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Methods and workflow for spatial conservation prioritization using Zonation☆

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ABSTRACT

Spatial conservation prioritization concerns the effective allocation of conservation action. Its stages include development of an ecologically based model of conservation value, data pre-processing, spatial prioritization analysis, and interpretation of results for conservation action. Here we investigate the details of each stage for analyses done using the Zonation prioritization framework. While there is much literature about analytical methods implemented in Zonation, there is only scattered information available about what happens before and after the computational analysis. Here we fill this information gap by summarizing the pre-analysis and post-analysis stages of the Zonation framework. Concerning the entire process, we summarize the full workflow and list examples of operational best-case, worst-case, and typical scenarios for each analysis stage. We discuss resources needed in different analysis stages. We also discuss benefits, disadvantages, and risks involved in the application of spatial prioritization from the perspective of different stakeholders. Concerning pre-analysis stages, we explain the development of the ecological model and discuss the setting of priority weights and connectivity responses. We also explain practical aspects of data pre-processing and the post-processing interpretation of results for different conservation objectives. This work facilitates well-informed design and application of Zonation analyses for the purpose of spatial conservation planning. It should be useful for both scientists working on conservation related research as well as for practitioners looking for useful tools for conservation resource allocation.

1. Introduction

Conservation prioritization is about decision support for conservation planning (Ferrier and Wintle, 2009). It aims to answer questions about when, where, and how we can efficiently achieve conservation goals (Pressey et al., 2007; Wilson et al., 2007). Spatial conservation prioritization utilizes computational tools and analyses that are relevant for ecologically informed spatial allocation of conservation actions or placement of other land uses (Kukkala and Moilanen, 2012). Methods of spatial prioritization evolved starting from simple complementarity-based minimum set reserve selection algorithms that operated on relatively small data sets and presence-absence data (reviewed by Sarkar et al. (2006)). More recently, methods have become able to accommodate various cost factors and much increased ecological realism by implementing, for example, methods to deal with species-specific connectivity and uncertainty, and software implementations have become able to deal with much larger landscapes and a variety of data types (Kukkala and Moilanen, 2012).

Spatial conservation prioritisation is a form of conservation assessment (*sensu* Knight et al., 2006) which can be utilized as a technical phase inside the broader operational model of systematic conservation planning (SCP) that focuses on planning, implementing, and monitoring conservation (Margules and Pressey, 2000; Margules and Sarkar, 2007; Pressey and Bottrill, 2008; Kukkala and Moilanen, 2012). In this study, we concentrate on the interface between spatial conservation prioritization and implementation-oriented conservation planning, specifically in the context of the Zonation spatial planning software[2] (Moilanen et al., 2005, 2009b).

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[2] Zonation version 3 is freely available from http://cbig.it.helsinki.fi/software/zonation/ for MS Windows.

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There are several categories of factors that can introduce their own nuances into prioritization problems (Moilanen et al., 2009c). Details of the planning problem depend on the type of conservation action considered, including protection, management, maintenance, and restoration of habitats (Pressey et al., 2007; Wilson et al., 2009). A reserve network could be planned for immediate implementation or for recurrent yearly operations (Costello and Polasky, 2004; Pressey et al., 2007). Biodiversity could be considered from the perspective of representation in a reserve network or from the perspective of landscape-wide retention, which involves potential threats and opportunities both within reserves and the surrounding landscape (Pressey et al., 2004). The level of detail included in the ecological model that explicitly or implicitly underlies the decision-making influences the difficulty of implementing a decision analysis (Possingham et al., 2000; Wilson et al., 2009).

Spatial conservation prioritization is usually done within a wider decision-making context in which the needs of many land users and stakeholders are acknowledged (Ferrier and Wintle, 2009). At the outset of any planning process, it is crucial that objectives (aims, goals) are explicitly set for all of the processes and criteria involved (Ferrier and Wintle, 2009; Runge et al., 2011). This also includes the explicit consideration of which decision-support tool is most suitable for the task at hand which can involve integrating large biological and socio-economic datasets as well as several software tools (Segan et al., 2011). Furthermore, setting of objectives (Opdam et al., 2002; Wilson et al., 2009), stakeholder involvement (Knight et al., 2006), policy recommendations (Sutherland et al., 2006), quality verification (Langford et al., 2011), and monitoring (Lindenmayer and Likens, 2009) are all stages that may be repeated over periods of many years.

Here we describe a workflow for running a conservation prioritization analysis with the Zonation software (see Moilanen et al., 2005, 2009b, 2011a, 2012; Moilanen and Arponen, 2011 for references). Zonation has been applied across terrestrial, riverine, marine, and urban environments (Leathwick et al., 2008; Moilanen et al., 2008; Gordon et al., 2009). It includes a set of useful analysis features, including uncertainty analysis and seven ways of dealing with connectivity (Section 2.4). In can operate on species, ecosystems (Kremen et al., 2008; Lehtomäki et al., 2009), ecosystem services (Moilanen et al., 2011a; Thomas et al., 2012), or any such biodiversity feature, and can be applied to landscapes up to tens of millions of elements (grid cells) of biodiversity feature data (Arponen et al., 2012). In addition to target-based planning (Carwardine et al., 2009), Zonation includes multiple alternative ways of aggregating conservation value across species and space (Moilanen, 2007).

