**Title:**

Revisiting/refocusing/rethinking ecological integrity: expanding monitoring to include animal communities across taxa and environments

Revisiting/refocusing/rethinking ecological integrity: using functional ecology to monitor animal communities across taxa and environments

Revisiting/refocusing/rethinking ecological integrity: embracing the role of animal communities

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**Target journal:** Frontiers in Ecology and the Environment Concepts and Questions (2800 words from Introduction-Conclusion, including panel text; <= 40 references, 4-5 total figures, tables, and panels)

**Abstract (150 words)**

**In a nutshell (100 words)**

**Introduction (come up with flashier title to this section, maybe?)**

Ecological integrity is an important guiding concept for ecosystem assessment and monitoring globally (Figure X). As defined by Parrish et al. (2003), ecological integrity is “the ability of an ecological system to support and maintain a community of organisms that has species composition, diversity, and functional organization comparable to those of natural habitats within a region”. The concept and its application have evolved since its first articulation in the mid-20th century (Leopold 1949) to include both abiotic and biotic ecosystem components and has been enshrined in environmental law and land management policy globally, but particularly in North America (Woodley 2010, Faber-Langendoen et al. 2006, Carter et al. 2019, Nordman et al. 2021; SI Panel 1). Monitoring ecological integrity metrics is important for assessing whether restoration moved site conditions toward a historical baseline, or whether conditions at a site deviate from historical reference conditions in response to anthropogenic or natural influences.

As ecological integrity continues to be integrated into how we monitor ecosystems, it has become clear that metrics that capture the collective responses of entire communities of organisms (e.g., plants, animals) are vital for understanding the outcomes of ecosystem states facing multiple anthropogenic influences concurrently (e.g., Karr 1981, Carter et al. 2019).

Animal communities, in particular, provide important additive insights to many common measures of abiotic factors and primary producers. Karr (1981) highlights some of these for fish communities, which include inherent aspects of animal communities (e.g., they represent multiple trophic groups, we often know a lot about their life histories) as well as how we, as humans, view them (e.g., they are relatively charismatic and many taxa are easy to identify).

People are increasingly using ecological integrity as a guiding concept in monitoring and including animal communities in these monitoring efforts (Figure X). However, these efforts have focused on systems and taxa where animal communities are easier to monitor or where there are established protocols and baselines (e.g. pollution sensitivity in macroinverts; Figure X, Carter et al. 2019). Specifically, likely because the first literature encouraging the use of animal communities in ecological integrity assessments stemmed from aquatic systems (e.g. Karr 1981), the most common adoption of ecological integrity with standardized protocols still exist in these systems. Animal communities have been less integrated into assessments of ecological integrity in non-aquatic (e.g., terrestrial systems), and thus, in these systems, monitoring still heavily relies on assessments of animal communities either through a habitat-proxy approach (Palmer et al. 1997, Lee-Yaw et al. 2022) or through focal species monitoring (Burnett and Roberts 2015, Runge et al. 2019), both of which are not generally good predictors of animal community responses to change (Schwartz et al. 2015, Van Lanen et al. 2023).

In this piece, we argue that we are at a pivotal moment for adopting animal community metrics of ecological integrity. We highlight two key points that highlight that this is the time to integrate animal communities into ecological integrity monitoring. First, current and growing technological advances in monitoring and data analysis have alleviated many of the real or perceived barriers or challenges of monitoring animal communities. Second, we can develop metrics for animal communities that are generalizable and comparable across taxa and environments by focusing on functional ecology versus taxonomic identity of species in ecosystems. We highlight methodological and technological advances we find to be most promising in this endeavor and highlight literature demonstrating how using a functional ecology approach allows for building general protocols, baselines, and understanding of ecological integrity of animal communities across systems, taxa, and monitoring schema.

**Growth in monitoring, computation, and statistical capacity**

Historically, animal communities have been perceived as difficult to integrate into ecological integrity monitoring; however, new methods of data collection are making such integration possible. Many of the perceived limitations to including animal communities when monitoring for ecological integrity stem from current and historical data collection challenges as well as the complexity of modeling animal community data. In addition to a growing number of long-term monitoring programs (e.g. Breeding Bird Survey: https://www.pwrc.usgs.gov/bbs/, NABat: https://sciencebase.usgs.gov/nabat/#/results, LTER network: https://lternet.edu/) and databases of animal functional traits (i.e., AVONET for birds; Tobias et al. 2022), new technology such as acoustic recording units (ARUs), camera traps, environmental DNA (eDNA), and drones are allowing us to collect data for animal communities at much broader spatial and temporal scales (Rees et al. 2014; Steenweg et al. 2017; Wood et al. 2019).

