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An evaluation framework based on sustainability-related indicators for the comparison of conceptual approaches for ecological networks

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ABSTRACT

Ecological networks (EN) are designed to maintain biodiversity and ecological processes by protecting habitats and their linkages. By considering the functional role of the landscape, EN can support the integration of ecological sustainability with human activities. Although all EN share the same general objectives, there are many different approaches for determining the spatial configuration of their components. The choice of an approach for the design of an EN has a major impact on the spatial configuration, ecological value, and ease of implementation of the resulting network. We applied different approaches to construct EN for the Saint-François River watershed (8700 km^2) in southern Quebec, Canada. The approaches were based on single-species, multi-species, and landscape modeling categories. All of the resulting EN were evaluated using ecological, economic, and social spatial thematic indicators (*TI*) relevant to sustainable landscape management. This allowed us to quantitatively assess the impact of each approach and to establish their relative performance within a common framework. Our results showed that the conceptual approach for EN has a direct influence on their spatial configuration and performance. Single-species-, multi-species- and landscape-based categories produced very different EN. These results emphasize the importance of the selection of focal species and/or key environments for the design of EN. Our results also highlight the importance of adequately defining the desired objectives and expected functions of an EN, knowing that the results of the conceptual approach will be modified depending on the environment. Results are discussed in relation to the objectives sought by the implementation of the EN, spatial scale, and land use. Our evaluation framework is a useful tool for mitigating uncertainties associated with EN by facilitating the integration of stakeholders' priorities and landscape management objectives.

1. Introduction

Habitat loss and fragmentation represent a major cause of decreasing biodiversity (Fahrig, 2003; Krauss et al., 2010). The concept of ecological networks (EN) emerged from a desire to protect biodiversity by not only conserving isolated natural areas but also protecting ecological processes that operate at the landscape scale and maintaining habitat connectivity. The concept of EN developed from a synthesis of ideas from the theory of island biogeography (MacArthur and Wilson, 1967) and metapopulation theory (Levins, 1969) that were integrated within the landscape ecology discipline. The underlying principle is that habitat fragmentation threatens species survival by decreasing the available habitat and by limiting movement (i.e. by dispersal and migration) and genetic exchange (Fahrig, 2003; Bennett and Mulongoy, 2006; Driscoll et al., 2014).

The term EN refers to a set of ecosystems that are linked by a flow of organisms in a spatially coherent system and that are also in interaction with the landscape matrix (i.e. the dominant component of the landscape) in which it is embedded (Opdam et al., 2006). EN aim for two principal objectives: (1) to preserve the functionality of ecosystems for species and/or habitat conservation, and (2) to protect biodiversity from the alterations related to human activities (Bennett and Wit, 2001). How models of EN are developed varies according to the natural and cultural characteristics of a given territory in addition to the existing policies for land use management (Jongman et al., 2011). In the most widespread model, an EN comprises two principal elements, core areas and corridors, to which buffer zones are added (Bennett and Mulongoy, 2006; Doko and Chen, 2012).

The proper implementation of EN can help to ensure the ecological sustainability of a landscape by integrating biodiversity

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conservation in landscape planning (Opdam et al., 2006). There is increasing interest and investment in the implementation of EN despite theoretical weaknesses in the EN concept itself (Boitani et al., 2007). Although a growing number of studies are demonstrating the positive impact of corridors on connected populations (Damschen and Brudvig, 2010; Gilbert-Norton et al., 2010), others have demonstrated negative impacts (Åström and Pärt, 2013) or no impacts (Horskins et al., 2006) on the abundance, species richness, and gene flow. In addition, the assumption that the structural connectivity provided by corridors supports functional connectivity is not always true, even though this is assumed to be the case (Taylor et al., 2006). For example, some species can migrate between resource patches even if they are placed in matrices with inhospitable characteristics (i.e. structurally fragmented). Inversely, the presence of a corridor does not mean it will be used (i.e. functional connectivity) by the species (Taylor et al., 2006; Boitani et al., 2007). Focal species are used in the design of EN assuming that biodiversity as a whole will benefit, but this is also based on several assumptions, particularly the ability of one species, such as keystone species, to be representative of other species and certain habitats (Nicholson et al., 2013). Meanwhile, the models and data defining the regional conservation plans are important sources of uncertainty (Burgman et al., 2005). Although it seems appropriate to apply the precautionary principle to conservation, many aspects concerning the effectiveness of EN must be further explored. One of these aspects is the impact of methodological choices on EN configuration and their efficiency. Increasing computing capabilities and a wide array of analysis tools led to many potential approaches to implement EN, but it also imposed a need to make many methodological choices (Poos, 2010). Conservation-based models are strongly influenced by these choices for which a better understanding of their effect is sorely needed (Poos, 2010).

