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Review Paper

Finding the essential: Improving conservation monitoring across scales

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ABSTRACT

To account for progress towards conservation targets, monitoring systems should capture not only information on biodiversity but also knowledge on the dynamics of ecological processes and the related effects on human well-being. Protected areas represent complex social-ecological systems with strong human-nature interactions. They are able to provide relevant information about how global and local scale drivers (e.g., climate change, land use change) impact biodiversity and ecosystem services. Here we develop a framework that uses an ecosystem-focused approach to support managers in identifying essential variables in an integrated and scalable approach. We advocate that this approach can complement current essential variable developments, by allowing conservation managers to draw on system-level knowledge and theory of biodiversity and ecosystems to identify locally important variables that meet the local or sub-global needs for conservation data. This requires the development of system narratives and causal diagrams that pinpoints the

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social-ecological variables that represent the state and drivers of the different components, and their relationships. We describe a scalable framework that builds on system based narratives to describe all system components, the models used to represent them and the data needed. Considering the global distribution of protected areas, with an investment in standards, transparency, and on active data mobilisation strategies for essential variables, these have the potential to be the backbone of global biodiversity monitoring, benefiting countries, biodiversity observation networks and the global biodiversity community.

1. Introduction

Conservation management mediates the interactions between nature, human development and environmental impacts (Johnson et al., 2017; Pecl et al., 2017). It needs to be guided by clear conservation goals, and underpinned by information on the state and trends of social-ecological interactions (Ostrom, 2009). Protected areas are managed for a variety of conservation goals, from the protection of keystone species to the conservation and maintenance of entire ecosystems (Naughton-Treves et al., 2005). Despite their current aims, future expectations for their role may change due to changing environmental, demographic, social and political conditions, including new conservation objectives that were not previously considered (Rands et al., 2010).

To account for progress towards conservation targets, monitoring systems should capture information on biodiversity change but also knowledge on the dynamics of ecological processes and their effects on human well-being (Defries and Nagendra, 2017; Eisenhauer et al., 2019). These, integrated data needs will require the implementation of new monitoring approaches that include a wider characterization and quantification of social-ecological systems, and the optimization of available operational resources for long-term monitoring (Carpenter et al., 2009). Effective monitoring systems must also capture information on pressures and threats to allow for the identification of causal mechanisms of change (Maron et al., 2017). Without such integration, monitoring systems would be blind to the mechanisms driving ecological trends and thus, unable to guide effective policy responses (Nichols and Williams, 2006).

Protected areas constitute, in many parts of the planet, one of the main sources of in situ biodiversity information (Martin et al., 2012). These areas represent complex social-ecological systems with strong human-nature interactions, being able to provide relevant information about how global and local scale drivers impact biodiversity and ecosystem services. Nevertheless, effective monitoring systems must be scalable as many drivers of biodiversity change occur at scales beyond individual conservation areas, thereby, requiring integrated monitoring approaches that allow for the detection of drivers operating at broader scales (Navarro et al., 2018; Eisenhauer et al., 2019).

Recently, Pereira et al. (2013) argued that, to overcome the current gap in biodiversity data and to improve the scalability of observation systems, the scientific and practice communities should focus on identifying and capturing essential variables, i.e. critical measurements required for the study, report, and management of global biodiversity and ecosystem change, as well as other social-ecological dimensions e.g. (Bojinski et al., 2014). Here we develop a framework that uses an ecosystem-focused approach to support managers in identifying essential variables in an integrated and scalable approach.

2. From essential variables to conservation management

Monitoring biodiversity, entire ecosystems, and the services they provide often involves the implementation of costly monitoring programs that seek to combine targeted, hypothesis-driven and/or surveillance monitoring from different sources (Lindenmayer et al., 2018; Pereira et al., 2017). When establishing a monitoring program, conservation managers face the challenge of balancing available resources between monitoring activities, operational costs, research and conservation action (Gill et al., 2017). This often leaves monitoring programs with limited financial and logistic resources, hampering their usefulness and encompassing nature. Since the purpose of monitoring activities in this context is to facilitate more effective conservation actions, it is imperative that monitoring systems be as targeted and efficient as possible. If they fail to meet this objective, they risk misinforming conservation actions and draining resources (Legg and Nagy, 2006; Cameron et al., in press).

