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RE-NEW OPINION ARTICLE

Invertebrate responses to rewilding: a monitoring framework for practitioners

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Rewilding presents a unique opportunity to better understand the processes influencing ecological communities and how they function. Although empirical evidence on the effects of rewilding is growing rapidly, knowledge gain is unbalanced, particularly for invertebrates, despite this group representing a large proportion of biodiversity and being fundamental to key ecosystem processes. Here, we advocate for more targeted systematic monitoring and experimental research, providing a site-based framework for practitioners to evaluate project effects on invertebrate biodiversity. This framework utilizes taxonomic indicators of change, representative of processes important to ecosystem functioning. Implementation of this framework and the associated opportunities and challenges for practitioners are discussed. Adopting this framework would broaden the taxonomic groups and ecosystem processes evaluated by rewilding projects, transform the sector from opinion-based to evidence-based, and help address some of the most pressing ecological and conservation questions of the twenty-first century.

Key words: evidence-based conservation, framework, invertebrates, monitoring, rewilding

Implications for Practice

- Invertebrate monitoring remains limited in rewilding projects.
- Many ecological processes are underpinned by invertebrates, and they should be considered fundamentally important in judging the success of rewilding projects.
- The framework provided allows practitioners to select invertebrate groups for monitoring that are most representative of the ecological processes being supported in their rewilding project.
- Being nearly halfway through the United Nations Decade of Ecosystem Restoration, funders should prioritize coordinated long-term monitoring, especially as the number of rewilding sites proliferates.

Introduction

Rewilding focuses on restoring ecosystem processes to create dynamic, self-sustaining ecosystems with no predicted trajectories or end points in their development (Carver et al. 2021). Outside the scientific community, monitoring and research on rewilding could be viewed as a threat to implementing rewilding projects, with perceptions that data may reduce the aura of rewilding by tainting it with the normal metrics used to judge success or that the fundamental concept of rewilding is so different from traditional conservation that conventional monitoring approaches are inappropriate (Sutherland 2002; Jepson et al. 2018; Genes et al. 2019). The dynamism and fundamentally open-ended outcomes of rewilding, alongside the large spatial scales involved, present a challenge to the development of monitoring protocols for practitioners seeking to assess the progress of projects (Hughes et al. 2011). Conversely, the dynamism of rewilding also presents one of the most exciting global, monitoring, and research opportunities of the twenty-first century. This raises poignant questions about what to monitor given the unpredictability of future changes and how practitioners would select areas representative of the biodiversity of a site, or indeed, whether to monitor rewilding effects at all. Here, we argue that the potential opportunities of monitoring outweigh the risks, provide a platform to broaden the audience, and robustly evidence the scope for rewilding to recover a nature-depleted planet (Jepson 2019).

Monitoring is a core activity in conservation biology, but despite the expanding application of rewilding, integration into wider policy and upscaling of projects remains limited in part by the scarcity of empirical evidence (Svenning et al. 2016; van Klink & WallisDeVries 2018). It is becoming increasingly relevant and imperative for practitioners to know if and how ecosystem complexity (species, trophic structure, and connectivity) and related ecosystem processes (function and resilience) are ultimately enhanced by rewilding, especially as we progress

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through the United Nations Decade of Ecosystem Restoration (Bullock et al. 2022). The framework developed by Torres et al. (2018) has provided a positive step toward developing a repeatable rewilding metric to measure progress for practitioners. The metric calculates ecological integrity based on a series of indicators, largely evaluated through expert-based opinion, including threats (e.g. mining), processes (e.g. fire), land use, and large-bodied species populations. This approach, however, needs to be calibrated against systematically collected monitoring data across multiple taxonomic groups (e.g. see multi-taxa studies in beaver wetlands, e.g. Orazi et al. 2022) and ecological processes to formally assess change over time (van Klink & WallisDeVries 2018; van Klink et al. 2022*b*).

