively.

## 411 4. Discussion

### 412 4.1 Result drivers

413 When MSA is the target metric the overall performance for NNL for LIFE and STAR  
 414 evaluation metrics worsens with increasing geographic constraints, but the reverse (although  
 415 small) effect is observed when LIFE or STAR are the target metric. We also observed that under  
 416 the global constraint, the area restored is much larger for simulations with MSA as the target  
 417 metric, than those using LIFE or STAR as a target metric. These results are driven by the nature

418 of the metrics and of the optimisation, which determines the smallest possible area to restore.  
419 LIFE and STAR gain values have a much larger distribution compared to MSA: the value of  
420 the 95<sup>th</sup> percentile of potential gain for MSA is approximately five times greater than the median,  
421 while for LIFE and STAR it is close to 40 and 140 times the median, respectively (Figure S9,  
422 Supplementary Material 3). This stems from the different components of nature that the metrics  
423 measure. MSA is an ecosystem condition metric, looking at local ('alpha') species diversity  
424 within any particular ecosystem, while LIFE and STAR are influenced by the highly skewed  
425 overall geographical distributions of individual species. For MSA, cells for restoration selected  
426 first (*i.e.*, with the greatest potential gain through restoration) are those with very little  
427 remaining biodiversity, where land-use has been the dominant source of biodiversity loss and  
428 where most/all of the cell is restorable. For LIFE and STAR, potential gains from restoration  
429 can take extreme values in cells that are within the former AOH of one or more species with a  
430 very small global area of current AOH. These extreme high-value cells occur in only a few  
431 places. As the scale is reduced to country and further to ecoregion, fewer very high-value cells  
432 are available (Figure S10, Supplementary Material 3). It appears from the results that the cells  
433 that have highest MSA potential gain globally also happen to have unusually high LIFE/STAR  
434 potential gain values, while this relationship is weaker for country and ecoregion scales. When  
435 the target metric is LIFE or STAR, increasing geographic constraint means that there are fewer  
436 cells with high values available for restoration, so a larger overall area needs to be restored,  
437 which in turn will generally increase the gains expressed in MSA.km<sup>2</sup>.

#### 438 4.2 Implications for the use of complementary biodiversity metrics

439 Our results highlight the challenges in choosing and applying appropriate currencies for  
440 biodiversity compensation (Mayfield et al., 2022), and the importance of understanding clearly  
441 what metrics actually measure and how. In the specific case of offsetting, it is unlikely that  
442 MSA would be used as an assessment metric for direct-operations offsets, despite its relevance  
443 for measuring ecosystem condition, as it cannot easily be measured in-field, requiring extensive  
444 ecological surveys (CDC Biodiversité, 2020). STAR has been proposed (but not yet used) as  
445 an offset metric (IBAT, 2021), focusing on priority features. This requires use of field-collected  
446 data to calibrate estimated values and assess realized gains (Mair et al., in prep.) – the same  
447 would be needed for LIFE to be used as an offset metric. For the less well-defined impacts  
448 occurring in value-chains however, it is more likely that business and finance will be looking  
449 to metrics such as MSA, STAR and LIFE for assessing both potential losses and gains. MSA  
450 and STAR are already in use for corporate impact measurement (CDC Biodiversité, 2023), and  
451 recommended by the TNFD and the GBF (see section 1. Introduction).

452 From the analysis performed here, overall outcomes for biodiversity will be more  
453 satisfactory if using two or more complementary metrics – MSA and STAR and/or LIFE – for  
454 value-chain level NNL assessments. Indeed, a single metric alone does not guarantee NNL in  
455 biodiversity: loss in another dimension of biodiversity that is not measured by the single  
456 indicator could still occur, or gains in one biodiversity dimension may not equate to gains in  
457 another. Comparing the Biodiversity Habitat Index (BHI) and the Red List Index (RLI) across  
458 ecoregions globally, Stevenson et al. (2024) also found some disagreement between BHI and  
459 RLI, with a number of ecoregions showing high BHI and low RLI scores, or the reverse. These  
460 metrics are conceptually similar respectively to MSA, and LIFE and STAR, although their  
461 application is at large geographical scales, and BHI focuses on gamma diversity, contrary to  
462 MSA. Our findings specifically reinforce the previously highlighted complementarity between  
463 an approach based on ecosystem condition, measured for example by MSA which reports  
464 changes in alpha diversity at a local scale, and one based on species extinction risk like STAR  
465 or LIFE, reporting changes in gamma diversity, for assessment of corporate impact risks and

466 opportunities (Hawkins et al., 2023). Two main approaches could be used: dimensioning  
467 compensation to ensure NNL as measured by both (or all three) metrics, or using STAR/LIFE  
468 as a significance weighting for MSA in calculating impacts. The former is likely to be more  
469 demanding in terms of overall compensation requirements; the latter is more likely to focus  
470 investment in the most important locations for biodiversity in terms of species persistence.

