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3 **Manuscript title:** Biodiversity indicators miss local and short-term change: A blank space
4 waiting to be filled

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17 **Abstract**

18 The year 2030 is rapidly approaching. Building, monitoring, and reporting indicators to evaluate
19 the 2030 targets in the Kunming-Montreal Global Biodiversity Framework (GBF) is a major
20 challenge that requires, at minimum, nations to assess their progress at least once within the next
21 five years. To effectively capture this progress, we need indicators that capture fast-paced, on-
22 the-ground biodiversity change, alongside slower, more diffuse biodiversity trends at national
23 scales. We gathered a group of biodiversity scientists and practitioners to evaluate how well
24 common types of indicators cover the space-time continuum of biodiversity changes. We
25 highlight a striking, nearly unanimously agreed upon, gap in the available indicator toolbox in
26 our ability to capture on-the-ground biodiversity changes. To fill this blank space, we call for
27 investment in local-scale and short-term monitoring, research on how to optimize this monitoring
28 for rapid detection, and urgent development of indicators at these more actionable scales.

29 **Introduction**

30 Biodiversity indicators characterize the state of biodiversity through time, typically measured
31 with Essential Biodiversity Variables (EBV, Pereira et al., 2013), to draw inferences about
32 changes in that state (Jones et al., 2011). Ideally, a biodiversity indicator summarizes complex
33 data into a meaningful value that can be interpreted to inform policy, management, and
34 conservation actions. In short, indicators are essential to monitor progress towards global
35 biodiversity targets.

36 Summarizing biodiversity change with indicators represents an enormous challenge: an indicator
37 must simplify the variability of biodiversity change into a value that can be used to make
38 decision, while retaining enough information to provide a reliable portrait of the state of
39 biodiversity (Jones et al., 2011). In addition to the challenge of developing a simple metric
40 without sacrificing reliability, detecting signals of biodiversity change from uncertain data is a
41 major challenge (Johnson et al., 2024; Leung & Gonzalez, 2024), which is particularly difficult
42 at local scales (Valdez et al., 2023). Because no single indicator can capture the many
43 dimensions (from gene to ecosystem) and scales (from local to landscape) of biodiversity (Noss,
44 1990; Bundy, Gomez, & Cook, 2019), it is essential to rely on a suite of indicators with
45 complementary abilities to detect changes.

46 It is particularly important to report indicators at scales that are relevant for decision-making
47 (Piipponen-Doyle et al., 2021). In the context of the Kunming-Montreal Global Biodiversity
48 Framework, this means that we need indicators that can evaluate the targets that are set for 2030
49 as well as longer-term goals for 2050 (CBD, 2022a). To be effective, indicators should be
50 reported frequently enough to proactively detect biodiversity changes while actions are still

51 feasible (Schmeller et al., 2018). To meet the 2030 deadline, biodiversity targets must be
52 evaluated at least once within the next five years, though progress should be reported much
53 earlier to proactively implement and adjust national biodiversity strategies. On this tight
54 schedule, much of the progress towards national targets will be made at local scales (such as
55 municipalities, or parks), where the effects of conservation action and decision-making are most
56 immediate. Though national-scale indicators are essential to summarise progress towards targets,
57 they are too zoomed out to reflect the local changes that set the course of biodiversity trends in
58 the short term. As such, the suite of indicators that measure progress towards the 2030 targets
59 must be carefully assembled to capture a range of spatiotemporal scales of biodiversity change.

60 Despite the rapid proliferation of indicators, we lack an overall picture of how well-suited our
61 leading indicators work together to monitor biodiversity changes across space and time. To
62 evaluate how well indicators cover the space-time continuum of biodiversity changes, in the
63 “Tracking a Moving Target” workshop at the 2023 GeoBON: Monitoring for Biodiversity
64 conference, we asked 78 participants to delineate how well-equipped we are to monitor short-
65 term (< 5 years) to long-term (50+ years) biodiversity changes, from local (e.g., municipalities
66 and parks) to national scales with a selection of indicators (Table 1). The workshop participants
67 were experts, decision-makers, and practitioners in biodiversity science, monitoring, and the
68 development and assessment of biodiversity indicators. The consensus reveals a gap in our
69 ability to track short-term local changes with the current indicator toolbox. To meet the fast-
70 approaching 2030 targets, we call for focused monitoring and indicator development at local and
71 short-term scales, to ensure that we can monitor biodiversity change at actionable scales.

