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Methods

Incorporating the value of ecological networks into cost–benefit analysis to improve spatially explicit land-use planning

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ABSTRACT

Our research is based on the assumption that cost–benefit analysis facilitates efficient and effective decision-making in spatially explicit land-use planning where there are competing land uses. Land-use planning can be improved if the value of the spatial relationships between land uses can be computed sufficiently easily. In this paper, we developed an economically sound way to incorporate the spatial dimensions (size and connectedness) of ecological networks within cost–benefit analysis. The methodology computes the value of ecological networks by accounting for the essential spatial characteristics (size and configuration) of areas of natural land. This methodology can be generalised to other land uses, which we illustrate using a hypothetical case study that contains all the relevant elements. The optimal configuration of different land uses, which accounts for the value of the ecosystem network, will generate a land-use plan with the highest net benefit.

1. Introduction

Increasing pressure on land demands a careful assessment of competing activities in land-use planning. Cost–benefit analysis (CBA) is increasingly used in planning processes to select the land-use plan that delivers the highest net social benefits. Accurate assessment of the value of the competing land uses is necessary for the credible use of CBA in planning processes. Aggregate measures of non-market values, though useful, can obscure the heterogeneous nature of the underlying resources that provide those services (Troy and Wilson, 2006). The adoption of a spatially explicit approach to economic valuation when non-market values are important is desirable because this can lead to more accurate economic valuation figures (Eade and Moran, 1996).

The concept of ecological networks is of growing importance in land-use planning. Spatial modelling of values and the valuation of ecosystem networks will be a valuable tool for planning processes in which different spatial configurations (i.e., ecological networks) must be chosen from among a group of competing land uses. Land-use planning can be improved if the value of spatial relationships between land uses can be computed (or can be computed easily enough that this computation can be included in the cost–benefit analysis). In this paper, we focus on an approach that will permit efficient and effective decision-making when ecological networks exist amidst other land uses. We develop a methodology to assess the economic value of these ecological networks based on the ecological value that depends on the size and configuration of the natural areas. This value of ecological networks is based on species. We then extend this methodology to compute the economic value of different spatial configurations of land uses (given a few regularity assumptions) so as to enable the selection of a more economically efficient layout based on CBA.

Three areas of research that support spatial planning for natural areas can be distinguished. First, there are methodologies designed to assess the ecological value of a region within a planning procedure based on specific targets and restrictions. Examples include the work of Opdam et al. (2003, 2006) and Termorshuizen and Opdam (2009). This first area of research explicitly incorporates size and configuration effects, but often concentrates on a single land-use function, preventing the analysis from seeking an overall balance among several competing land-use functions. Perfecto and Vandermeer (2002) and Vandermeer and Perfecto (2007) expanded this analysis beyond a single function by analysing the spatial interaction between agriculture and forests. Termorshuizen and Opdam (2009) addressed two prerequisites that landscape ecological science must meet for this field to effectively produce appropriate knowledge capable of supporting bottom-up landscape-development processes: the analysis must include a valuation component, and it must be suitable for use in collaborative decision-making at a local scale. In the present study, we address both criteria, but focus on the valuation criterion.

The second group of studies developed methods to compute the balance between costs and benefits for various alternative layouts of a region that includes natural areas (e.g., Van der Heide et al., 2008; Van der Horst, 2006). In these studies, the value of a specific land use (e.g., nature conservation) is expressed per unit area, and therefore fails to capture the influence of the shape and size of the patches

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within the surrounding landscape. A particular value per unit area of natural land is generally used (based on benefit transfers or specific surveys) for the entire mosaic of land uses, irrespective of the sizes and shapes of the patches of each land use within the wider landscape. This line of research concentrates on quantification of the (monetary) value of land functions, but generally ignores the dependence of these values on the size and configuration of the patches. Incorporating size and configuration effects in CBA is essential to obtain a realistic economic valuation that accounts for the value of ecological networks in a region (Hanink, 1995; Heidkamp, 2008). This observation is not a peculiarity of ecological values; it holds, in principle, for all activities with strong interaction or scale effects, such as housing and the establishment of industrial sites and nature conservation areas. Interactions can refer to scale effects on a single activity or to values that arise from the adjacency of distinct functions, such as the increase in value of houses established near natural areas or bodies of water (Cheshire and Sheppard, 1995; Fik et al., 2003; Geoghegan et al., 1997).

Finally, the third group of studies is concerned with modelling at a detailed grid level using (for example) simulation experiments and automata theory (e.g., Drechsler and Wätzold, 2009; Parkhurst and Shogren, 2007). This domain of research introduces interesting concepts that relate to order that arises from local interactions and spatial correlations. However, the fragmentation thresholds used in landscape ecology to characterise ecological networks do not play a dominant role in this approach. In the work of Polasky et al. (2005, 2010), Groeneveld et al. (2005), Groeneveld and Weikard (2006), and Lewis et al. (2011), the effect of fragmentation on the biodiversity score of a landscape was accounted for explicitly, as was the economic value of other land uses. The biodiversity quality in these studies, however, was not converted into monetary values and empirical information on anthropogenic valuation of species and habitats is not fully exploited. Instead, the ecological and economic values were expressed in their own units, resulting in trade-offs during boundary analysis.