As with any sophisticated tool, using Zonation requires both conceptual understanding about analysis options as well as experience and knowledge on how to establish a sensible workflow, which can be a major obstacle in the use of Zonation, due to the many analysis options available. While the analytical features available in Zonation are well documented, there is a scarcity of accessible information about what should happen before and after the computational analysis itself. Here we summarize previously scattered information about the process of implementing spatial conservation prioritization with Zonation. We explain all parts of the typical workflow, concentrating on what happens before and after the computational analysis itself. While the present work is most relevant for Zonation, much of the workflow should be relevant for any method and software that is applied for spatial prioritization.

2. Methods

2.1. Zonation: main concepts, algorithms, and outputs

Because the details of the Zonation software and its algorithms have been extensively documented elsewhere (Moilanen et al., 2005, 2009b, 2011a, 2012), we summarize only the features that facilitate understanding of the present material, including interpretation of output (Section 2.7). Zonation develops a priority ranking of the entire landscape. It starts from the assumption that protecting everything would be best for conservation. It then proceeds to iteratively rank sites, at each step removing the spatial unit (grid cell, planning unit) that leads to the smallest aggregate marginal loss in biodiversity. In this process, which is called the Zonation meta-algorithm, the least useful sites receive the lowest ranks (close to 0) and areas most valuable for biodiversity receive the highest ranks (close to 1). This ranking is nested, meaning that the top 1% is within the top 2%, which is within the top 5% and so on. It is possible to identify any given top fraction or bottom fraction of the landscape in terms of perceived conservation value from this ranking, which can be visualized as a priority rank map with different colours indicating rank values (see inset in Fig. 1 and Moilanen et al., 2012). The priority rank map is paired with another main output, the performance curves (see inset in Fig. 1 and Moilanen et al., 2012). These curves quantify the proportion of the original occurrences remaining for each feature when successively smaller fractions of the landscape remain for conservation (it is implicitly assumed that all unprotected sites are lost from conservation). Performance curves are most often investigated as averaged across all features or across a small number of subgroups of features. It is also informative to investigate the minimum value across all features or subgroups as it will show the situation of the worst-off feature when a given fraction of the landscape remains for conservation. Individual performance curves are not always useful as there can be up to tens of thousands of features in the analysis.

The main principle of the computational strategy of Zonation can be summarised as seeking to maximise retention of weighted range-size corrected feature richness (Moilanen et al., 2011a). A key to the operation of Zonation is the definition of marginal loss of biodiversity inside the Zonation meta-algorithm. For this loss there are multiple alternative definitions, which allow various concepts of conservation value, including those that emphasize species richness (the additive benefit function formulation, ABF) or rarity (core-area Zonation, CAZ) to variable degrees (Moilanen, 2007; Moilanen et al., 2011a). In fact, one of the first choices faced when initiating analysis is between ABF and CAZ. ABF produces high return on investment (Laitila and Moilanen, 2012), but may allow lowered representation levels for features occurring in species-poor or expensive parts of the landscape (Moilanen, 2007). ABF is appropriate when the data is considered to be a surrogate for biodiversity broadly. CAZ aims to ensure high-quality locations for all features (Moilanen et al., 2005, 2011a), which may result in a lower return on investment because relatively higher effort must be expended on features that occur in species poor or expensive areas. CAZ is most appropriate when the analysis features primarily represent themselves. Zonation also supports common target-based planning approaches (Moilanen, 2007).

2.2. The analysis framework

Fig. 1 summarizes the stages of a typical spatial conservation prioritization project using Zonation. Many of the stages are not Zonation-specific, and other analytical tools could be introduced into the process with small structural changes in analysis flow. It is worth noting that conservation prioritization is only one part of an operational model for conservation planning (Knight et al., 2006), and to deliver successful conservation action, effective conservation implementation and management strategies are also needed.

The first step is setting conservation objectives and assessing whether the particular objectives require spatial conservation prioritization. Questions that can be addressed with Zonation are summarized in Section 2.7 (Interpretation of results). The second stage is preparation of an ecologically based model of conservation value (Section 2.3) that must be informative for the objectives of the overall study. Often, the preparation of the ecological model requires the setting of weights and connectivity responses for biodiversity features (Section 2.4). Ideally, the ecological model would be developed based primarily on ecological data describing the distribution and state of biodiversity coupled with a good understanding of species' autoecology and anthropogenic factors such as conservation preferences. However, in reality the model must rely on data that is available, and the preparation of the ecological model goes hand in hand with the preparation of data. Section 2.5 summarizes factors relevant for data pre-processing.

After the objectives of the prioritization have been defined, and the ecological model and corresponding data prepared, it is possible to initiate spatial analysis. To understand how different analysis options influence results, it is important to develop the analysis in stages of increasing complexity (Section 2.6). At a more practical level, awareness of analysis options feeds back into formulation of the ecological model and into data processing—it is useless to plan for an analysis that cannot be executed. The third major stage is verification and interpretation of results (Section 2.7). To conclude, we discuss factors that may influence the full planning and analysis process, advantages and disadvantages perceived by stakeholders (Section 2.8), and resources needed by the different process stages (Section 2.9).

Spatial priority maps generated using a tool such as Zonation would typically be only one component influencing conservation resource allocation and action, and inputs from experts and stakeholders would influence the ultimate decisions (Knight et al., 2006; Ferrier and Wintle, 2009). Conservation action is frequently implemented iteratively and incrementally over many years, instead of all at the