72 **Building a portrait of indicator sensitivity across space and time**

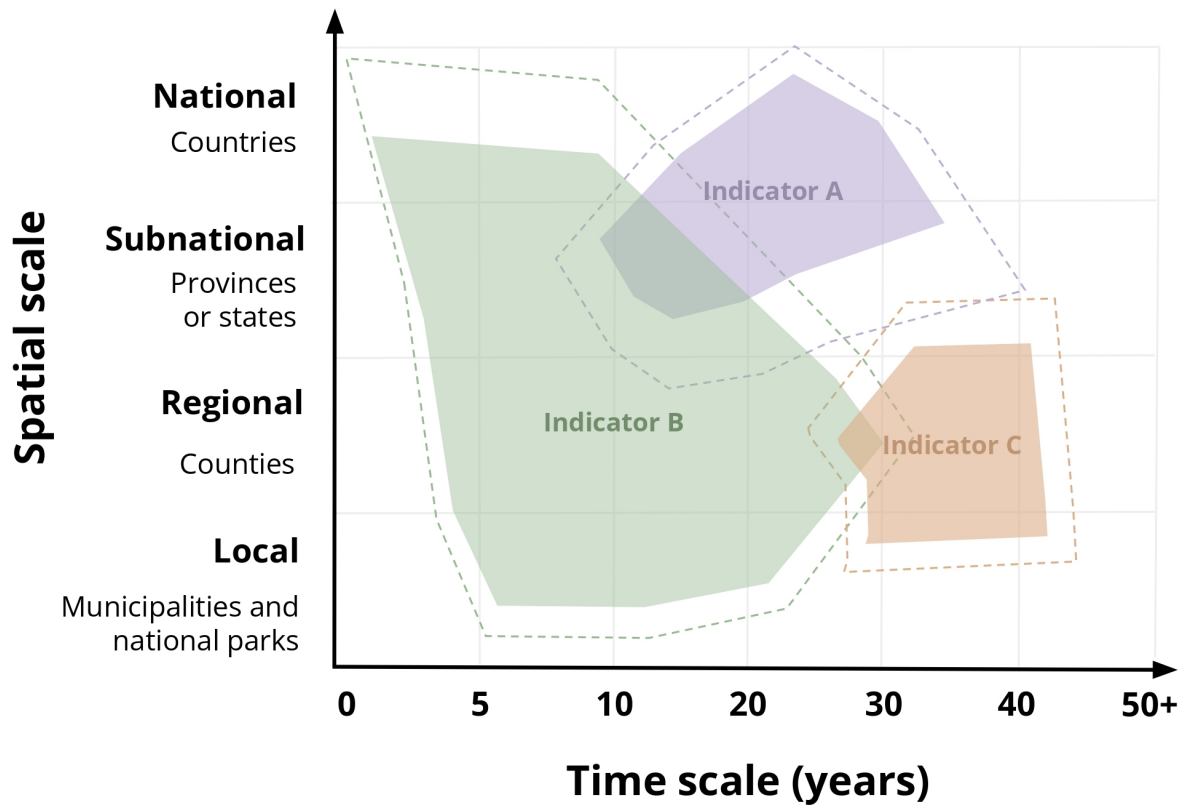
73 The “Tracking a Moving Target” workshop at the GeoBON: Monitoring for Biodiversity
74 conference in Montreal, Canada in October 2023 gathered biodiversity scientists and
75 practitioners to discuss the sensitivity of our current indicator toolbox across a range of temporal
76 and spatial scales. The objective of the workshop was to build a first portrait of how well
77 common types of indicators cover the range of spatiotemporal scales that are relevant for
78 monitoring and decision support. The workshop spanned two sessions (Session 1 = 90 minutes,
79 Session 2 = 120 minutes), during which a total of 78 participants self-organised into 12 groups of
80 5 to 10 people.

81 Each group was given a list of six indicators of species-level and ecosystem-level biodiversity
82 trends (Table 1) adopted in the Kunming-Montreal Global Biodiversity Framework with the goal
83 to define the efficiency of each indicator in capturing local to national scale change across a short
84 to long time period. Importantly, this exercise assumed that data is unlimited and unbiased to
85 focus discussions on indicator properties rather than the limits of available data. Participants
86 delineated the suitability of the six indicators on a categorical space-time grid. The spatial axis
87 covered different scales at which conservation action, decision-making, and policies are applied,
88 ranging from local scales (municipalities and parks) to regional scales (counties, ecoregions),
89 subnational scales (provinces, states), and national scales (countries). The time axis covered
90 different periods to evaluate progress within the GBF, ranging from short-term evaluation of the
91 2030 targets (0-2, 2-4, 4-6 years), to post-2030 assessments for the 2050 goals (6-10, 10-20
92 years), to long-term reporting beyond 2050 (20-50, and 50+ years). For each indicator, each
93 group outlined an area on the space-time grid where they determined the indicator to be useful
94 for decision support and/or monitoring of biodiversity changes (Fig. 1). This outline was drawn

95 as a solid line if participants considered their delineation to be certain, and as a dotted line if it
96 was uncertain.