471 In either case, consideration should be given to the appropriate scale of fungibility for  
472 gains and losses. Global fungibility could involve compensation for potentially very different  
473 biodiversity features than those that are impacted. Country or ecoregion-level are candidate  
474 geographical units for bounding loss/gain assessments, large enough to allow some flexibility,  
475 but relatively coherent in terms of socio-economic or ecological characteristics, respectively.  
476 These could also help support linkage of offsetting outcomes to jurisdictional biodiversity  
477 targets, aligned with GBF goals (Simmonds et al., 2020). We observed that adding such spatial  
478 scale constraints led to several instances where NNL could not be achieved for the chosen target  
479 metric. This highlights the imperative to carefully consider locations of corporate activities;  
480 NNL could be impossible to achieve depending on where losses occur. Following the mitigation  
481 hierarchy at the level of value chain impacts (Maron et al., 2023) should ensure that these  
482 situations are properly evaluated and any losses avoided or reduced if possible. These  
483 constraints also did not align achievement of NNL across the three metrics. Stricter equivalence  
484 rules, for example on the ecosystem type, landscape and species lost, could also allow better  
485 alignment of the outcomes. This could also avoid the risks associated with measuring NNL with  
486 any of these metrics in coarse ways, such as compensating for the potential extinction of a  
487 species by restoring habitat of other threatened species. While both of these outcomes are  
488 comparable in a metric, there is in reality no offset for extinction. Such strict equivalence rules  
489 would however be challenging to implement for real-world value chain impacts, since their  
490 exact location is likely unknown, for those occurring higher up in the chain in particular. Using  
491 country ecoregion components (the portions of ecoregions within a particular country) as a  
492 default geographical unit could be a practical approach, providing relatively high socio-  
493 economic and ecological coherence together with a degree of flexibility.

494 Our aim was not to comment on the relative merits of the three biodiversity metrics studied,  
495 or present one as superior to the others. We highlight their main limitations in Supplementary  
496 Material 3, to further discourage such interpretation of these results. By design, there are a  
497 number of components of biodiversity that they do not capture; this cannot be considered as a  
498 limitation of the metrics themselves. These include genetic and phylogenetic diversity,  
499 functional integrity and diversity, and ecosystem services, among many (Convention on  
500 Biological Diversity, 2022; Gardner et al., 2013; Richardson et al., 2023). Aiming for NNL  
501 with respect to all such components would be ideal, but generally impractical. This study  
502 highlights the challenges of choosing which few proxy measures can feasibly be assessed and  
503 used in a simplified framework for biodiversity compensation.

#### 504 4.3 Outlook and future work

505 While the three metrics conceptually cover biodiversity from all taxonomic groups, the  
506 available data layers expressing global biodiversity state with each metric have limited coverage  
507 to date. In this study, all three data layers used cover mammals and birds, with the MSA data  
508 also covering terrestrial plants, LIFE amphibians and reptiles, and STAR amphibians; these  
509 characteristics are susceptible to change as the data layers are updated, and could influence the  
510 magnitude of gains and losses. For instance, terrestrial plant data are not yet available globally  
511 for STAR, however using the metric at the national level Mair et al. (2023) found that STAR<sub>T</sub>  
512 values for plants were 30 times those for vertebrates in their case study in South Africa. As  
513 updated values become available for the metrics across taxa, applying the framework for each

514 species group – for LIFE and STAR, as this is not possible for MSA – could provide refinements  
515 to the results presented here. Indeed, Eyres et al. (2024) observed some regional differences in  
516 the effect of habitat degradation and restoration for amphibians and reptiles. It should be noted  
517 that the metrics differ also in their approach to land cover mapping (see Table S1,  
518 Supplementary Material 1). Former AOH for STAR and LIFE also use different timeframes,  
519 and LIFE covers all species in the taxon groups included, while STAR covers only threatened  
520 and near-threatened species. We expect that these factors influence the results much less  
521 substantially than differences in overall skew of potential gain values discussed in section 4.1.

522 Assumptions were made for the simulation of the losses and restoration actions. Regarding  
523 the losses, corporate activities were assumed to totally destroy the habitat at the location of  
524 impact, to allow comparability across the three metrics studied. Losses could however be  
525 calculated outside of this assumption:  $MSA_i$  in Eq. 1 would no longer be the biodiversity state  
526 prior to habitat destruction (entirely lost), but equal to the difference between the biodiversity  
527 state before and after negative impacts on biodiversity (some biodiversity could remain despite  
528 corporate activities). The global data layer for MSA already includes broad levels of intensity  
529 for the different pressures, allowing the measure of changes in management practices. For LIFE  
530 scores, alternative habitat destruction scenarios could be defined and computed, such as  
531 conversion of habitats and pastures to arable land, as in (Eyres et al., 2024). Such scenarios  
532 would be more challenging to compute for STAR, but could potentially be achieved through  
533 only taking into account certain threats in Eq. 5. For both LIFE and STAR, another approach  
534 for refinement could be to weight different habitats/land-use types by their suitability for each  
535 species. This could be explored in future work. In the context of corporate impact minimisation,  
536 increasing the ability of these metrics to capture nuanced changes in management practices, as  
537 opposed to only the effects of drastic actions, should be a research priority.

