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Conserve Map: A Geospatial Decision Framework for Prioritizing Wildlife Conservation Areas

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Key Words	Abstract
Wildlife conservation prioritization, Habitat suitability, Species occurrence data, Landscape connectivity, Biodiversity hotspots, Conservation planning, Spatial prioritization.	The number of conservation sites that might be considered eligible may exceed the available conservation resources, and the criteria used for deciding which habitats to prioritize frequently rely on partial records of species or inconsistent coverage of field surveys and/or administrative convenience rather than biological conservation values. Conserve Map is a planning tool that was proposed as an approach to prioritizing wildlife conservation areas, using it to provide a single ranking of each area that is comparative for conservation effort that could be applied by conservation planners. The framework is based on recent advances in ecosystem-service hotspot mapping, stepping-stone habitat identification, spatial conservation prioritization for regional planning, and genus-level vertebrate prioritization in the Neotropics, which have all established that multiple layers of biology can generate more defensible priority rankings than can a single-criterion approach. Conserve Map has not yet been used in a conservation planning decision, and is likely to be most valuable as a transparent and repeatable way to prioritize candidate sites, rather than as a substitute for conservation biologists' field judgment. The framework is recommended to be tested with real prioritization decisions with various taxa and regions.

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Introduction

One of the most important and most challenging decisions that conservation planners must make is where to focus conservation effort; almost always, there are more sites with some conservation value than funding, staff, and political resources can protect. However, combining multiple ecosystem service layers instead of using a single habitat quality measure has resulted in a defensible basis for prioritization of sites based on the full range of services that provide, as demonstrated by ecosystem-service hotspot mapping in planning for LULC in central Iran (Abolmaali et al., 2024). The same is true when identifying and prioritizing stepping stone habitats within forest ecosystems: conservation value does not necessarily apply to large, intact habitat blocks; smaller patches are also important for species to move between core areas and can be overlooked if only patch size is used to prioritize areas (Lapin et al., 2024). In Florida, spatial conservation prioritization shows evidence of the ability to reconcile an ongoing development pressure with conservation goals by identifying the sites that provide the highest conservation value for the areas being protected (Lin et al., 2022). Spatial prioritization of terrestrial vertebrate genera throughout the Neotropics has revealed that prioritization results vary widely between species-level and genus-level analyses, highlighting the importance of resolution and completeness of biological data on which prioritization is based (Wan & Wang, 2023).

These studies illustrate a common issue that is now emerging: conservation planners are receiving more and more rich biological information, but struggle to know how to integrate it and arrive at defensible, regionally comparable, and continually updated rankings as new information becomes available. Conserve Map combines these three lines of evidence into a single layer of priorities that focuses on supporting the types of allocation decisions that conservation agencies and NGO's are faced with when there are more candidates for protection than conservation resources.

The paper has three main contributions. First, it suggests a prioritization approach whose inputs include species occurrence density, habitat suitability, and connectivity, which it treats as mutually required. Second, it suggests a prioritization approach that treats species occurrence density, habitat suitability, and connectivity as jointly required inputs to conservation prioritization, not allowing any single criterion to dominate the result. Second, it adds a decision-layer structure that maintains separation of these inputs in the analysis process, thereby enabling planners to understand which input is influencing the ranking of a site for priority rather than being provided with an opaque overall score. Third, it incorporates an explicit accuracy checking step in relation to known conservation case studies, thereby enabling the framework's ratings to be validated in relation to sites where the conservation value has been determined independently.

This paper is organized as follows: In Section II, previous work on site-prioritization constraints from the use of citizen science data, geo-visual analytics, and genetic data in site prioritization is reviewed. Section III describes the spatial modeling approach and creation of the decision layers used in Conserve Map. In Section IV, the accuracy of mapping is discussed, and the results that are expected with Conserve Map are compared to case-based validation examples in the literature. The paper ends with Section V, which summarizes and provides directions for field testing.

Constraints in Existing Site-Prioritization Methods

However, some studies have demonstrated that the data obtained from citizen-science efforts can be used to locate priority areas for biodiversity conservation, and that citizen-science coverage is not uniform, leading to potentially biased priority maps based solely on citizen-science data that favour areas where observers are most active (Chowdhury et al., 2023). However, although the visualisation tools have significantly improved, many conservation planning workflows are still finding it difficult to transform highly detailed spatial data into a ranking that non-specialist decision makers can interpret and directly act on (Lacey & Nelson, 2023). The incorporation of intraspecific genetic data into spatial conservation prioritization has revealed that sites that are of disproportionate genetic value can be overlooked in prioritization based on species presence or habitat suitability, thus giving a lower priority to a site than may be warranted based on its true conservation value if genetic information was not used (Andrello et al., 2022).