97 Each group was also asked to consider one of three scenarios of biodiversity change (Table S1;
98 early signs of decline, improving ecosystem health, increasing uncertainty from changing
99 disturbance regimes) and one of two use cases (monitoring, or decision-support), to determine
100 whether we are better equipped to measure biodiversity change in specific contexts
101 (Supplementary material S1). However, the consensus among groups (Fig. 2) did not strongly
102 differ by scenario (Fig. S1) or by use case (Fig. S2) when these were reported.

103 To visualise the coverage of indicators on the space-time continuum, we digitized each space-
104 time grid and overlaid a grid on each one that matched the axis labels drawn by each group. We
105 counted grid cells that were at least 50% occupied by an indicator's boundaries, and noted
106 whether the grid cells were marked as certain or uncertain. To describe the coverage of the
107 indicator suite, we took the z-score of counts per cell across all indicators. To illustrate each
108 indicator's suitability, we set a box bound by the 25% and 75% quantiles of grid cell counts on
109 the time and the space axis. These portraits represent the confidence that participants had in the
110 suitability of the indicators to monitor biodiversity changes across spatiotemporal scales and
111 should not be interpreted as a quantitative assessment of indicator sensitivity.

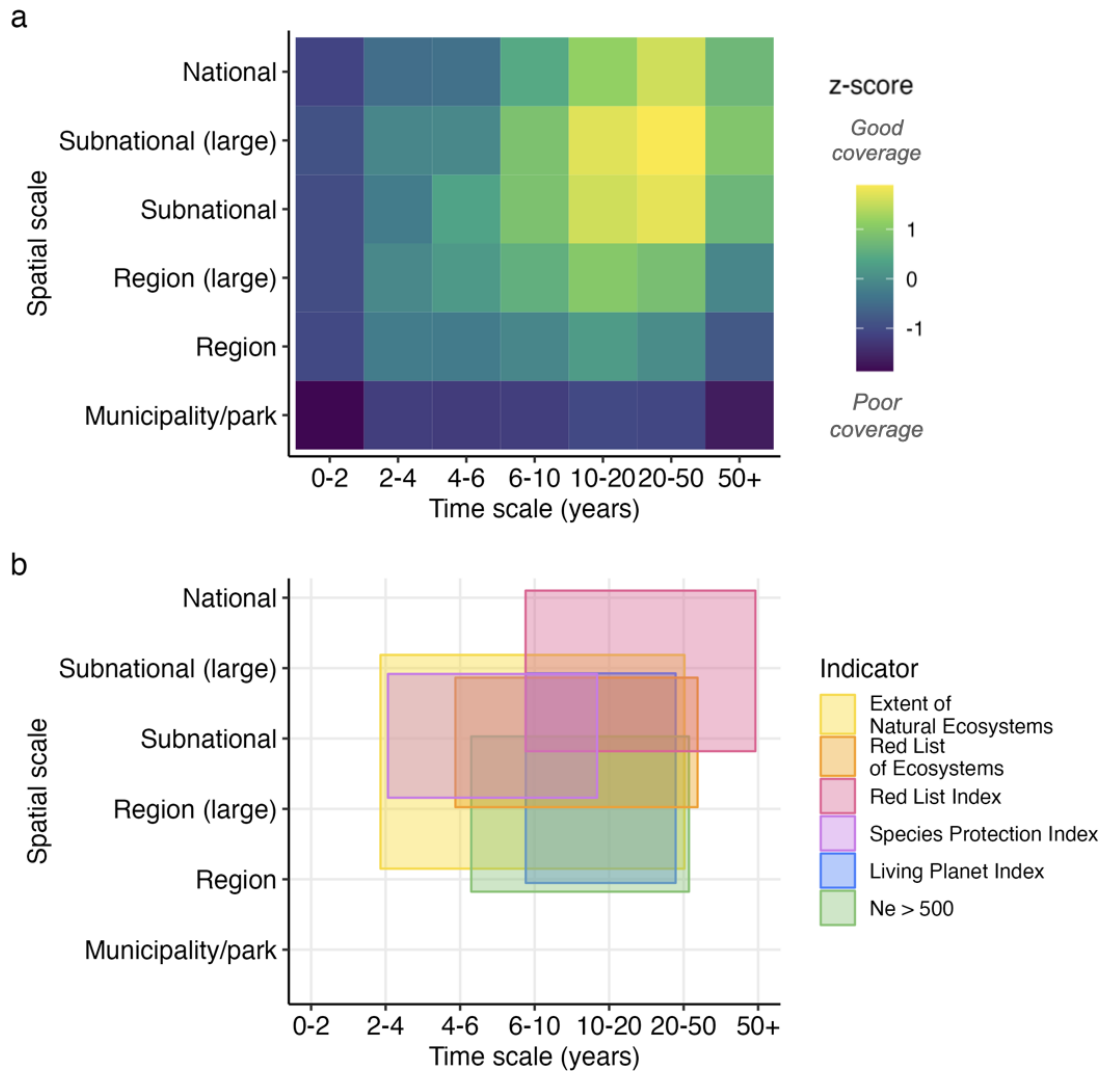


112

113 **Figure 1.** Example of a space-time grid showing the suitability of three indicators on a space-
 114 time gradient for decision support and monitoring of biodiversity changes. Certain (solid line)
 115 and uncertain (dashed line) boundaries are drawn for three example indicators (A, B, C).