The process of identifying essential variables is not an exclusion process but rather a priority setting process, where central elements of monitoring effort are identified to improve the understanding of social-ecological dynamics. It facilitates the prioritization and optimization of resources and allows for a transparent and direct way to communicate monitoring needs through different levels of knowledge and decision-making. The identification of essential variables often uses a top-down approach, where experts define at the global level what variables should be monitored. Here we advocate that this approach can be complemented with a bottom-up approach, where conservation managers draw on system-level knowledge and theory (Liu et al., 2015) to identify locally important variables that meet local or sub-global needs for conservation data (Turak et al., 2016a, Fig. 1).

Our framework proceeds in four sequential steps, that we introduce briefly below:

1. ***Narratives** are used to describe the complexity of ecological and social interactions that influence a specific conservation or management goal*. These narratives should be harnessed to identify the major **system components, functions and processes**, and the underlying causal relationships that affect them. Using existing ecological knowledge, ecosystems supporting similar communities and processes, or facing comparable anthropogenic pressures can be grouped and systematically described (Turak et al., 2016b). These elements collectively summarize the monitoring needs to assess a given conservation goal. By examining the causal relations that link the social-ecological system, it is also possible to represent the focal system elements that are conditioned or condition the entire social-ecological system.
2. *To quantitatively address these system elements and their changes through time, **models** that can describe the spatial and temporal interactions are often necessary*. These models seek to describe critical ecosystem dynamics and can only be operationalized contingent upon the availability of interpretable information and technical capacity to implement them. Some of these models only use static variables, describing the state of a given system component (e.g. topography), but others rely on dynamic variables (e.g. species abundance) that can be analyzed to evaluate trends and make scenarios of future conservation trajectories.
3. *Independent of the type of information used, modelling approaches rely on a set of **variables** that condense and summarize observations*. These strongly depend on source datasets, making their identification a critical step to operationalize the models and create the foundation for the design and implementation of monitoring systems. Within these, conservation managers are able to identify concrete groups of locally important variables that together describe the social-ecological system.
4. ***Observations** constitute the source datasets that are the basic building blocks of any given monitoring system and of which the variables are derived*. These are usually dynamic measures that require the consideration of both in situ and remote (e.g. satellite data) monitoring activities (Vihervaara et al., 2017), but can also include information with smaller temporal variability that is still critical to understand system dynamics (e.g. soil type). Conservation managers must prioritize which observations must be collected in situ. Other data requirements can be met through the establishment of institutional collaborations that allows to maintain a constant flow of information, recognizing the fact that many important ecological processes and drivers of change are occurring at scales beyond the extent of the protected area in question.

3. Creating narratives to capture the complexity of social-ecological systems

The use of narratives can contribute to the identification of monitoring priorities targeting specific system elements that are fundamental to understand a social-ecological system. Such narratives have been widely used to facilitate communication between stakeholders engaged in biodiversity conservation and beyond (Metz et al., 2007; Moon et al., 2019). At the same

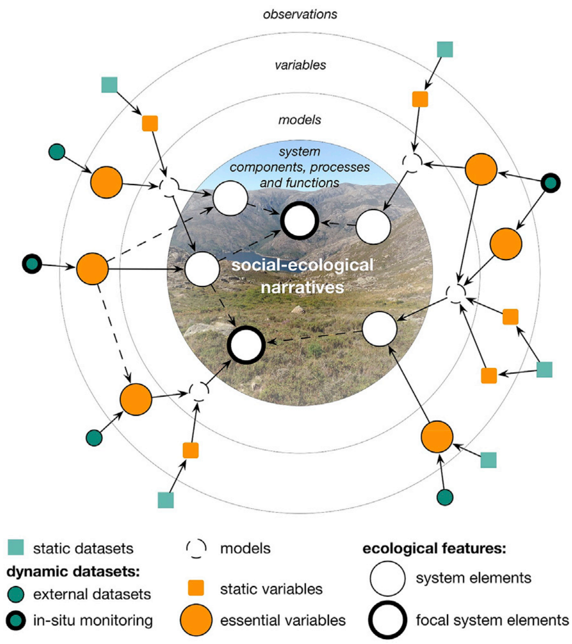

Fig. 1. Conceptual representation of a system approach to identify essential variables and monitoring priorities in conservation areas. The arrows in the Figure differentiate between direct data dependencies (full lines) and the expected causal relations between system components and essential variables (dashed lines). Illustrative implementation examples are given in Fig. 2a and Fig. 2b.