Paired with modeling approaches such as multi-species occupancy models (Iknayan et al. 2014) and combining multiple data sources (including those collected by community scientists, e.g. eBIRD) via data integration (Miller et al. 2019), we can model animal communities while accounting for uncertainty and detection error (Iknayan et al. 2014). Advancements in methods have been paired with increased computational power and access allowing for efficient analyses of community data (Yackulic et al. 2020). Thus, with analytical and technological advances, the time has perhaps never been better to integrate animals into ecological integrity monitoring.

Nevertheless, proposed changes to monitoring programs can be met with skepticism, and challenges will certainly confront efforts to integrate animals into ecological integrity monitoring. Many emerging sampling technologies (i.e., ARUs, camera traps, eDNA) are designed as multi-species sampling approaches that facilitate the ability to passively or non-invasively sample across large areas. Where concerns exist about the additional cost of multi-species sampling, community-level monitoring could be simplified over time as part of goal-efficient monitoring approaches to mitigate the expense of long-term monitoring programs (Golding et al, in review) through optimal sampling approaches (i.e., Sanderlin et al. 2014). In a goal-efficient monitoring approach, baseline community data are collected to identify sensitive groups of species that require additional sampling effort, while maintaining the ability to quantify community metrics. Then, further monitoring can focus on sampling designs that increase detections of these sensitive groups of species within multi-species sampling designs.

**Functional ecology as a general framework for animal community ecological integrity**

Alongside these growing data streams and capacity to analyze those data, we also can develop generalizable metrics of ecological integrity that accommodate differences in methodologies across systems and taxa. To do this, we can use functional ecology to create general, cross-system ways to measure animal communities. [there’s a good figure, Figure 3 in Carter et al. 2019 about different metrics]. Animal communities and their functional configuration shape ecosystems across the globe. Animal communities perform processes such as nutrient cycling (Schmitz et al. 2014, Schneider et al. 2016, Saba et al. 2021), seed and pollen dispersal (Fricke et al. 2022, Gonzales-Robles et al. 2021), and disease spread (e.g., bark beetles Rodman et al. 2022). Which species or functional groups are represented in an animal community shape how these processes play out to shape ecosystems (e.g., Bello et al., recent paper in Science about megaherbivores, seed dispersal/size paper).

Many of these functions are general across ecosystems, while others may be more specific to an ecosystem or certain taxonomic groups. However, they provide a way to link across systems and taxa and to build predictions about the mechanisms that may shape ecosystems and ecological integrity. However, there are multiple examples of how animal communities are used to track aspects of ecological integrity (structure, composition, diversity, and connectivity) and multiple ways these could be extended to integrate into monitoring for ecological integrity.

*Structure*

[Examples from literature looking at the structure of animal communities WRT functional ecology and ecological integrity]

*Composition/Diversity*

[Examples from literature looking at the composition/diversity of animal communities WRT functional ecology and ecological integrity]

*Connectivity*

[Examples from literature looking at the connectivity of animal communities WRT functional ecology and ecological integrity]

**Conclusion**

[Something cohesive here, TBD, stand in content below]

We are in a new era of methodological and computational advances that can allow us to better monitor how land management, restoration, and conservation efforts shape ecosystems. There is a growing awareness that everything in ecosystems is intrinsically linked, and that even actions that are meant to improve the resiliency and integrity of an ecosystem have a variety of outcomes depending on where in the ecosystem actions occur (Pearson et al. 2022). Expanding monitoring to include animal community metrics of ecological integrity will help land management agencies better understand how communities are structured and how management actions shape ecosystems, without disregarding crucial players in ecosystems.

**Figures:**

Literature review figure from Gavin

Literature review figure or two highlighting biases in implementation across systems/taxa

Conceptual figure of monitoring, computation, and statistical approaches

Functional ecology figure – either conceptual or pretty pictures of example taxa

**Boxes:**

Conceptual box of monitoring, computation, and statistical approaches

Functional ecology box – an example or two from the literature on using functional ecology to track ecological integrity.

Maybe: current caveat about ecological integrity as a concept

**Supplements:**

Methods for the qualitative literature review – Gavin

Other figures from the qualitative review