116 **Table 1:** The suite of indicators to be placed on space-time grids during the “Tracking a Moving
 117 Target” workshop at the GeoBON: Monitoring for Biodiversity conference.

Indicator	GBF Category	Type	What it measures	Reference
Red List Index	Headline	Species	Average trend in the extinction risk status of species assessed by the IUCN Red List.	(Butchart et al., 2005)
Living Planet Index	Component	Species	Change in vertebrate population size relative to 1970.	(Collen et al., 2009)
Ne > 500	Headline	Species	Proportion of populations within species with an effective population size > 500.	(Hoban et al., 2020)
Species Protection Index	Component	Species	Biodiversity representativeness of terrestrial protected areas.	(Jetz et al., 2022)
Red List of Ecosystems	Headline	Ecosystem	Risk of collapse status of ecosystems.	(Nicholson et al., 2024)
Extent of natural ecosystems	Headline	Ecosystem	Area of natural ecosystems defined based on IUCN GET biomes.	(UN-WCMC, 2023)



119

120 **Figure 2.** Consensus from the 24 grids drawn by 12 groups of workshop participants, showing
 121 the coverage of the indicator suite to support decisions and monitor biodiversity change from
 122 local to national scales, and from short-term (0-6 years) to long-term (50+ years) scales. (a) Z-
 123 scores of the counts of groups' delineations for all indicators on the space-time grid, weighted by
 124 certainty level, where the weight of uncertain boundaries is halved. (b) Each indicator's coverage
 125 of biodiversity changes across temporal and spatial scales. Each box delineates the 25% and 75%
 126 quantiles of the grid cell counts that describe each indicator's suitability as drawn by the
 127 workshop participants. The boundaries are lightly jittered to show overlapping boxes.

128 **We lack indicators at actionable time scales**

129 To successfully meet the Global Biodiversity Framework's targets, we need indicators that can
130 detect changes in the state of biodiversity within politically-relevant timeframes (Piipponen-
131 Doyle, Bolam, & Mair, 2021). However, biodiversity experts and practitioners do not feel they
132 have indicators in their toolbox that can capture changes within the short timeframe (< 6 years)
133 that is needed to evaluate progress towards biodiversity targets by 2030, and this applies across
134 all spatial scales (Fig. 2a). Given that biodiversity does not respond immediately to conservation
135 action (Watts et al., 2020), we are likely overestimating our current ability to detect progress
136 towards the 2030 global targets in six years. In other words, the current indicators will not be
137 used to guide or validate the decisions or conservation actions that are needed to make progress
138 towards the 2030 targets.

139 Indicators that are sensitive to actions, rather than to biodiversity change itself, may prove most
140 helpful to gauge short-term (< 6 years) progress towards global targets. For example, decision-
141 oriented indicators like the Species Protection Index (SPI) reflect the creation of conserved or
142 protected areas and may change immediately in response to conservation action, though they will
143 not respond directly to biodiversity change. This short-term sensitivity to action is in contrast to
144 ecosystem-oriented or species-oriented indicators which may require several years to disentangle
145 trends from random variability (Stevenson et al., 2021), but which directly measure the state of
146 biodiversity. However, even indicators that can be compiled annually like the Living Planet
147 Index or the Wild Bird Index may only reflect species' responses to conservation action after a
148 time lag (Watts et al., 2020), or may not have the power required to detect them at all (Leung &
149 Gonzalez, 2024). To effectively capture progress towards global targets, the suite of reported
150 indicators must therefore assemble metrics that have complementary sensitivity to different

151 temporal signatures of the outcomes of conservation action (i.e., some indicators that directly
152 reflect action, while others measure the outcomes of these actions on biodiversity).

153 **Progress towards global targets must be measured at the scale of conservation**

154 The workshop uncovered a consensus that we lack confidence in our capacity to evaluate
155 progress at local scales with the current indicator toolbox (Fig. 2a). Participants were, in fact,
156 very certain that there is a lack of suitable indicators to measure changes at the municipality or
157 park scales, particularly over longer time periods (50+ years) (Fig. 3). None of the proposed
158 indicators were considered to be suitable for tracking local-scale trends by the workshop
159 participants (Fig. 2b), though the Living Planet Index, $Ne > 500$, and the Extent of Natural
160 Ecosystems may be suitable at regional scales. However, local conservation actions are at the
161 core of our ability to prevent or reverse biodiversity loss, and their outcomes scale up to drive
162 progress towards national and global biodiversity targets (Saterson et al., 2004; Shin et al.,
163 2022). For this reason, the Intergovernmental Panel on Biodiversity and Ecosystem Services
164 (IPBES) has emphasized the importance of integrating local and regional knowledge in
165 measurements of biodiversity loss, and in strategies to slow, prevent, and reduce this loss
166 (IPBES, 2019).