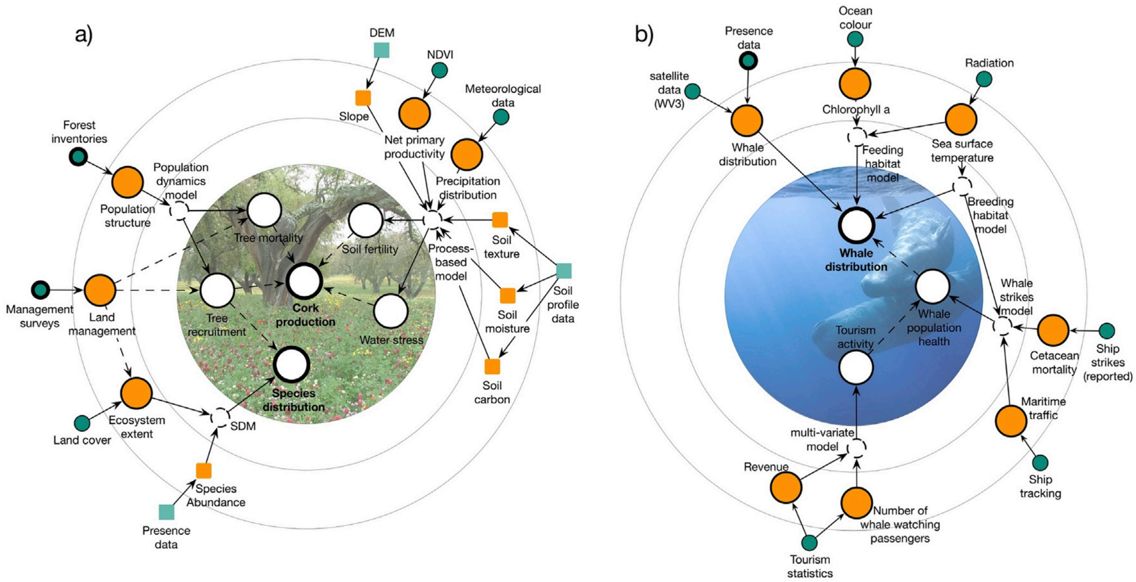

Fig. 2. Illustrative examples of a system approach to identify essential variables and monitoring priorities in two conservation areas focusing on preservation of key species and the maintenance of relevant ecosystem services: a) a Montado wood-pasture system in the south of Portugal (S1); and b) a Mediterranean marine system in the Pelagos sanctuary for marine mammals™ (S2).

time, protected areas often collect data regarding the drivers, states, impacts and pressures affecting the conservation status of species and ecosystems. This DPSIR approach gives land managers and researchers' strong indicators to further develop system models, formulate hypotheses, and follow the system responses to a particular driver or set of drivers (Masó et al., 2019).

A narrative is a description of what is happening to a social-ecological system (S1, S2). It may start with an introduction to the system and the conservation objectives, but at its core, it is a story about how the main drivers are evolving and how they negatively or positively affect the different components of the system (Hayes et al., 2015). The development of narratives should be an open and iterative process, fostering the inclusion of contributions not only from conservation managers but also from a wider set of stakeholders including resource users, researchers and local knowledge holders (Spruijt et al., 2014).

Narratives support the development of causal diagrams that pinpoint the social-ecological variables that represent the state and drivers of the different components, and their relationships (Fig. 1). These also contribute to effectively describe the main aspects and causal relations within the social-ecological system being managed, often including their related threats and drivers, as well as the biodiversity and ecosystem elements and functions that are critical to meet the conservation goals that have been set (Lindenmayer and Likens, 2010, Fig. 2a and b; Giling et al., 2018).

Here we propose a new approach to identify essential variables based on causal diagrams constructed from system narratives. In our approach, two types of flows are represented (Fig. 1): i) a causal flow that is represented by the directional links between the variables of the system; and ii) an information flow that is organized into concentric layers from raw data to system components, functions, and processes. The causal flow makes it explicit how different variables and data sources are combined to model system components. It also declares expectations and knowledge about relationships between the different variables which are important to understand the social-ecological system dynamics. The information flow identifies the variables that can be observed, and what monitoring schemes, observations, and data sources are needed to inform them.