Invertebrate Monitoring Framework

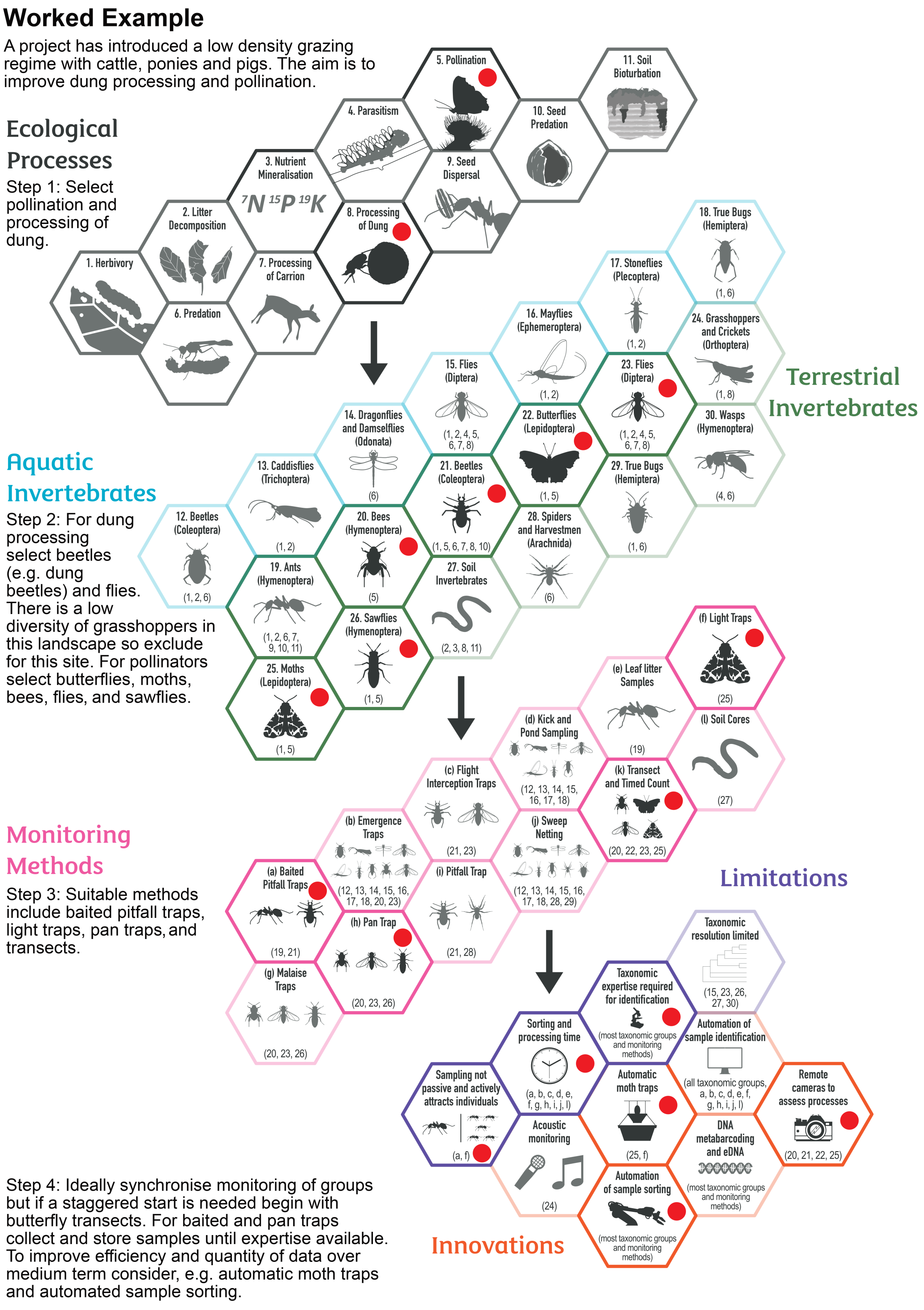
Thus far, invertebrates have been largely neglected in rewilding monitoring and experiments, with the focus on mammals and birds, despite these groups representing only a selection of ecosystem processes (van Klink & WallisDeVries 2018). Invertebrates are nonetheless critical and diverse components of biodiversity that underpin many ecosystem processes whose enhancement is integral to the underlying philosophy of rewilding (de Bello et al. 2010; Eisenhauer et al. 2023). As a group, invertebrates display a very wide range of ecological preferences and varying rates of sensitivity and response, spatially and temporally, to environmental change, making them ideal candidates for monitoring (Meier et al. 2022; van Klink et al. 2022*b*). Invertebrate monitoring in rewilding remains in its infancy, although scientifically robust monitoring methods already exist, albeit with a bias toward taxa such as butterflies, which are readily identifiable to species (van Klink et al. 2015). Partial or complete monitoring of different invertebrate groups will greatly enhance the knowledge and understanding practitioners can acquire regarding biodiversity responses to rewilding.