In this paper, we examined a major source of uncertainty for the implementation of EN: the choice of the modeling strategy and the conceptual approach. Indeed, there are many modeling strategies (i.e. category of approaches) for identifying the components of EN with the common aim of preserving biodiversity. The choice of a category and conceptual approach is the first step in the design of EN and thus it will guide the subsequent methodological choices. The selected conceptual approaches can be grouped into three main modeling categories according to the importance given to functional and structural considerations: single-species, multi-species, and landscape-based (Etlicher et al., 2008).

The single-species category is based on the ecological requirements of a single focal species to identify the components of an EN (Hoctor, 2003; Driscoll et al., 2014; Lacher and Wilkerson, 2014; Morato et al., 2014). The concept of a focal species designates one species whose needs, in regards to its habitat, encompass those of several other species thus allowing the protection of key habitats for the conservation of ecological processes (Beazley and Cardinal, 2004; Nicholson et al., 2013). Focal species are often species with large home ranges and for which there is a particular economic or social interest for conservation (e.g. Canada lynx (*Lynx canadensis*), Eastern pipistrelle (*Pipistrellus subflavus*), Atlantic salmon (*Salmo salar*), or Black bear (*Ursus americanus*)). Consequently, they are more focused on functional considerations. The multi-species category integrates the needs of several focal species and take into account a larger diversity of habitats and ecological processes in the design of EN (Berthoud et al., 2004; Beier et al., 2006; Huber et al., 2010); thus, the functional and structural considerations have a variable role. The category based on landscape focuses on structural aspects exclusively, such as ecosystem and landscape structure, instead of taking into account the needs of particular species as in the other two categories (Jongman et al., 2011; Battisti, 2013). Elements such as the geographic size of natural environments, habitat diversity, the representativeness of landscapes, the amount of human disturbance, or the presence of protected areas are used to identify EN.

Each modeling category can be represented by various conceptual approaches. The approach selected will have a direct influence on the spatial configuration of the resulting EN, and this affects its ecological value and the possibility of its implementation (Hawkins and Selman, 2002). One way to manage this uncertainty is to provide several scenarios that are ecologically sustainable and to determine which scenarios better integrate the environmental, economic, and social issues and, as a result, provide the best strategies for attaining regional sustainability in a given location (Opdam et al., 2006). In order to evaluate the performance of different conceptual approaches, it is thus necessary to put in place a common and quantitative analytical framework. Even if previous studies have shown that the choice of the modeling category and conceptual approach has a strong influence on the resulting EN (Hoctor, 2003), few studies have tried to evaluate alternative scenarios for EN, and previous evaluations have generally only focused on the ecological sustainability of networks (Cook, 2002; McHugh and Thompson, 2011). Furthermore, other ecological, social, and economic aspects can influence sustainability and the possibility of implementing EN. In related fields such as regional planning, there are examples of evaluation frameworks that use aggregated indicators to support decision-making when sustainable development issues are being addressed (Paracchini et al., 2011). To our knowledge, an evaluation framework specifically for EN has not been developed prior to this study while only a few studies have compared different EN conceptual approaches (Bennett and Mulongoy, 2006; Scheurer et al., 2008; Doko and Chen, 2012).

The objective of this study was to apply a quantitative evaluation tool to compare different EN produced by a variety of approaches using the three main categories for EN design. To do so, we used different existing models to develop several EN for the same region, which were then evaluated quantitatively based on a common set of criteria related to the concept of sustainable landscape development (Opdam et al., 2006; Dramstad and Fjellstad, 2011). The study had two specific objectives: (1) implement an evaluation framework to test which EN offers the best compromise and (2) establish how the evaluation framework can help us understand the implications of the methodological choices.

2. Material and methods

2.1. Study area

The EN were designed for the Saint-François River watershed (8700 km^2) in southern Quebec, Canada. Temperate forests cover 66% of the region (26% deciduous, 22% mixed, and 18% conifer stands) and the largest forested areas are in the eastern portion of the study area (Fig. 1). Land tenure is mainly private and natural forest logging is widespread. Agriculture is also an important activity and covers 23% of the region, which is composed of 65% hay and 34% cereals, corn, and soya. The most intensively cultivated agricultural areas are in the northwest portion of the watershed and in the Coaticook region. Besides these intensively cultivated areas, agricultural land forms a mosaic with forested environments. The hydrographical network covers 6% of the region with more than 100 lakes and several large rivers of which the largest, the Saint-François River, is more than 216 km long. The population of approximately 350,000 inhabitants (COGESAF, 2006) is concentrated in the main urban centers: Drummondville, Sherbrooke, Magog, Coaticook, and Windsor. The major road network (i.e. highways and national roads) mainly passes through these cities, but several roads crisscross the territory. Urban areas and road network cover 5% of the region. Clusters of higher density population, agricultural areas,