538 Regarding restoration, it was assumed to only change land cover, as it is likely that restored  
539 habitat can still undergo the effects of other pressures, such as nitrogen deposition, if it is close  
540 to agricultural land for example, or climate change. We did not investigate restoration actions  
541 that could reduce the impact of these pressures, which could be accounted for with MSA and  
542 STAR, since the most recent global MSA values cover the impact of climate change, land-use,  
543 roads, atmospheric nitrogen deposition and hunting (Schipper et al., 2020), and STAR covers  
544 IUCN Red List threats (Mair et al., 2021). LIFE accounts for changes in AOH only, so this  
545 could not be tested (Eyres et al., 2024). It should also be noted that LIFE and STAR account  
546 for changes in AOH without considering how fragmented the total AOH may be. Since the  
547 probability of impact of a given threat on biodiversity is unequally distributed globally (Harfoot  
548 et al., 2021), we expect that including other threats could affect the results presented here.

549 Furthermore, our framework determines the restoration requirement by minimising the  
550 overall area to restore. Realistically, the choice of restoration locations is also likely influenced  
551 by economic considerations within the company of concern, since cost-effectiveness is an  
552 important consideration when selecting corporate impact mitigation actions (White et al., 2023).  
553 Future work could include the use of opportunity cost data to construct the planning units,  
554 comparing the outcomes to those based on area. As areas with lower costs of restoration are  
555 likely to be the ones with lower potential gain through restoration (Strassburg et al., 2020), this  
556 question raises interesting issues regarding the trade-off between restoration areas and costs.

557 Finally, the potential gain from restoration will likely materialise a long time in the future,  
558 and is a maximum potentially attainable gain (or loss in some cases with LIFE scores). This  
559 time lag and the uncertainty of biodiversity recovery following a release in anthropogenic  
560 pressures or restoration (Jones et al., 2018; Maron et al., 2012; Quétier and Lavorel, 2011;  
561 Schipper et al., 2016) should be addressed when designing offsets for given losses of

562 biodiversity, as stressed in Eyres et al. (2024). Regarding temporality, the gain expressed with  
563 MSA and LIFE could be discounted in the same way as STAR based on a defined time-frame  
564 for restoration (10 years in this study, resulting in a weighting of 0.29 for parameter  $M_{j,s}$  in Eq.  
565 6 (Mair et al., 2021)). This would be expected to increase the area required to achieve NNL for  
566 both of these target metrics. Regarding the uncertainty of biodiversity recovery, Mair et al.  
567 (2021) use results presented in (Jones et al., 2018) to parameterise the temporal factor  $M_{j,s}$  in  
568 Eq. 6. Jones et al. (2018) also evaluate the extent of ecosystem recovery for different ecosystems  
569 under various disturbance types; gains expressed in Eq. 2, Eq. 4 and Eq. 6 could be corrected  
570 using factors derived from these results, to account for the expected incomplete ecosystem  
571 recovery. Calibration of the global datasets with information from the ground will also be  
572 necessary. For LIFE and STAR, this would include an evaluation of the feasibility of species  
573 recolonising restored habitat. Overall, the uncertainty of restoration outcomes further supports  
574 the strict application of the mitigation hierarchy regarding corporate impacts, as mentioned  
575 above: minimising impacts will reduce the reliance on uncertain restoration outcomes in  
576 corporate NNL journeys.

## 577 **5. Conclusion**

578 The goal of the present framework is not to inform exact restoration requirements or justify  
579 the adequacy of a specific NNL policy. We discourage the use of it as such, as these  
580 requirements would necessarily be inaccurate, considering the use of global datasets for the  
581 three metrics, involving modelling and simplifications on the basis of assumptions presented  
582 above. Field-verification would be crucial to obtain specific measurements and calculate  
583 satisfactory restoration requirements if applied to real corporate losses of biodiversity. This  
584 study uses restoration as an illustration of how three metrics – MSA, LIFE and STAR – compare  
585 with respect to evaluating NNL. We illustrate that achieving NNL for a single biodiversity  
586 indicator does not guarantee NNL for indicators that address other dimensions of biodiversity.  
587 Considering the wealth of biodiversity impact metrics available and the momentum around  
588 concepts of NNL in the corporate sphere, our results are cause for caution in the use of these  
589 metrics. Although it is unfeasible to consider a large number of different indicators, corporates  
590 should carefully choose a set of metrics that represents the biodiversity components relevant to  
591 their activity, and aim for NNL with respect to this selected set, as opposed to a single metric.

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612 curation, Writing - Original Draft, Visualization, Project administration, Funding acquisition

613 **Leon Bennun:** Conceptualization, Methodology, Writing - Review & Editing

614 **Joshua Berger:** Conceptualization, Methodology, Writing - Review & Editing, Supervision,  
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616 **Alison Eyres:** Resources, Data curation, Writing - Review & Editing

617 **Koen J.J. Kuipers:** Conceptualization, Methodology, Writing - Review & Editing

618 **Louise Mair:** Resources, Data curation, Writing - Review & Editing

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620 Review & Editing, Supervision, Project administration, Funding acquisition

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622 Project administration, Funding acquisition

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