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1 **Nature restoration legislation means redefining targets and**
2 **forecasting progress**

3 **Running head**

4 Nature restoration under legislation

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13 **Author contributions**

14 DS, SN conceived of the manuscript; DS wrote the initial version of the manuscript; all authors revised
15 the manuscript

16 **Abstract**

17 Nature restoration is at a pivotal moment, driven by global initiatives like the EU Nature Restoration Law
18 and the Kunming-Montreal Biodiversity Framework. These frameworks pose key challenges to how
19 restoration targets are defined to ensure they are not only achievable and measurable but also resilient
20 to future environmental changes. This requires addressing two key challenges: setting forward-looking
21 restoration targets that account for dynamic environmental changes and developing methods to predict
22 and forecast progress. We propose that restoration should focus on restoring ecosystem functions that
23 represent the natural state based on current conditions, ecological history, and are resilient to future
24 environmental change. Secondly, restoration efforts must be predictive, and we propose a two-stage
25 process to predict outcomes prior to an intervention, and forecast progress over time. We argue that
26 only by integrating these approaches, can restoration policies lead to large scale restoration for
27 ecological recovery and long-term societal benefits.

28 **Keywords**

29 Nature restoration, restoration outcomes, biodiversity targets, temporal prediction, restoration
30 legislation

31 **Implications**

- 32 • Large-scale and coordinated nature restoration driven by legislation should set targets for
33 restoration based on missing ecological processes that are resilient to future conditions,
34 rather than a historical or contemporary reference state
- 35 • Advancements in restoration prediction are urgently required so restoration measures and
36 interventions can be evaluated so they lead to net positive outcomes
- 37 • Being able to quantitatively measure restoration success is crucial for accounting of
38 restoration interventions towards national and international restoration targets

39

40 **Introduction – International restoration targets**

41 Ecological restoration, defined as “the process of assisting the recovery of an ecosystem that has been
42 degraded, damaged, or destroyed” (Gann et al. 2019), has become a key aspect of international nature
43 management and conservation strategies. Restoration is fundamental to transitioning towards a net
44 positive outcome for nature by overcompensating biodiversity loss rather than simply preventing further
45 decline (Bull et al. 2020). Restoration can counter climate change, restore natural capital and ecosystem
46 services, and provide broad benefits to society and human health (Newbold et al. 2015; Breed et al.
47 2020; Bradbury et al. 2021). In recognition of these benefits, several global movements have pushed
48 nature restoration into the spotlight, including the 2021-2030 UN declaration on the “Decade of
49 Ecosystem Restoration” (UN General Assembly 2019), the 2022 Convention on Biological Diversity
50 Kunming-Montreal Biodiversity Framework (KMBF) (CBD 2022), and most notably the EU Nature
51 Restoration Law (EUNRL) in 2024 (European Commission 2024).

52 The EUNRL is unique in that it is a legal requirement, mandating each member state to restore 20% of
53 total land area and 30% of “not in good condition” habitat area by 2030 (European Commission 2024),
54 whereas previous commitments have been voluntary at best. The passing of nature restoration as a
55 legal requirement makes successful implementation of passive and active restoration crucial from a
56 political angle, in addition to the ecological perspective. Here we do not distinguish between active or
57 passive restoration, in line with the EUNRL definition of restoration as “actively or passively assisting the
58 recovery of an ecosystem” (European Commission 2024), and we use the term intervention to describe
59 both.

60 For this law to be effective, it is necessary to reconsider the goals and strategies for restoration.
61 Currently, the vast majority of restoration projects are site specific rather than at landscape level (von
62 Holle et al. 2020). However, for these national and international restoration goals to be effective in
63 transitioning society towards a nature-positive future, restoration needs to change to be part of a
64 landscape-level and systematic process (Aronson et al. 2020). This is particularly important in the EU,
65 where each member state has quantitative goals they must achieve and report on (European
66 Commission 2024).

