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Discussion

Monitoring ecological consequences of efforts to restore landscape-scale connectivity

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ABSTRACT

Managing and restoring connectivity that enables wildlife movement through landscapes is the primary approach to reduce harmful effects of habitat loss and fragmentation. Improved connectivity is also increasingly invoked as a strategy to mitigate negative impacts of climate change by enabling species to track preferred environments and maintain evolutionary processes. Although initiatives to improve connectivity using restoration are becoming commonplace, we do not know how successful these actions are, nor which mechanisms underlie biotic responses.

Most ecological monitoring focuses on site condition or quality rather than those landscape-scale processes that connectivity is intended to facilitate. To assess biodiversity responses to connectivity initiatives, we argue that new monitoring approaches are needed that distinguish the roles of connectivity restoration from those of habitat augmentation or improvement.

To address this critical gap, we developed a conceptual model of the hypothesised roles of connectivity in complex landscapes and a linked framework to guide design of connectivity monitoring approaches in an adaptive management context. We demonstrate that integrated monitoring approaches using complementary methods are essential to reveal whether long-term landscape-scale goals are being achieved, and to determine whether connectivity management and restoration are the mechanisms responsible.

We summarize a real-world example of applying our approach to assist government develop a monitoring plan for a large-scale connectivity conservation initiative in the Australian Capital Territory. As well as highlighting the utility of the framework to help managers make informed choices about monitoring, this example illustrates the difficulties of convincing funding bodies to include monitoring in project budgets and the questions more likely to be answered with limited funds.

Synthesis and applications. Implementing an effective strategy to monitor connectivity conservation initiatives necessarily involves more work but we argue it is an essential investment rather than an additional cost. By optimizing allocation of limited monitoring resources, we can more effectively implement management that improves functional connectivity, and understand how changing connectivity affects population persistence.

1. Introduction

There has been a worldwide shift away from managing biodiversity within individual protected areas toward whole-of-landscape approaches (Worboys et al., 2010). This is partly because individual reserves are generally too small to support viable populations of many species, so multiple patches need to be connected by movements of individuals and genes to ensure persistence (Crooks and Sanjayan, 2006; Hilty et al., 2006). Moreover, with climates changing at unprecedented rates, the future of many ecosystems (even biomes; Moen et al., 2014) depends on the ability of species to adapt or track shifting regions of

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habitat suitability. Adaptation to new climates and range-shifting are more likely if populations are functionally large and genetically diverse, both of which are facilitated by ecological connectivity (Sgrò et al., 2011; Driscoll et al., 2012).

This growing appreciation that effective conservation needs large, connected populations has led to landscape-scale connectivity initiatives (or 'connectivity conservation' initiatives; Worboys et al., 2010) proliferating in governmental and non-governmental programs (Fig. 1). Several countries base their national conservation strategies on large-scale connectivity (e.g., DeClerck et al., 2010), with concepts like 'defragmentation' and 'rewilding' being increasingly used to frame policy discussions (Fischman et al., 2014; Drenthen and Keulartz, 2014; Nogués-Bravo et al., 2016). Rather than being motivated by explicit research questions, the intent is usually to manage or restore structural connectivity (physical links between areas) to facilitate movement of individuals and/or genes through the landscape or support large-scale abiotic processes (Soulé et al., 2004). Connectivity is typically viewed in terms of structural measures of habitat (e.g., tree-cover) but such measures may not relate directly to movement or permeability (Kadoya, 2009). That is, *structural* connectivity need not beget *functional* connectivity and the conditions required for movement by species vary widely, even within the same region (Amos et al., 2014; see 'Definitions of connectivity concepts' section, below). Furthermore, movement needed to support ecological and demographic processes may differ from that needed to support evolutionary processes (Lowe and Allendorf, 2010). Thus monitoring the ecological and evolutionary outcomes of attempts to enhance connectivity is critical to understand which approaches actually achieve their intended purpose.

Fig. 1. Top: the Coto Brus valley on the Costa Rica-Panama border, a region where strategic restoration efforts have re-established connections between the Talamanca Range in the background and the Osa Peninsula, linking these two extensive reserves to the Mesoamerican Biological Corridor spanning eight countries. Large-scale monitoring is required to determine whether restoration of high elevation forests is more important for species persistence than augmenting extent of intervening lowland habitats. (Photo DM Watson). Bottom: Riparian corridor in farmland in south-eastern Australia, where revegetation efforts are focused on augmenting existing linear features in the landscape, increasing woodland habitats and facilitating animal movements as part of the continental-scale Great Eastern Ranges Initiative. Long-term monitoring is required to identify which species do not use linear features for movement, and may require targeted translocation to effect genetic interchange and minimise local extinctions (Photo M Crane, used with permission).

A major impediment to monitoring connectivity conservation initiatives is that existing approaches to ecological monitoring focus on quantifying changes in metrics such as abundance of target species, species occurrence at patch scales (Worboys et al., 2010) or indirect measures such as habitat extent and configuration (Tischendorf and Fahrig, 2000). While these may be among the desired outcomes of connectivity management initiatives, such approaches do not quantify changes to connectivity nor their influence on biodiversity or ecological dynamics (including modified fire or flow regimes). Moreover, indirect measures of connectivity cannot distinguish proximate changes to populations and ecological processes from effects of habitat augmentation and/or improvement (Driscoll et al., 2014). Thus, conventional inventory- and habitat-based methods are often inappropriate for monitoring connectivity—misaligned with the immediate objectives of connectivity management and the spatial and temporal scales over which actions are expected to have desired effects (Kadoya, 2009; Gregory and Beier, 2014). New monitoring approaches are required to generate consistent and comparable measures of functional connectivity. An integrated approach is also critical to working across the spatial and temporal scales involved to inform on-ground management and restoration efforts in the context of landscape-scale conservation.

Implementing an effective strategy to monitor connectivity conservation initiatives necessarily involves more work but we argue that it is an essential investment rather than an 'added extra'. Currently, we have no way of judging which on-ground method has the greatest effect on a population, how to make methods work more effectively, or whether these interventions are addressing the long-term objectives of initiatives. In addition to generating information critical for reporting and evaluating effectiveness for particular projects, monitoring multiple initiatives using comparable approaches would enhance our generalized understanding of *how* connectivity affects populations. For example, are more connected populations necessarily more resistant to stochastic events; does increased connectivity across landscapes reduce the likelihood of invasion by exotic species and resultant changes to community dynamics? By measuring relevant response variables consistently at multiple scales across multiple systems, the mechanistic basis of observed patterns can be revealed, and generalized answers to these questions will emerge, improving our ability to make robust predictions and extrapolate projected outcomes to new sites, species or systems.

To improve connectivity monitoring strategies, we developed a process to guide decisions about what, where, when and how to monitor connectivity management and restoration. Rather than a generic "how to design a connectivity conservation monitoring strategy" or comparing the pros and cons of particular methods or objectives, we provide a novel framework for biologists, conservation managers and policy makers to align objectives of any initiative with planned actions, allowing them to determine how best to monitor the effectiveness of those actions in achieving the stated objectives. We build a conceptual model that makes explicit the many hypothesised links from on-ground connectivity management to organismal movement to the demographic parameters that define population processes and finally to the ultimate conservation outcomes intended. We embed this model within an adaptive management framework (Westgate et al., 2013) to provide a decision-support tool that links objectives to achievable monitoring goals, advising on the most appropriate methods to use for understanding, managing and reporting effects of connectivity restoration. We