167 Because biodiversity targets are set at international political scales, it can be difficult to maintain
168 a clear link between local conservation actions and global, or even national, strategies to halt
169 biodiversity loss (Perino et al., 2022). Framing biodiversity loss as a global issue is essential to
170 set international conservation priorities, allocate resources for conservation, and support
171 decision-making based on the most complete global knowledge (Chaplin-Kramer et al., 2022).
172 However, local conservation actions are required to make progress towards national and global

173 targets (Langhammer et al., 2024). As such, it is equally important to assess local trends in the
174 state of biodiversity to measure progress at the scale of conservation action (Saterson et al.
175 2004). To integrate more fine-scale assessments of progress into the GBF monitoring framework,
176 a monitoring strategy must be designed to capture local-scale changes in biodiversity but also the
177 outcomes of local conservation actions (Leung & Gonzalez, 2024). Strengthening this link
178 between global indicators and local actions must be a priority going forward (Nicholson et al.,
179 2021).

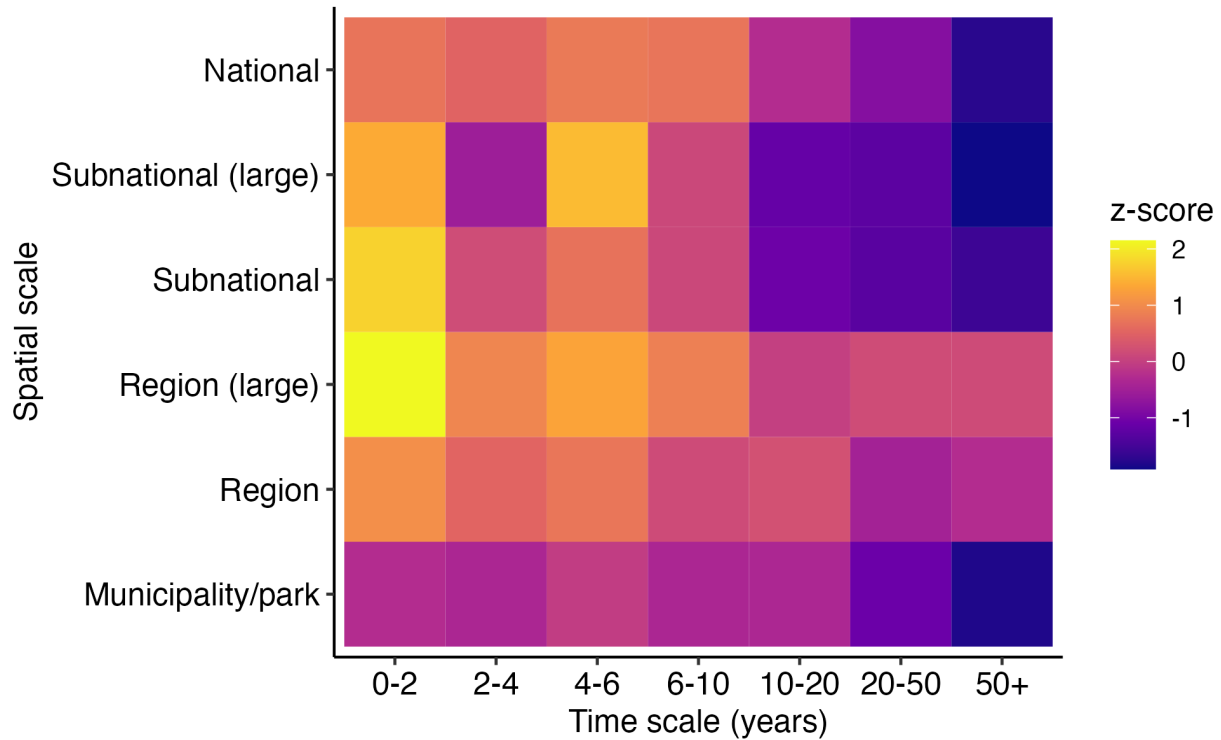
180 **A pressing need to assess indicator performance in scenarios of biodiversity change**

181 Delineating the suitability of indicators on the space-time grids revealed that it is often difficult
182 to know exactly where indicators work best in time and space. Given that this workshop was
183 presented during the GeoBON: Monitoring for Biodiversity conference, most participants had
184 some familiarity or direct experience with the development, use, and reporting of the indicators
185 that were presented for discussion (Table 1). Even with some prior knowledge of the proposed
186 indicators, the consensus reveals nearly unanimous uncertainty in the suitability of the indicator
187 suite to monitor biodiversity changes at short time scales (< 6 years) across all geographic scales
188 (Fig. 3). This highlights a gap in our ability to measure changes at the time scales that are needed
189 to evaluate the 2030 targets in the Global Biodiversity Framework.

