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Review

A management-oriented framework for selecting metrics used to assess habitat- and path-specific quality in spatially structured populations

Sam Nicol[a,*], Ruscena Wiederholt[b,c], Jay E. Diffendorfer[d], Brady J. Mattsson[e], Wayne E. Thogmartin[f], Darius J. Semmens[d], Laura López-Hoffman[b,c], D. Ryan Norris[g]

[a] CSIRO Land and Water, EcoSciences Precinct, Dutton Park, QLD 4102, Australia
[b] School of Natural Resources & the Environment, The University of Arizona, Tucson, AZ 85721, USA
[c] Udall Center for Studies of Public Policy, The University of Arizona, Tucson, AZ 85721, USA
[d] U.S. Geological Survey, Geosciences and Environmental Change Science Center, Denver, CO 80225, USA
[e] Institute of Silviculture, University of Natural Resources and Life Sciences, Vienna, Austria
[f] United States Geological Survey, Upper Midwest Environmental Sciences Center, 2630 Fanta Reed Road, La Crosse, WI 54603, USA
[g] Department of Integrative Biology, University of Guelph, Ontario N1G 2W1, Canada

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ABSTRACT

Mobile species with complex spatial dynamics can be difficult to manage because their population distributions vary across space and time, and because the consequences of managing particular habitats are uncertain when evaluated at the level of the entire population. Metrics to assess the importance of habitats and pathways connecting habitats in a network are necessary to guide a variety of management decisions. Given the many metrics developed for spatially structured models, it can be challenging to select the most appropriate one for a particular decision. To guide the management of spatially structured populations, we define three classes of metrics describing habitat and pathway quality based on their data requirements (graph-based, occupancy-based, and demographic-based metrics) and synopsize the ecological literature relating to these classes. Applying the first steps of a formal decision-making approach (problem framing, objectives, and management actions), we assess the utility of metrics for particular types of management decisions. Our framework can help managers with problem framing, choosing metrics of habitat and pathway quality, and to elucidate the data needs for a particular metric. Our goal is to help managers to narrow the range of suitable metrics for a management project, and aid in decision-making to make the best use of limited resources.

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* Corresponding author.
E-mail address: sam.nicol@csiro.au (S. Nicol).

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1. Introduction

Spatial structure in populations occurs when a population occupies two or more distinct habitats that are connected by the regular movement of individuals. Spatial structure can be characterized in many ways, including classic metapopulations (Hanski, 1994), seasonal migratory systems (Mattsson et al., 2012; Nicol et al., 2015), nomadic systems (Dean, 2004) and even biophysical marine circulation systems (Cowen et al., 2006). Because movement links the dynamics between habitats, making decisions about how to effectively manage and conserve spatially structured populations poses enormous challenges (Skagen and Knopf, 1993; Kremen et al., 2007; Martin et al., 2007; Behrens et al., 2008; Miller, 2011). Further, species in spatially structured populations are often highly mobile, which can lead to social, economic, and political management challenges that cross multiple jurisdictions (Behrens et al., 2008; Semmens et al., 2011; Dallimer and Strange, 2015). In this context, managers need to decide where and when to take action to maximize the chances of meeting their objectives. Acting at the wrong time or place could result in misallocation of limited resources and lost opportunities to protect species (Martin et al., 2007; McCarthy et al., 2010). Uncertainty about the cause and effect relationships between management actions and objectives can also have unintended consequences—for example acting in one location may be offset by habitat losses, density dependence, or altered harvest quotas in another location (Sheehy et al., 2010; Runge et al., 2014).

One of the key questions for most decision makers interested in managing spatially structured populations is which habitat(s) or connections between habitats should be managed or protected to maximize the benefit to the population as a whole? This question is at the heart of decisions about how to allocate limited resources across space and time. Habitat-quality metrics, representing contributions of distinct habitats and the pathways which connect habitats to population dynamics, can be useful indicators to guide the allocation of conservation resources. However, the multitude of available metrics can make selecting an appropriate metric daunting. In a review of habitat-quality metrics within a metapopulation context, Runge et al. (2006) reported over 34 different metrics used to distinguish sources from sinks. Other studies have detailed a wide range of metrics to assess landscape connectivity (Urban and Keitt, 2001; Proulx et al., 2005; Urban et al., 2009), which is indirectly related to spatial population dynamics. Given the enormous range of metrics available for spatially structured models, how should a manager choose an appropriate metric or set of metrics to guide their decision making?

In this paper, we present a framework to help managers select a habitat- or pathway-specific quality metric based on the decision context of a spatially structured population. Our framework is based on common decision-making and management-planning frameworks including (structured decision making (Gregory et al., 2012); PrOACT (Hammond et al., 1999); and Open Standards for the Practice of Conservation (Conservation Measures Partnership, 2013)). We argue that metric selection depends on the management objective, the available management actions, and the data available. After introducing our framework, we illustrate how it can be used to select metrics in decision contexts involving common management objectives and actions from theory and practice. We do this by first reviewing objectives and actions found in the literature and then reviewing and classifying existing metrics into three classes based on their data requirements. We then identify suitable habitat-quality metrics for each management objective and action by using our metric classification scheme that is based on data requirements for objective-action combinations. Finally, we use our approach to make general observations about metric selection in spatially structured populations and to reveal knowledge gaps where new metrics may be needed.

2. Definitions and scope

We define habitats as distinct locations inhabited by part of all of a population during a given time period. Paths are dispersal or migration routes that connect habitats; individuals may pass along paths but do not spend much time there relative to time spent in habitats. A combination of habitats and paths forms a spatially structured population.

For the purposes of this study, we considered only habitat- and pathway-quality metrics for single-species population models. Although we acknowledge the importance of multi-species models, management objectives and actions are often species specific (Iwamura et al., 2013). We consider only metrics that can be used to evaluate individual habitat-specific and pathway-specific quality relative to a management objective, as opposed to metrics describing the response of whole networks or multiple habitats and pathways within a network (Moilanen and Hanski, 2001).

Our study reviews only those metrics which assume that the landscape used by a population is binary; that is, a given area is either habitat or non-habitat. This distinguishes our review from the broader study of landscape metrics, which accounts for landscape patterns in heterogeneous landscapes, but does not necessarily focus on habitat quality for any one species (e.g., Wu et al. (2002)).

Numerous studies review existing habitat-quality metrics (Tischendorf and Fahrig, 2000; Goodwin, 2003; Calabrese and Fagan, 2004; Kindlmann and Burel, 2008) but none link with decision theory to aid their use in management applications. Rather than providing a comprehensive review of all potential metrics that could be used for spatially structured populations, we provide an overview of categories of habitat- and pathway-quality metrics based on the relevant management objectives, management actions, and data requirements.

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