

Spatial Ecology: Compiled Readings from Recent Research

for

Lesson – Spatial Ecology: Landscape Design Contest

1. Introduction to Spatial Ecology and its Relevance for Conservation

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[Many] subdisciplines share concepts and analytical methods that stem from the field of spatial ecology: a field coined by Tilman and Kareiva in 1997. Since then, the term “spatial ecology” has been used in a wide range of ways depending on each ecological subdiscipline and field. **Biogeography** focuses on species geographic distributions (Lomolino 2017). **Landscape ecology** relates spatial heterogeneity to ecological processes and species distribution (Turner and Gardner 2015). **Movement ecology** focuses on organismal dispersal and migration (Nathan et al. 2008). **Macroecology** investigates the relation of processes and species at large spatial scales (Gaston and Blackburn 2000). **Metaecology** considers dispersal and spatial interactions at different spatial scales to model ecological processes that affect species distribution and dynamics (i.e., metapopulations, metacommunities, metaecosystems; Massol et al. 2011). **Spatial and landscape genetics** relate how landscape features affect gene flow and local adaptation (Manel et al. 2003; Guillot et al. 2009). Finally, **conservation biology** develops and applies spatial solutions to a variety of problems, including mitigating the effects of roads, protected area networks, and spatial prioritization in conservation planning (Primack 2014) (Fig. 1.1).

The foundation for spatial ecology can be traced largely to the seminal paper of Watt (1947) on the relationship between spatial pattern and ecological processes. Watt (1947) emphasized that plants occurred in bounded communities—patches—that form a dynamic mosaic across the landscape, what has become known as the “shifting-mosaic steady state” concept (Bormann and Likens 1979). Then, in the 1950s and 1960s, there were three key areas of research that emphasized the importance of space for ecological processes and its relevance for conservation. First, some influential experimental studies highlighted the importance of space for ecology. In a seminal experiment, Huffaker (1958) showed how predator–prey dynamics could be stable when including the potential for spatial refugia of prey, while stability was not possible in small, homogenous habitats. This result was important because prior to that time, spatial concepts had not been formally considered in theory and concepts regarding species coexistence. This experiment emphasized the role of movement in altering species interactions and community structure, a theme that has persisted and grown over time.

Ecological concepts and analytical tools developed in the fields of landscape ecology, geography, and spatial statistics are now commonly used in conservation so that informed decisions about planning strategies and management can be made (e.g., Moilanen et al. 2009). Indeed, most conservation planning and management requires knowledge and the explicit spatial modeling of space and its major consequences on species spatial variation and responses to global change. **The inclusion of space is therefore crucial when modeling species ecology and responses to a changing world such as (1) species dispersal, (2)**

species interactions, (3) disturbance dynamics, and (4) environmental change. Furthermore, as the field

of conservation aims to provide better management recommendations to mitigate threats to biodiversity, implicit and explicit aspects of space need to be incorporated into applied solutions such as restoration, species reintroductions, and maintaining connectivity among habitat patches. In all these conservation applications the spatial scale of implementation is key.

2. The effects of landscape patterns on ecosystem services: meta-analyses of landscape services

Duarte, G.T., Santos, P.M., Cornelissen, T.G. et al. (2018). The effects of landscape patterns on ecosystem services: meta-analyses of landscape services. *Landscape Ecology*, 33, 1247–1257. <https://doi.org/10.1007/s10980-018-0673-5>

The landscape services concept encompasses the notion that a complete landscape can provide services through its multi-functionality and the processes that emerge from a set of unique ecosystems (Frank et al. 2012; Hodder et al. 2014), in both natural and human-modified habitats. This concept may prove useful for landscape planning, as the integration of ecological services could increase stakeholder participation, financial funding, and encompass working landscapes.

Our hypothesis regarding landscape complexity was confirmed for **water quality, pollination, both pest control indicators, and aesthetic value.** Therefore, the role of landscape complexity on increasing the provision of different services suggests that the **restoration of natural areas using a land-sharing perspective could be important for the provision of multi-ecosystem functions**, which corroborates with results from Barral et al.

Landowners and society could benefit from an increase in natural areas in rural regions, which consequently carries improved ecosystem services. For example, landowners could benefit from restoration strategies that increase habitat for natural enemies on their lands (Chaplin-Kramer et al. 2011), or water for irrigation of their crops. Therefore, land managers should consider the creation of mechanisms that lead to greater landowner cooperation.

Combined, these findings lend support to the theoretical design proposed by Brosi et al. (2008), who suggested that, in order to increase pollination services in agricultural landscapes, **there should be areas large enough to sustain pollinator populations, with other smaller natural areas within the crop matrix with distances not much greater than pollinators' foraging distances.** Although we observed a significant effect of aggregation metrics on one fauna-related service (pollination), this did not fully confirm our primary hypotheses. However, a recent review by Fahrig (2017) suggests that ecological responses to fragmentation typically have other influences aside from landscape structure.

Notably, **landscape heterogeneity had an important effect on the perception of aesthetic value** reported by the interviewees in the selected studies, which confirms our hypothesis. However, due to the small sample size available (only six studies), this result was insufficiently robust. Although many other articles have studied this landscape service, their data was not adequately reported for inclusion in our meta-analysis. However, the conclusions of these excluded articles are similar in that landscape heterogeneity is important to peoples' perception of aesthetic value.