4. From locally important variables to essential variables

Conservation monitoring often focuses on locally important variables without a clear concern for data comparability across scales or regions. Implementing systematic monitoring schemes requires moving from a locally important set of variables to a more consolidated set of essential variables that are relevant across borders, scales and ecosystems. This has also to be coupled with transparent ways to aggregate and disaggregate all relevant information. One of the main challenges is that, across scales, monitoring systems often address different purposes, stakeholders and, more significantly, different types of questions or conservation goals (Turak et al., 2016a).

In previous research (e.g. Schmeller et al., 2017) the criteria for "essentiality" has already been established for the identification of essential variables for climate and broad biodiversity classes. Here we approach the problem of "essentiality" from the specific needs of sub-global conservation management. Nevertheless, locally important variables that characterize the social-ecological dynamics of interest to local managers and researchers are potentially only a subset of a wider array of variables needed by users in different regions of the world.

However, matching locally important variables with global essential variables is needed to foster the scalability of the data collected by protected areas. For instance, collection, mobilisation, and publishing of data regarding species distribution and population structure can use the standards, methods and tools being developed for essential biodiversity variables (Kissling et al., 2018). In doing so, automated data flows can be established and feed the development of global datasets critical for biodiversity monitoring and research (Navarro et al., 2018).

Still, there are consistency and scalability issues when several conservation areas consider the same essential variable. As an example, different conservation areas can identify species distribution as a monitoring variable without the necessary thematic consistency (e.g. in Fig. 2a species distribution corresponds to forest species while in Fig. 2b it corresponds to cetaceans). Addressing such thematic, and eventually temporal, inconsistencies will be critical when considering interoperability across conservation areas. A solution would imply direct coordination of monitoring activities (e.g. at the national level) that allows information to move across scales and ecosystems, as part of a multi-level conservation strategy.

Ultimately, the global selection of essential biodiversity variables needs also to be informed by these bottom-up variable selection efforts. Considering the relevance of the information collected by conservation areas, developing global monitoring schemes for essential biodiversity variables needs to draw on those efforts. Therefore, locally important variables which are identified across multiple sub-global regions or protected areas are likely to be those most viable to be monitored globally. This happens not only from a practical data availability point of view but also because variables that are systematically identified as locally important are probably also globally important for international conventions and countries.

5. Future implications

One of the challenges faced by conservation managers is to establish, maintain and highlight the need for long-term repeated measurements of data relevant for conservation purposes. It is critical that any monitoring system first clearly considers the policy and conservation objectives that the system needs to serve, ensuring a clear link to decision-making. These links typically involve a co-development process where decision-makers, managers, and researchers work together to identify key goals and objectives providing a clear roadmap for the development and operation of the monitoring system (Craine et al., 2007). With clear objectives in hand, the identification of essential variables is a useful way to prioritize data collection efforts needed for operational and policy-relevant conservation monitoring systems. It allows to focus resources, identify capacity building plus data needs, and to mobilize knowledge including the resources necessary to sustain local and cross-scale assessments.

Establishing a group of essential variables that can commonly be assessed across conservation goals and conservation areas allows monitoring systems to contribute directly to high level (e.g. national and international) monitoring efforts. At the same time, the benefits generated by such a coordinated monitoring program can be multiplied across spatial scales, increasing the effectiveness and usefulness of conservation management and monitoring for a variety of objectives. This harmonized approach requires specific guidelines that structure and standardize monitoring efforts but has the potential to maximize the outcomes from conservation efforts, allowing monitoring efforts to go beyond borders, ecosystem types and realms. It also requires that, in the context of conservation monitoring, essential biodiversity variables cannot be seen as a closed box and EBVs have to be seen in the context of others (e.g., ECVs, EOVs, etc.).

Considering their global distribution, covering all ecoregions (Dinerstein et al., 2017), current targets (e.g., Aichi target 11), and the essential variable based approach here described, protected areas have the potential to be the backbone of global biodiversity monitoring. Even considering that only a fraction of these globally distributed areas would be able or willing to participate in such initiative, thousands of sites would be able to report data. A step forward would be to attach to global conservation targets the global monitoring of these conservation areas and to establish a global biodiversity monitoring backbone. With strong political support, an investment in standards, transparent methods, and on active data mobilisation strategies (Navarro et al., 2018), in the face of climate and land use change, these areas could be pivotal as early warning systems to signal major regional and global nature shifts. Such an approach would benefit from being written into the post-2020 CBD targets, giving the International Union for Conservation of Nature the necessary political support to make this a reality and provide a global baseline for nature status and conservation.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.gecco.2019.e00601.

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