190 This uncertainty is due, in part, to a lack of assessments of indicator performance, which limits
191 our ability to precisely identify the spatiotemporal scales at which each indicator performs well
192 enough for monitoring and/or decision support. The urgent need to monitor biodiversity change
193 means that indicators are often calculated and reported before their ability to detect expected
194 changes has been tested. Some indicators have been tested more rigorously (Watermeyer et al.,

195 2021; Vicente et al., 2022), including the Living Planet Index (McRae, Deinet, & Freeman,
196 2017; Leung et al., 2020; Buschke, Hagan, Santini, & Coetzee, 2021; Hébert & Gravel, 2023;
197 Leung & Gonzalez, 2024), which helped to clarify the limits of their accuracy and uncertainty
198 and thus how to use them. However, such a thorough assessment is exceptional, and most
199 indicators are selected to evaluate future targets even if it is not yet clear if they can capture the
200 targeted changes.

201 It must become standard practice to test the conditions under which indicators detect the changes
202 they are intended to monitor (Nicholson et al., 2021), especially at the spatiotemporal scales that
203 are required for decision support and monitoring. Biodiversity indicators summarise large
204 volumes of noisy information into a simplified metric, which is a calculation that can accumulate
205 uncertainty and distort studied trends (Hébert & Gravel, 2023). Evaluating the impact of this
206 uncertainty on our ability to detect changes is essential (Johnson et al., 2024), and each indicator
207 must be interpreted carefully while considering the bounds of its reliability, according to the
208 level of certainty we require to make decisions (Leung & Gonzalez, 2024). The accuracy and
209 uncertainty of indicators must be evaluated under scenarios of biodiversity change (e.g., Table
210 S1) to establish how confidently they should be interpreted as metrics of biodiversity change in
211 space and time.



212

213 **Figure 3.** Uncertainty in the indicators' applicability from local to national scales, and from
 214 short-term (0-6 years) to long-term (50+ years) scales. This uncertainty is a consensus from the
 215 24 grids drawn by 12 groups of workshop participants. Uncertainty is shown as the z-scores of
 216 the counts of groups' delineations for all indicators on the space-time grid that were marked as
 217 uncertain, where a grid cell with a high z-score (yellow) shows that participants thought some
 218 indicators could be suitable for the given scale but were mostly uncertain, while a grid cell with a
 219 low z-score (purple) shows that participants were generally certain in the coverage or lack of
 220 coverage of the given scale.

221

222 **A suite of indicators is more than the sum of its parts**

223 Biodiversity change unfolds differently across scales (Chase et al., 2018), and it is important to
224 monitor this change with a suite of indicators that can capture multiple dimensions of
225 biodiversity (Perino et al., 2022; Vicente et al., 2022). Evaluating indicators as a set, rather than a
226 collection of individual metrics, is key to assess the complementarity and redundancy in their
227 combined capacity to capture biodiversity change across scales (Nicholson et al., 2021;
228 Stevenson et al., 2024).

229 Identifying gaps and redundancies in the sensitivity of a suite of indicators is a critical first step
230 to set priorities for monitoring and indicator development. For example, although only a handful
231 of indicators (Table 1) were considered during the workshop, the consensus highlights
232 redundancy among indicators that are well-suited to capture biodiversity changes at the mid- to
233 long-term (10 to 50 years) and at regional to national scales (Fig. 2a). The existing redundancy in
234 the coverage of long-term and large-scale biodiversity changes could be leveraged to cross-
235 validate trends across similar indicators (Stevenson et al., 2024), to assess progress towards long-
236 term goals with multiple datasets and metrics. However, rather than deepening these
237 redundancies, the development of new indicators and monitoring schemes must urgently target
238 the gaps in the indicator suite's coverage of biodiversity changes across space and time.

239 **Conclusion: We need strategic monitoring and indicator development at more actionable**
240 **scales**

241 The development of indicators has been prolific to fulfill the urgent need to evaluate the global
242 biodiversity targets set by the Convention on Biological Diversity. This burst in indicator
243 development is reflected in the large catalogue of indicators that have been proposed in the

244 Kunming-Montreal Global Biodiversity Framework (CBD, 2022b). However, if indicators
245 continue to be developed without considering their contribution to the pre-existing “toolbox”
246 (Sparks et al., 2011), we risk investing time and resources in metrics that offer redundant
247 information while missing critical dimensions of biodiversity change.

