**Comparing spatial prioritization methods for biodiversity conservation and ecosystem service supply in Europe**

**Joona Lehtomäki**1\* and **Peter verburg**1

1Environmental Geography Group, Department of Earth Sciences, De Boelelaan 1105, 1081 HV Amsterdam, Vrije Universiteit Amsterdam, the Netherlands.

\* Corresponding author

**Contact:** j.lehtomaki@vu.nl, tel. +31-20-59-87294  
ORCID: 0000-0002-7891-0843

peter.verburg@vu.nl, tel. +31-20-59-83594

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**Abstract:**

Identifying priority areas that simultaneously target safeguarding the supply of ecosystem services as well as biodiversity underlying the supply of ecosystem services is essential for well-informed decision-making on land use and conservation planning. Multiple methods for the spatial prioritization of locations supplying individual or multiple ecosystem services, and for the balanced or optimal allocation of biodiversity conservation actions exist, but the benefits and disadvantages of using these methods are seldom explored. Furthermore, the technical complexity, data requirements and the transparency of the method parameterization further make a great difference in the usability of each method in practical work. Here, we compare a simple scoring method, heuristic prioritization software Zonation, and an exact spatial optimization method in prioritizing locations important for multiple ecosystem services and biodiversity at the European scale. Each method is used within a realistic, but hypothetical decision-making context. We show that for very simple analysis types, the scoring-type of approach performs very similarly to Zonation and the exact optimization method. However, more complex - and arguably more policy-relevant - analysis types can only be accommodated by the more complex methods. We demonstrate the practical implications of using each approach in operationalizing the concept ecosystem services and biodiversity conservation planning into more widespread practical use. We argue that the road forward in using planning methods is a combination of technical credibility, decision-making relevance, and effort in opening up the planning process to the stakeholders involved.

**Keywords:** spatial prioritization; ecosystem services; biodiversity conservation; Zonation; optimization; environmental decision-making

**Software and/or data availability:**

# 1. Introduction

Ecosystem services, activities or functions of ecosystems that provide benefit (or occasionally disbenefit) to humans (Mace et al., 2012), is today one of the most popular concepts guiding decisions on environmental management. Ecosystems are thought to provide a broad spectrum of different services that directly or indirectly contribute to the human well-being on multiple spatiotemporal scales (REFS). Given the strong emphasis placed on ecosystem services especially in the national and international policy arenas (REFS), the operationalization of the concept of ecosystem services is still well underway. Part of this operationalization process is the development of methods and tools for spatial planning that integrates multiple objectives simultaneously in a transparent and cost-effective manner. Spatial planning and spatial support systems are widely studied and used in environmental context in land use, natural resource, urban and conservation planning (REFS). For practical relevance, spatial planning needs to be able to include ecological, economic and social factors relevant for whatever decision-making problem is at hand. Integrating spatial planning with decision-analytical methods has been done under the rubrics such as multi-criteria decision making (REFS), XXX (REFS) and XXX (REFS). Management decisions will increasingly need to account for both biodiversity conservation and the provision of ecosystem services (Goldman and Tallis, 2009) and therefore methods able to quantify the associated trade-offs are urgently needed (Cordingley et al., 2016).

In the field of conservation science, systematic conservation planning (Margules and Pressey, 2000) has been a particularly influential framework combining aspects of spatial planning to implementation of biodiversity conservation (Kukkala and Moilanen, 2012). Within this broader decision-analytical framework, the more technical biogeographic-economic assessment of which areas are the most important for biodiversity and when and how particular actions should be implemented to achieving conservation goals, is called spatial conservation prioritization (Ferrier and Wintle, 2009; Kukkala and Moilanen, 2012; Wilson et al., 2007). In addition to ecological effectiveness, socio-economic efficiency is a key aspect of spatial conservation prioritization: how should limited resources be invested to maximize expected outcomes (the persistence of biodiversity)(Evans et al., 2015). While spatial conservation prioritization was originally developed for designing more effective protected area networks, the underlying principles and methods developed on top of them in are, in fact, suitable for prioritizing between a suite of different actions (REFS). For example, spatial conservation prioritization has been applied in context of natural resource extraction (Kareksela et al., 2013), habitat restoration (Thomson et al., 2009) and also ecosystem services (Casalegno et al., 2014; Nin et al., 2016; Schröter et al., 2014). Given the closely linked, albeit not always clear, relationship between the occurrence of biodiversity and the provision of ecosystem services, spatial conservation prioritization holds potential for prioritizing areas important for ES provision as well. Many spatial conservation prioritization methods have also been implemented as operational software tools (REFS) embedded in actual decision-making processes, which lowers the barrier to their use also in the context of ES.