3. Advancing Landscape and SeascapE Ecology from a 2D to a 3D Science

Lepczyk, C.A., Wedding, L.M., Asner, G.P. et al. (2021). Advancing Landscape and SeascapE Ecology from a 2D to a 3D Science. *BioScience*, 71(6), 596–608.
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Information about the landscape and seascapE in the vertical dimension has been underused in ecology, in part because of limited data availability, uncertainty around data quality, the coarse grain nature of the data, the dominance of 2D conceptual models, and the specialist analytical ability required for 3D data processing. What has been achieved, however, demonstrates that the integration, or fusion, of 3D information with other remotely sensed data across a range of spatial and temporal scales holds great potential to provide new ecological insights.

Case study: Mapping tropical forest biodiversity. Global biodiversity is greatest in tropical forests, which are rapidly being altered and destroyed by human activity, including land conversion, timber harvesting, and climate change, across broad spatial extents (Alroy 2017). Therefore, understanding how tropical forests are changing is one of the key challenges facing modern science and conservation. One of the most innovative uses of fused 2D and 3D imagery has focused on rapid high-resolution mapping, characterization, and monitoring of tropical forests. By combining hyperspectral and lidar observations, Féret and Asner (2014b) used microtopography of lowland Amazon forest canopy (Madre de Dios and Tambopata River landscapes, Peru) to predict plant species composition and diversity. Lidar data were first used to mask nonforest canopy pixels in the hyperspectral data and the portions of each tree crown that were shaded at the time of overflight. By taking this approach the hyperspectral data were made more comparable between tree crowns, and the confounding effects of varying canopy structure were minimized. The hyperspectral data were then used to directly classify and map the diversity (alpha and beta diversity) and spatial variability of the forest canopy using a spectral-species technique (Féret and Asner 2014a). Finally, the lidar data were used to develop a DEM of the land surface beneath the forest canopy. Using this DEM, Féret and Asner (2014b) partitioned the remotely sensed diversity from the hyperspectral data into landscape units for analysis, yielding new information on topographic controls on the regional diversity of tropical forest canopies.

Synthesis and future directions

Scientific research in imagery and 3D data fusion and integration has grown in the last decade, and landscape and seascapE ecologists can now critically frame 3D ecological questions that, until recently, have been challenging to answer at broad spatial scales. **For terrestrial applications, understanding geomorphology from a 3D perspective offers great potential to advance our knowledge of the functional links between geomorphic and anthropogenic structures (e.g., buildings) and ecological processes in the environment.**

Beyond the biophysical realm, the next steps involve a socioecological systems approach that also incorporates the 3D patterns of human use and the effects of human activities that alter the 3D landscape structure. Human activities have long been considered on terrestrial landscapes (i.e., cultural landscapes) in Europe (Naveh 1995) and increasingly so in other regions of the world. As a result, **3D visualization of human dominated landscape and seascapE structure can advance our understanding of how humans use the 3D environment in both space and time and support advances in management of both space and time and support advances in management of complex socioecological systems.** Furthermore, the integration of this 3D approach in natural resource management may support the development of conservation and

management plans and shift the way that policymakers evaluate current and future regulations in a dynamic environment.

Related to socioecological systems, another area within which integration of approaches would be of great benefit is urban ecology and the design, management, and policy decisions that affect cities. Specifically, the integration of data could provide important information for **designing and planning urban green spaces** (parks, roofs, etc.), which is critically needed for addressing contemporary urban biodiversity questions (Aronson et al. 2017, Lepczyk et al. 2017). For instance, 3D data on rooftop height from the ground may be important for green roof networks. Using a 3D perspective could also provide needed insight into advancing urban gradient studies that have traditionally focused only on two dimensions. Cities have abundant sensing technologies embedded in them already and much of the data are publicly accessible. Remote sensing data could be fused with lidar and other imagery to develop a more complete picture of the ecological characteristics in cities.

The disciplines of landscape and seascape ecology are at the point of being revolutionized through the advancement of a new generation of spatial technologies that yield extremely voluminous and complex data sets (i.e., big data) together with advanced processing and informatics suitable to work with big data. The integration of large and disparate data types presents new challenges in how ecologists analyze and synthesize big data and the amount of information available offers unprecedented opportunities for understanding both the landscape and seascape in a way that informs management decisions at multiple scales. Future emerging lidar technology and data fusion streams from other satellite-based sensors will increasingly allow for analysis of big data, offering unprecedented opportunities to study and understand ecosystem dynamics and swiftly inform management decisions. **However, the true utility of harnessing the power of big data lies in the distillation of the data into knowledge in a way that can effectively provide the best available science to inform management and policy.** We anticipate that a focus on establishing, developing, and maintaining stronger communication channels between the remote sensing community, conservation biologists, natural resource managers, and policymakers will become increasingly important in collaborative work and fundamental for the development of a coordinated, effective research agenda (Pettorelli et al. 2014). As a result, the distillation and communication of 3D-based scientific findings will be an important consideration to ensure the successful uptake of information and timely responses from resource managers and policymakers.