Integration of existing taxonomic monitoring, which represents community composition, and process-led monitoring, as already employed in-stream restoration projects (Beechie et al. 2010; Hughes et al. 2011), will likely provide the most reliable and quantitative knowledge gains for invertebrates in rewilding projects. Integration of diverse invertebrate taxonomy, within the monitoring framework will provide opportunities for comparisons with existing conservation methods, analysis of community composition, production of population trends, and evaluation across taxonomic groups with contrasting ecological requirements. Recognizing, as we must, that practitioners, as with scientists, cannot monitor everything, the selected taxonomic groups must capture various key ecological processes (e.g. pollination and nutrient cycling) important to ecosystem functioning (de Bello et al. 2010; Eisenhauer et al. 2023). In Figure 1, we propose a site-based framework, with a worked example, targeted toward practitioners to make informed decisions to stimulate invertebrate monitoring in rewilding projects. The four-step framework covers ecosystem processes linked to their most influential invertebrate taxonomic groups, current monitoring methods, the limitations of these methods, and technological innovations. We then discuss the implementation of this framework, the challenges and opportunities, and prioritize steps ahead.

Steps 1–3: Implementation of the Framework

Practitioners should identify which ecosystem processes are most relevant to their objectives or site and select suitable taxonomic groups and monitoring methods (Fig. 1). Given the open-ended nature of rewilding, this step is best informed by local site knowledge but may also need to be adapted over time if unexpected outcomes from rewilding projects emerge. Initial selection of highly represented processes (e.g. herbivory, pollination, and predation in terrestrial ecosystems and herbivory and litter decomposition in freshwater ecosystems), where relevant, would ensure widespread data collection for comparable groups and processes across sites while avoiding redundancy. Selecting different taxonomic groups would be encouraged, as population trends are often not always well correlated among invertebrate groups (van Klink et al. 2022*b*). The selective process we suggest will also allow practitioners to report towards international goals on ecosystem restoration for groups with opposing requirements, thereby increasing the capital of their projects. Monitoring of well-studied groups offers the second step for practitioners to commence invertebrate monitoring at the site level before expanding across a wider site network. Counts for these groups can reliably be undertaken by citizen scientists, at low cost to the project, and expertise can be sought from existing long-term monitoring schemes (eBMS 2024). For instance, regarding the latter point, training on the identification of these taxonomic groups and appropriate monitoring methods can readily be delivered to practitioners through online and field-based workshops. This approach would allow partial implementation of the framework, but with the caveat that it could miss the rapid changes that occur at the start of rewilding for some taxonomic groups, would be biased toward terrestrial groups mainly representative of pollination, or to areas with existing monitoring networks and an availability of volunteers, and to sites where access is straightforward.

To maximize the impact of the framework, implementation would be required across networks of sites and over decadal time series. Networks spanning site, landscape, and continental scales would be particularly beneficial for evaluating invertebrate responses to rewilding at multiple ecological scales. This can be achieved by using existing site networks (e.g. European Rewilding Network) (Rewilding Europe 2024). Carefully nested site selection will be required to ensure sites of varying size, surrounding land cover types, and baseline habitats are represented. Selection of these sites would allow robust spatial replication and facilitate small- and large-scale analyses. Initially, shorter-term studies are feasible through existing monitoring and research funding agencies, but longer-term projects are not always amenable to current funding sources (e.g. PhD funding at universities). The framework must be repeatable and financially viable over long time series (e.g. decades) to maximize its impact, so alternative funding sources should be considered. Given that we are nearly halfway through the United



Worked Example

A project has introduced a low density grazing regime with cattle, ponies and pigs. The aim is to improve dung processing and pollination.

Step 1: Select pollination and processing of dung.

Step 2: For dung processing select beetles (e.g. dung beetles) and flies. There is a low diversity of grasshoppers in this landscape so exclude for this site. For pollinators select butterflies, moths, bees, flies, and sawflies.

Step 3: Suitable methods include baited pitfall traps, light traps, pan traps, and transects.

Step 4: Ideally synchronise monitoring of groups but if a staggered start is needed begin with butterfly transects. For baited and pan traps collect and store samples until expertise available. To improve efficiency and quantity of data over medium term consider, e.g. automatic moth traps and automated sample sorting.

Figure 1. Four step framework for monitoring invertebrates in rewilding experiments. The framework describes step 1 relevant ecological processes, step 2 taxonomic groups representative of these processes, step 3 suitable monitoring methods, and step 4 method limitations and innovations in monitoring techniques. Projects should identify clear monitoring objectives and select the ecological processes that are being restored. Subsequently, suitable taxonomic groups to represent these processes can be selected with suitable monitoring methods based on the framework. A worked example is provided to show how the framework can be used for practitioners.

Nations Decade of Ecosystem Restoration, we argue that governments and their research bodies, Non-Governmental Organisations and relevant land managers should prioritize funding for coordinated long-term monitoring, especially as the number of rewilding sites rapidly accelerates.