248 The blank space in the indicator suite at local and short-term scales means that we are lacking
249 sensitivity to biodiversity change at actionable scales. First, the indicator suite is poorly equipped
250 to detect changes before 2030, which means political and conservation actions cannot be
251 proactively assessed to ensure that we are on track to successfully meet the 2030 targets in the
252 Kunming-Montreal Global Biodiversity Framework. Second, the lack of sensitivity to smaller
253 organisation scales (municipalities and parks) means that target progress cannot be evaluated or
254 reported at the scale of critical conservation action and decision-making (Christie et al., 2020).

255 To ensure that progress towards global biodiversity targets can be reported by 2030, we must
256 focus efforts on better integrating local and short-term biodiversity trends into our assessments of
257 national biodiversity targets. The blank space in indicator suitability at actionable scales must be
258 remedied through strategic monitoring and indicator development with the specific objective of
259 tracking finer-scale evidence of progress towards global biodiversity targets.

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Supplementary material

S1. Scenarios of biodiversity change and indicator use cases

Each group was asked to select one of three scenarios of biodiversity change to consider when drawing the space-time coverage of each indicator on their grid (Table S1). The consensus results presented in the main text (Fig. 2 and Fig. 3) do not discern between these scenarios because the coverage of indicators on the space-time grids did not strongly differ between Scenarios 1 and 2 (Fig. S1), and Scenario 3 was not discussed as it was only addressed by one group.

Each group was also asked to discuss one of two use cases when placing indicators on the space-time grids: (1) monitoring, or (2) decision-support. The results in the main text do not differentiate between use cases, because the consensus from the grids was very similar between use cases as well.

Table S1: Scenarios of biodiversity change that were discussed during the workshop.

Scenario	Description
1	Rapid habitat conversion of native ecosystems to a degraded state or converted to non-natural ecosystems with increasing habitat fragmentation and early signs of population and ecosystem function decline.
2	Increased protection and effective management have improved the outlook for biodiversity with rebounding wildlife populations and ecosystem health.

3	Rapid changes in disturbance regimes (e.g. increased fire frequency, extreme heat events) causing potential ecosystem shifts, but modelled projections are uncertain as to how this might happen.
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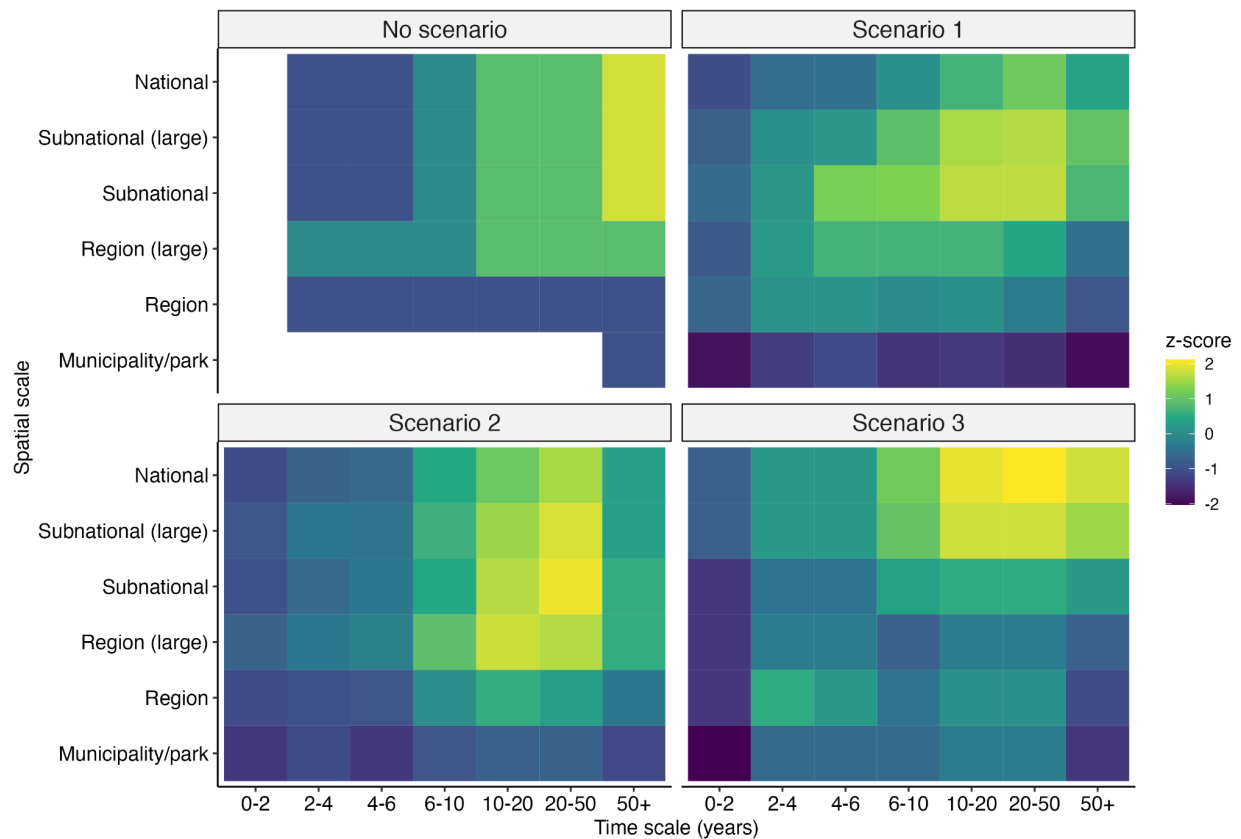