67 Additionally, both the EUNRL and KMBF refer to “restoration measures” and “effective restoration” to
68 be in place by 2030 (European Commission 2024; CBD 2022). This leads to an important question of
69 how the effectiveness of interventions can be measured, particularly considering that the ecosystem
70 may take many decades to fully respond (Jones et al. 2018; Moreno-Mateos et al. 2020). Setting
71 effective targets that are achievable and measurable is fundamental, as well as a way to predict the
72 success of a restoration intervention so that it may be accounted towards the 20 and 30% targets set in
73 the EUNRL and KMBF respectively (European Commission 2024; CBD 2022).

74 In this context, restoration under national and international goals should not be viewed as *the return* to
75 a specific state of the environment. Instead, it should be seen as *the process* that guides an ecosystem
76 towards a net positive and resilient state. This leads to two critical questions: how do we define what the
77 targets for restoration should be, and how can we assess whether ecosystems are progressing in that
78 direction?

79 **Redefining targets - What should the end of the line be?**

80 Targets and references are fundamental for restoration efforts as the success of a restoration effort can
81 only be measured by comparing the current state, to the target or reference state. Traditionally,
82 restoration has sought to return an ecosystem to a pre-disturbance or even pre-human state, evident in
83 early definitions of ecological restoration defining it as “the intentional alteration of a site to establish a
84 defined indigenous, historic ecosystem” (as cited by Aronson et al., 1993). However, over time this has
85 shifted to be more inclusive of future conditions and the changing role of ecological restoration. The
86 most recent definition by the Society for Ecological Restoration defines ecological restoration as “the
87 process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed”
88 (Gann et al. 2019). The removal of references towards a “indigenous, historic ecosystem” broadens the
89 scope of restoration to be any action that seeks to assist the recovery of an ecosystem, rather than
90 returning to a specific historical state.

91 However, while the paradigm has started to shift in definition, in practice the use of present and past
92 reference states is pervasive. A review by Shackelford et al., (2021) found that more than 90% of
93 restoration efforts used contemporary references to measure success, and a mix of historical and
94 contemporary references for goal setting. Only a tiny minority considered any kind of future states.

95 The question is then why is this an issue? This was discussed by Choi (2004) on what it meant for
96 restoration to be “futuristic”. Rather than setting goals based on the past or present, in the context of
97 ongoing global change, restoration should seek to set dynamic goals for the future (Choi 2004). This
98 was also discussed by Reyes-Aldana (2024), stating that the historic reference state, or “Pristine
99 Reference State” (PRS), sets an unrealistic and unachievable goal for restoration, disregarding the
100 dynamic and variable nature of ecosystems. Instead, restoration should aim to create resilient, functional
101 ecosystems using a more holistic approach (Choi 2007). This accepts that restored ecosystems may
102 differ in structure and composition compared to the historical state, but prioritises functions that ensure
103 their persistence in the face of future environmental changes and help mitigate global change (Choi
104 2007; Harris et al. 2006). This can be described as Futuristic Restoration, as coined by Choi (2004).

105 Futuristic Restoration is not to say the historical state should be disregarded. On the contrary, it is crucial
106 that the historical state be considered to inform what the intervention should seek to recreate (Manzano
107 et al. 2020; Higgs et al. 2014). The value of the historical state lies in its contextualisation of what should
108 be considered natural for the local conditions (Willis & Birks 2006; Willis et al. 2007, 2010). This
109 fundamentally differs to the philosophy of the PRS, where the historical state is assumed to be better
110 purely because it is historical. Therefore, historical information is crucial for understanding what
111 complexities and functions the restored ecosystem should reproduce, given the environmental context
112 (Higgs et al. 2014; Fuller et al. 2017).

113 In the realm of endangered species conservation, Jachowski et al. (2015) operationalised a decision
114 framework describing when the historical state should be pragmatically abandoned, to ensure long term
115 species persistence into a changing future. We argue that such a framework should be adopted in
116 ecosystem restoration, to help ecosystems persist into a changing future and maintain their functions.
117 Among practitioners, views are already shifting towards supporting frameworks that take into account
118 expected losses and greater ecosystem novelty (Hagerman & Satterfield 2014).