Step 4: Inclusion of Technology to Overcome Limitations

The use of new technologies could revolutionize and upscale monitoring of invertebrates for rewilding practitioners, increasing the adaptability of the framework and allowing coverage of taxonomic groups currently absent from or challenging to cover in monitoring schemes, despite their acknowledged importance for ecosystem functioning (van Klink et al. 2024). Examples of relevant technology include the use of computer vision and deep learning to identify individuals (Blair et al. 2020; Bjerge et al. 2021), applications on smartphones to facilitate widespread and robust data capture by citizen scientists, robots to sort and identify samples (Ärje et al. 2020), and remote cameras to assess species interaction networks and ecosystem services (Alison et al. 2022). Benefits of technology compared to conventional methods include improved efficiency of data capture, higher spatial or temporal data capture especially in remote areas, the potential for engagement with novel or remote audiences, the provision of nonlethal alternatives, and better coverage of underrepresented taxa (e.g. flies, beetles, and ants, which underpin multiple ecosystem processes) that rely on specialist expertise (McClure et al. 2020; van Klink et al. 2022*a*). Molecular techniques (DNA metabarcoding and eDNA) provide considerable opportunity to monitor invertebrates, particularly those that defy conventional methods. Use of molecular monitoring techniques will likely expand as costs fall, the challenges of assessing abundance are overcome, and invertebrate reference libraries improve (van Klink et al. 2022*a*). Integration of technology into this framework will need careful implementation to allow calibration against existing datasets collected using traditional methods and to overcome the current limitations of novel technologies.

Opportunities

Implementation of replicable invertebrate monitoring over decadal time series and the selection of suitable controls or Before-After-Control-Impact experiments would allow scientists to better understand and test hypothesis-driven questions about rewilding against the backdrop of ongoing wider environmental change. Such questions include the area required to implement effective rewilding, the importance of the surrounding landscape context and baseline habitats, interactions between invertebrate groups, the relationship between functional diversity and ecosystem processes, and how large animals (across all trophic levels) influence invertebrate communities (Jepson 2016; Svenning et al. 2016). This strategic approach would promote a learning and feedback culture in the rewilding community akin to restoration ecology (Eger et al. 2022; van Rees et al. 2022), based on past and present examples of rewilding, thus enhancing the transfer of knowledge among rewilding practitioners and other disciplines. To facilitate the dissemination of data among practitioners across languages, political boundaries, and disciplines, any projects in the framework should ensure compliance with findable, accessible, interoperable, and reusable (FAIR) guidance data principles (Wilkinson et al. 2016).

The implementation of rewilding for threatened invertebrates remains the subject of controversial debate between the rewilding community and traditional species-oriented conservation (Lorimer et al. 2015; van Klink & WallisDeVries 2018). Traditional conservation involves the prescriptive management of habitats to maintain suitable conditions and meet species-oriented goals for threatened invertebrates. Rewilding could deliver both positive and negative outcomes for threatened species (Lorimer et al. 2015). Positive outcomes arise through ecological surprises, where habitat specialists respond in unexpected ways to ecological processes or habitats generated by rewilding (Bartel et al. 2010; de Schaetzen et al. 2018; Orazi et al. 2022). Negative consequences often relate to the disruption of specific habitats already heavily diminished by anthropogenic impacts, reliant on continued conservation management, especially on small sites (Lorimer et al. 2015; van Klink & WallisDeVries 2018). The adoption of this framework should alleviate some of the anxieties around threatened species by supporting robust, evidence-based decisions. This would allow early detection of undesirable impacts on threatened species or invasive species establishment and inform intervention if required. However, the deployment of this monitoring also needs to be sufficiently extensive to capture the opportunities that may arise over time and at larger scales for threatened species arising from ecological dynamism.

Conclusions

Rewilding is an experimental process. The urgency of the biodiversity and climate crises dictates that we cannot exhaustively evaluate all potential solutions before their implementation, but an evidence base that encourages adaptive learning by practitioners is nevertheless paramount. Greater focus should be placed on invertebrates, which are responsible for the delivery of multiple ecosystem processes yet remain neglected in rewilding projects. Robust monitoring should be viewed as a vehicle for practitioners of rewilding to demonstrate its potential and document changes at focal sites. Prioritizing the steps identified in this article to implement this framework, combining existing and novel monitoring techniques, would capture such changes effectively and facilitate novel ecological research to address some of the most pressing challenges for conserving biodiversity in the twenty-first century.

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