The contribution of this paper to the literature is the consistent and transparent way in which the economic value of ecological networks is computed in a CBA context to support communication in land-use planning processes. First, we consider ecological networks and how to capture the essential spatial characteristics of these networks that must be introduced into the economic analysis. We formulate the valuation of ecological networks, as described by Termorshuizen et al. (2007), Opdam et al. (2008), and Pouwels et al. (2008), in such a way that this valuation can be easily integrated within economic analysis. In fact, the evaluation of ecological networks within this framework becomes a specific example of a more general methodology for the valuation of land-use changes. Second, we add the spatial aspects of ecological networks into their economic valuation by means of CBA. We extend this framework to other land uses and show its applicability for land-use planning using a hypothetical example. Last, we draw conclusions about the approach and the need for future research to elaborate on this framework. Particularly in our hypothetical analysis, we ground the analysis in the reality that any landscape comprises a matrix of existing land uses, and that changing land use to a more optimal pattern has costs that must be included in the analysis.

2. Modelling the Value of Ecological Networks

Here, we have defined ecological networks, *sensu* Opdam et al. (2003, 2006), as a series of ecosystems of a given type that are linked to create a spatially coherent system through flows of organisms, and that interact with the landscape matrix in which they are embedded.

A key feature of ecological networks is that they can have different configurations and still lead to comparable probabilities of the persistence of natural populations; that is, the different configurations have the same ecological value. This results from variations in the physical features of the ecological networks, combined with the natural ability of species to spread through such connected networks of habitat patches. To specify the ecological value of an ecological network, the valuation must account for the particular form and effect of the quality, size, and configuration of the natural areas (particularly their connectivity), since these aspects of natural areas constitute the main factors that determine their ecological value.

In the limiting case, a network that consists of a single large natural patch may contain a single population of a particular species or single populations of two or more species. If the network is less connected because the landscape contains two or more habitat patches, it may contain a *metapopulation* of a particular species; that is, the overall population may be subdivided into local populations in separate habitat patches that are connected by dispersal processes and separated by local extinction processes or barriers to dispersal (Hanski, 1994; Levins, 1970). In metapopulation theory, the viability of a network, which can be considered as a measure of its ecological value, depends on the presence of sufficiently large habitats within the overall landscape system. In general, three types of networks can be distinguished (Pouwels et al., 2002, 2008; Fig. 1).

1. Networks that are not fragmented and that contain a minimum viable population (MVP); that is, a population of a particular species that can survive without requiring other suitable neighbouring habitats. The criterion for survival (viability) is generally taken as an extinction probability ≤5% in 100 years (Opdam et al., 2003; Verboom et al., 2001).
2. Networks that are fragmented but that contain a so-called “key patch”, which is a habitat of sufficient size that when combined with other, neighbouring but detached patches, it makes the population within the network potentially viable. By definition, a key patch is smaller than a single large area capable of supporting the MVP. Whether a specific area can act as a key patch depends on its size and quality, as well as on the size, quality, and configuration of other suitable areas. The cumulative effect of surrounding patches can be calculated in ecological terms. If this result exceeds a given threshold, the overall system has the potential to sustain a viable metapopulation.
3. Networks that are fragmented and lack non-viable key patches. In this case, the network has insufficient carrying capacity to support even a metapopulation. The ecological value of the network to a given species is therefore negligible.

This classification, which has been developed based on ecological evidence, distinguishes between two thresholds (μ_1 and μ_2) that are measured in area units. The largest threshold, μ_1, characterises the presence of an MVP. Typical values for μ_1 range from less than 1 ha for some butterflies to well over 10,000 ha for birds such as the hoopoe (Pouwels et al., 2002, 2008). We designate the size of a patch P in the network as $\mu(P)$ and we designate its contribution (value) to the ecological value of the network as $v(P)$. Let $P_{\max}$ represent the largest patch in the network. If $\mu(P_{\max}) \geq \mu_1$, the network contains an MVP. We then make no further distinction with respect to the ecological value. That is:

$$v(P_{\max}) = v_1 \;\text{ if }\; \mu(P_{\max}) \geq \mu_1$$

$$v(P_{\max}) = v(P_{\max}) \;\text{ if }\; \mu(P_{\max}) < \mu_1.$$

This assumption means that enlarging the patch doesn't increase its ecological value once the threshold for an MVP has been reached. Obviously, this is based on a dichotomous (yes/no) definition of the viability criterion. If the ecological value is instead taken as a continuous variable, such as a variable that reflects the probability that a species will not become extinct in a given area within a certain time span, the ecological value continues to increase when $\mu(P_{\max}) > \mu_1$.