Figure S1. Consensus from the 24 grids drawn by the 12 groups of workshop participants for each scenario. Each grid shows the coverage of the indicator suite to support decisions and monitor biodiversity change from local to national scales, and from short-term (0-6 years) to long-term (50+ years) scales, for the scenarios described in Table S1. “No scenario” shows the results from one grid which was not labelled by workshop participants. “Scenario 1” contains 11 grids, “Scenario 2” contains 11 grids, and “Scenario 3” contains 4 grids (done by 1 group).

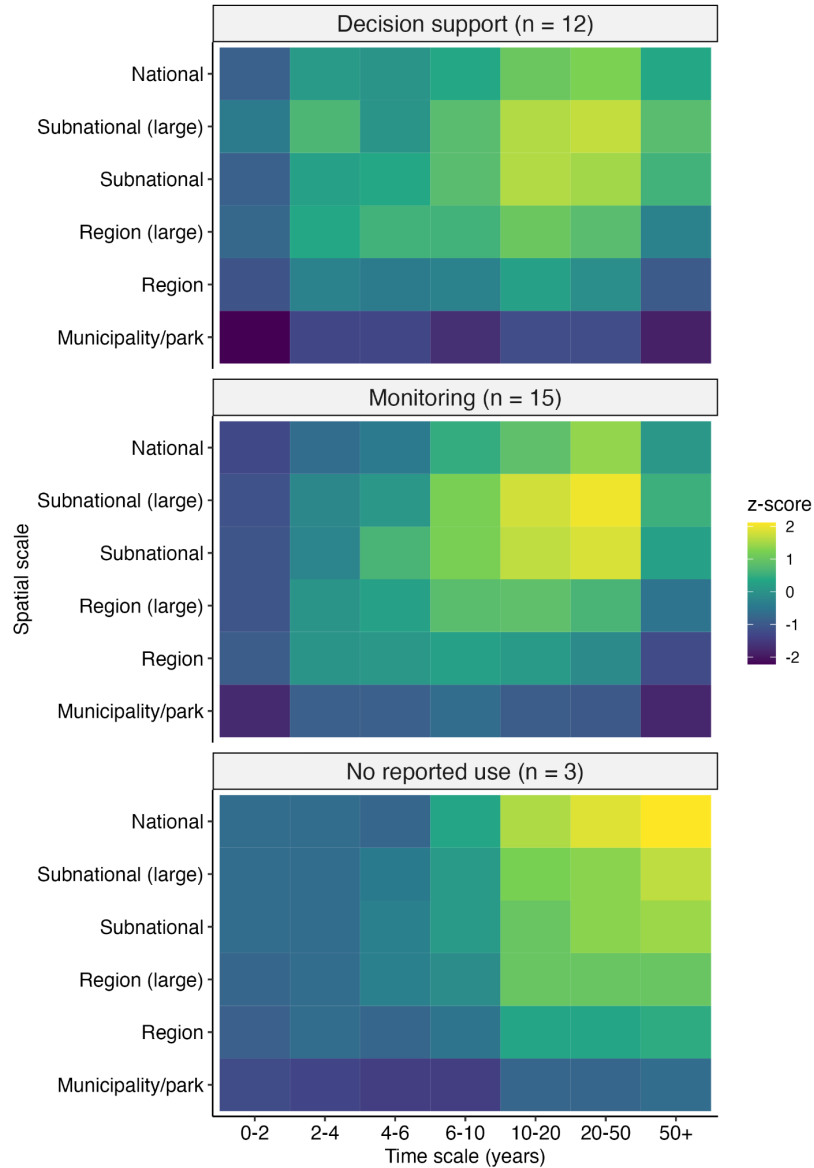


Figure S2. Consensus from the 24 grids drawn by the 12 groups of workshop participants for each use case. Each grid shows the coverage of the indicator suite to support decisions and monitor biodiversity change from local to national scales, and from short-term (0-6 years) to long-term (50+ years) scales. “No reported use” shows the results from three grids which were not labelled by workshop participants.