119 Achievability of restoration is also crucial from a legislative effectiveness lens. Both the EUNRL and
120 KMBF have defined goals for restoration, targeting 20 and 30% respectively of land under restoration
121 by 2030 (CBD 2022; European Commission 2024). Atkinson et al. (2022) found that globally, restoration
122 efforts rarely ever reached their reference states, indicating that there is likely a mismatch between what

123 is aspired to, i.e. historical or contemporary reference states, and what is achievable. If the restoration
124 reference states are inherently unachievable, then this may damage the political effectiveness of the
125 legislative efforts to spur restoration. By contrast, if the goals are to undertake achievable Futuristic
126 Restoration, then the 20 and 30% area targets are more able to succeed in driving large-scale
127 restoration.

128 In concert, these efforts to restore nature through futuristic and achievable interventions, informed
129 through ecological history, enable directly actionable efforts for restoration. This provides an approach
130 by which practitioners can modify degraded landscapes, and national and international governments to
131 track and account restoration towards pre-defined goals.

132 **Restoration predictions and forecasting - Predicting nature recovery over time**

133 As previously discussed, ecosystems can take a long time to fully respond to restoration interventions,
134 so while the intervention may happen immediately, the nature benefit may not materialise for many
135 decades. However, if we can accurately predict that an intervention will eventually lead the ecosystem
136 to a net positive outcome, the intervention should be considered successful. Article 4 of the EUNRL
137 stipulates “restoration measures shall be put in place” by 2030 (European Commission 2024), and so
138 for measures to count, outcome prediction is key.

139 For national governments to deem a restoration measure successful, predictive methods are needed to
140 identify what sites are suitable for restoration, taking into consideration potential future conditions, as
141 well as the likely success of an intervention. Inspired by the modelling cycle for restoration proposed by
142 Brudvig & Catano (2021), we propose a prediction and forecasting framework, with the novelty of
143 dividing the framework into two key predictive stages, to address the needs of legislation to be the most
144 effective (figure 1).

145 The first stage is *a priori* “Restoration Outcome Prediction”, where the aim is to predict the likely
146 outcomes of a restoration project prior to any intervention. Here, the current and future environmental
147 conditions should be considered to evaluate likely outcomes possible for the restoration site, and what
148 interventions could lead to desirable outcomes. This is where targets should be set, in line with the
149 Futuristic Restoration perspective previously discussed. This form of prediction is particularly key for

150 legislation effectiveness, as *a priori* Restoration Outcome Prediction can be used for restoration
151 prioritisation; prioritising sites that are likely to be the most positive for nature recovery, and have
152 the lowest uncertainty for success. Communicating uncertainty is also crucial for legislation to be
153 trustworthy, encourage local participation, and maintain political capital for restoration. Given limited
154 financial, human, and political resources, efficiently prioritising restoration through *a priori* predictions
155 is key for these legislative efforts to spur widespread restoration. In the case of the EUNRL specifically,
156 evaluating the current and potential future environmental conditions will inform the type of habitats that
157 can be restored, given the law stipulates the restoration of currently degraded habitats as defined in the
158 EU Habitats Directive. Current methodologies for Restoration Outcome Prediction are limited, and
159 should be a key target for future research.

160 The second stage is “Recovery Forecasting”, with the aim of predicting the rates of recovery and
161 trajectories post intervention and using ongoing monitoring information. With predictive forecasting,
162 restoration efforts can be monitored to ensure that they are on track to reach the desired outcome
163 based on targets set using Restoration Outcome Prediction. This is crucial information for the ongoing
164 management of a restoration site; if the current intervention is unlikely to reach the desired outcome,
165 management strategies can then be adjusted to change the rate and trajectory of recovery (Brudvig
166 2017). This also provides an opportunity for targets to be adjusted should the initially defined target be
167 deemed infeasible due to ecological limitations or resource constraints. Methods for Recovery
168 Forecasting already exist, such as those by Rydgren et al. (2019) using an ordination regression
169 approach, and Sinclair et al. (2018) proposing a restoration index.