A large number of spatial and non-spatial decision-support tools already exist for quantification and valuation of ecosystem services (Bagstad et al., 2013; Langemeyer et al., 2016). In addition, multiple methods and software tools designed for spatial conservation prioritization have also been used for prioritizing between areas important for ecosystem services (Chan et al., 2006; Moilanen et al., 2011; Nin et al., 2016; Schröter and Remme, 2016). The question of conceptual and operational differences between the different spatial prioritization tools therefore is an important one especially for practitioners. Bagstad et al. (2013) provide a useful list of criteria, which can be used to assess how well a tool can support quantifiable, replicable, credible, flexible and affordable ES assessments. For example, the tool outputs need to be quantitative and preferable able to also quantify the associated uncertainties. Furthermore, the tool need to be generalizable enough as to accommodate a broad set of potential use-cases and scalable enough to be able to deal large enough analytical needs. Time required to adapt a particular tool to a custom problem and the level of documentation available to facilitate this adaptation also matter a great deal. Therefore, these aspect of spatial prioritization tools should also be assessed in addition to the more conceptual suitability of a given tool.

In spatial conservation prioritization, and in spatial conservation planning more generally, the methods used vary in respect to the criteria given above. Relatively simple methods that sum the occurrence of biodiversity features (e.g. species) in a given area of interest have been popular exactly because of the simplicity of the approach (REFS). However, since most of these so-called “scoring” methods do not take into account complementarity, […], solutions produced are inefficient (Wilson et al., 2009). Spatial conservation prioritization problems concerning the selection of an optimal set of areas based on some selection criteria are also solvable exactly using spatial optimization techniques such as integer linear programming (ILP) (Beyer et al., 2016). The advantage of ILP methods is that they produce a truly optimal solution or a quantitative estimate on the sub-optimality of the solution. The downside is that accounting for all the factors relevant for real-life prioritization problems quickly renders the optimization computationally infeasible (REFS), or require simplifications reducing the relevance of the solution (Moilanen, 2008). This is why heuristic methods have proven to be popular in spatial conservation prioritization: they are flexible enough to accommodate factors relevant for decision-making while retaining computational tractability (REFS). They cannot, however, guarantee the optimality of the solution and are typically on the same level of technical complexity as exact optimization methods.

Here, we compare three quantitative methods developed for spatial conservation prioritization of biodiversity conservation. The methods differ in their level of complexity and ability to accommodate features important for real-life decision-analysis, but share enough of the theoretical underpinnings to warrant a cross-comparison. We apply each of the methods a set of 11 spatial datasets describing ecosystem services capacity on European scale. Furthermore, our analyses also include spatial datasets on the estimated extents of occurrence on 759 species of tetrapods (amphibians, birds, mammal and reptiles) in Europe.

# 2. Material and methods

# 3. Results

# 4. Discussion

The extent to which spatial prioritization methods and tools are applicable also to the prioritization of areas important for the supply of ecosystem services depends on multiple factors. First, many spatial conservation prioritization methods have been developed primarily with biodiversity in mind (Wilson et al., 2009). Some key features any many prioritization methods, such as placing higher value on rare features (Arponen et al., 2005) or ecological connectivity (Rudnick et al., 2012), do not necessarily make sense in context of ecosystem services.

# 5. Conclusions

# 6. Acknowledgements

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