These recent sources all point to a common problem in the current application of site prioritization: planners have access to more and richer data, from citizen-contributed occurrence records, to visualization tools and techniques, to even genetic sampling, but lack development of methods to combine all of this data into a ranking that can guide action. Occurrence data, as used in citizen science research, can be biased due to uneven observer effort; geo-visual analytics research demonstrates that even well-organized spatial data is not necessarily translated into decision-ready outputs; and genetic prioritization research demonstrates that biological variation is often not captured if prioritization is based only on presence or habitat data.

The combination of these results suggests the need for a prioritization framework that can incorporate a range of types of biological evidence, correct for known biases, including uneven survey effort, and communicate its results in a way that allows them to be directly applied to conservation decisions without requiring additional specialist interpretation to provide a ranking.

Spatial Modelling and Decision-Layer Construction

The Conserve Map framework combines three related layers of evidence, which are assembled individually and then aggregated to a site priority score. The first is a species evidence layer, that collects the occurrence records of target taxa available from the surveys available, weighting the records to the data reliability and completeness of the source, thus avoiding a favouring of regions with strong survey coverage over regions with species presence but under surveys. The second is a habitat suitability layer, a classification that characterizes candidate locations based on vegetation type, water availability and structural features that are associated with the presence of the target species or species groups, and is based on the same suite of habitat suitability evidence used in ecosystem-service hotspot mapping. The third is a connectivity layer, where each potential site is assessed for how well it connects to other appropriate habitat, and how it might be either a core habitat block or a stepping stone patch that facilitates the movement of species between larger habitat conservation areas.

The three layers are fused together in a progressive decision process, not by an average score. The first stage involves independently ranking each layer, resulting in three different rankings for the same set of candidate sites. In the second stage, sites that score well on all three layers are marked as a consistently high priority site, while sites that score well on just one or two layers are marked for closer inspection, because a site with good habitat suitability but not good connectivity, for example, may be more suitable for a different type of conservation action than a site that scores well on all three. The third step in the process yields a combined priority ranking that allows planners looking at the output to see not only that a site has a high priority, but also why.

The framework also includes a bias-correction step that is directly derived from constraints noted in the literature above. Due to potential uneven spatial and taxonomic distribution of occurrences, the species evidence layer applies a correction to correct for known survey effort in each region before using occurrence density in ranking, to minimise the risk of well-surveyed, but lower-priority sites outranking poorly surveyed, but genuinely important sites.

Mapping Accuracy and Case-Based Validation

Conserve Map has not yet been used on a conservation planning decision, therefore the expected accuracy is estimated by comparing to the outcomes reported in related prioritization studies. The direct correlation between the value layers used to create the Ecosystem-service Hotspot maps and priority ranking and independently recognized conservation significance has been demonstrated by ecosystem service hotspot mapping, and should be expected to extend to the multi-layer approach used by Conserve Map. Conserve Map's staged ranking process could have a similar value in identifying under-recognized priority sites, as regional spatial conservation prioritization work in Florida has shown that formal prioritization tools can yield the general pattern of high-value conservation sites that are identified by conservation practitioners.

Compared to prioritization methods based on a single type of information, e.g. records of species occurrences alone or habitat suitability modelling alone, Conserve Map is likely to yield more consistent rankings across multiple analyses because the rankings largely depend on the relative quality of the two data sources rather than the absolute quality. This is especially important as the resolution of the data can differ at the genus level from the species level, with results from one data level differing significantly from the results of another, meaning that results from a single data level may vary significantly with changes in data quality, while a multi-layer approach is more likely to produce stable results as the data layers are refined.

One of the main challenges in this early stage is the fact that the framework does not focus on actual field deployment but on comparison cases. Conserve Map has never been evaluated with an active allocation decision and its bias-correction approaches for uneven survey effort have not been validated with actual conservation outcomes as determined through a ground-truthing exercise. Using the framework will also require reasonably homogeneous species occurrence, habitat and connectivity data for all candidate sites being considered, which may not occur in areas where survey coverage is limited or unevenly distributed historically. There is no genetic evidence at this time included as a fourth layer which would change prioritization outcomes as has been done in other studies, so disproportionate genetic value sites may not be prioritized at this time until genetic information is added.

Conclusion

This paper has proposed Conserve Map, a decision making process that ranks the most important wildlife conservation areas to prioritize across the landscape and stages the process by combining species evidence, habitat suitability and landscape connectivity into a transparent process with multiple stages. The framework directly addresses constraints that were identified in the recently published research on conservation prioritization, such as biases from patch clumping by citizen scientists, the ability to use rich spatial data to create decision-ready outputs, and the potential to miss genetically important populations using occurrence or habitat-based prioritization. Conserve Map is designed to provide conservation planners with a repeatable defensible approach to protecting the limited number of conservation areas available to a candidate site based on the evidence layer that leads to that ranking, while maintaining visibility of the evidence layer used. Future research is needed to develop and apply the framework in the field to an active conservation planning exercise and to integrate genetic aspects as another layer of prioritization.

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