170 Brudvig & Catano (2021) describe the six key challenges currently limiting our ability to model
171 restoration – 1. Unclear Goals, 2. Outcomes Vary, But Why, 3. Model Parameter Limits, 4. Model
172 Uncertainty, 5. Scaling Up and Out, 6. Conditions Change Over Time – and we reiterate the need for
173 these six challenges to be addressed. We argue that our approach for target setting adequately
174 addresses challenge 1. The remaining challenges lay in the methodological realm, and so significant
175 advancements could be made without the need for additional and bespoke data collection. Large
176 databases of global biodiversity such as PREDICTS by Hudson et al. (2014) may be used to identify
177 mechanistic drivers of restoration variability – Challenge 2 and 6, and hindcasting methods using

178 existing restoration effort data may be used to test potential new methodologies – Challenge 3 and 4 in
179 Brudvig & Catano (2021).

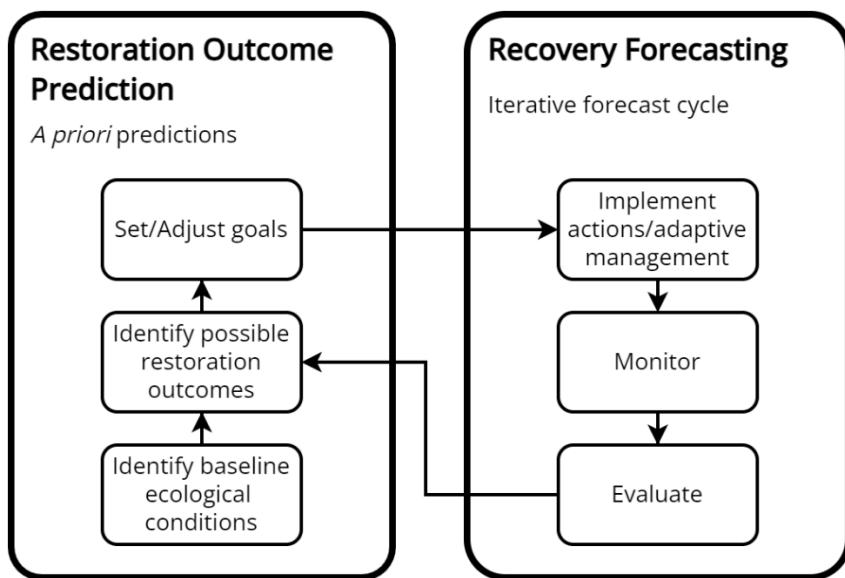
180 **Conclusions**

181 The push towards nature restoration since the 2020s, exemplified by the UN's Decade of Ecosystem
182 Restoration and the EUNRL, marks a pivotal moment in the field of restoration ecology. These global
183 movements require nature restoration to shift focus away from being a localised and ad hoc process, to
184 being predictive and systematically planned; the articles within the EUNRL require habitats to be
185 considered at landscape-level, requiring a high level of coordination.

186 Our suggested approaches for determining targets for restoration make a significant break from the
187 current paradigm of comparing with contemporary and historical states, however we argue this enables
188 more achievable restoration, as well as more resilient ecosystems in a changing world. Secondly, we
189 argue that significant advances in predicting restoration outcomes both before and after an intervention
190 are crucial to enable the scaling up of restoration and should be the key target for future research. By
191 adopting a future-thinking and predictive approach like this, integrating ecological theory with natural
192 history, these policies can lead to large-scale restoration, provide ecological and societal benefits, and
193 help transition towards a nature positive future.

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199

200 **Figure 1 Flowchart of monitoring and adaptive management of nature restoration. Key is the division of the stages of**
 201 **adaptive management into: 1. An *a priori* stage for predicting the outcomes of restoration prior to the start of an**
 202 **intervention, and identifying potential outcomes and goals, 2. An *a posteriori* forecasting stage to monitor the effect of**
 203 **intervention actions, rate of recovery and ongoing trajectory. Monitoring and evaluation of restoration sites are**
 204 **important, however here we focus on how they link to the two stages of predictive modelling.**

205

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