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Integrating landscape ecology in environmental impact assessment using GIS and ecological modelling

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Abstract

Ecological assessment in environmental impact assessment and strategic environmental assessment processes requires improvements. The descriptive and qualitative nature of many ecological assessments suggests a need to develop and implement quantitative and predictive methods to assess problems such as fragmentation and impacts on biodiversity. Such tools, from basic GIS applications to more advanced ecological models, already exist and have reached a level of development that allows practical implementation outside the research sphere. The chapter presents a literature review on the potential application and advantages of ecological models and GIS-based methods in carrying out ecological assessments in the Environmental Impact Assessment and Strategic Environmental Assessment

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processes. The implementation of such tools translates into practice certain concepts of landscape ecology related to ecological dynamic or spatial and temporal scales. Although data requirements and the complexity of ecological models are limitations to their reproducibility and application range, the integration of landscape-ecology concepts in ecological assessment through the use of ecological models and GIS tools would contribute to the sustainable management of landscapes and their ecological resources. Finally, I argue that predictive modelling and GIS tools can also serve as a platform to integrate other landscape components that can be characterized spatially such as recreational and cultural values.
Keywords: ecological assessment; strategic environmental assessment; GIS; predictive methods

Introduction

Changes in the landscape resulting from infrastructure, housing or industrial developments cause impacts on the natural environment with fragmentation and habitat loss being some of the main threats (Fahrig 1997). Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) are two essential tools for minimizing the impact of physical and landscape plans and have a strong legislative grounding. The EIA process was introduced more than 30 years ago in the USA whereas the grounds of the SEA process were defined less than 15 years ago.

For the United Nations Economic Commission for Europe (1991) EIA is "an assessment of the impact of a planned activity on the environment". Glasson et al. (Glasson, Therivel and Chadwick 1994) define it as "a systematic process that examines the environmental consequences of development actions, in advance". Defining and implementing SEA are subject to more discussion and controversy. SEA is stepping on the political scene, is related to concepts more than activities and therefore needs to be adapted to the existing decision-making processes (Partidário 2000). However, it could be defined as "a systematic process for evaluating the environmental consequences of proposed policy, plans and programmes initiatives in order to ensure they are fully included and appropriately addressed at the earliest appropriate stage of decision-making on par with economic and social considerations" (Sadler and Verheem 1996). In Europe, the EIA and SEA legislation for the European Union country members are based respectively on the directive on the assessment of the effects of certain public and private projects on the environment, or EIA directive (European Communities 1985), and the directive on the assessment of the effects of certain plans and programmes on the environment, or SEA directive (European Communities 2001). Both EIA and SEA regulations have requirements on the consideration of ecological and landscape issues and promote the sustainable use and development of the environment. While SEA is still at its infancy with the implementation of the European SEA directive approved in 2001 and coming into force in July 2004, the EIA process has been regulating large-scale developments in Europe for almost 20 years.

The EIA process has from its beginnings been an integrative process. The first regulations published on EIA mention the need to use an "interdisciplinary approach which will ensure the integrated use of the natural and social sciences and the environmental design arts in planning" (*The National Environmental Policy Act of 1969*). The EIA process is a meeting point between many disciplines, and the EIA research field reflects this integration challenge. Even though the EIA process is integrative by nature, its implementation remains a major issue and research on integrated assessment illustrates the problems. Both ecology and landscape are indisputably included in the scope of the EIA process, even though the definition and content of the ecological and landscape assessments can vary. Landscape assessment considers the aesthetical value of the landscape and leaves ecology-related issues to the ecological assessment. The lack of quality of ecological assessment within the EIA process has been pointed out over the years (Treweek et al. 1993; Thompson, Treweek and Thurling 1997; Atkinson et al. 2000; Byron et al. 2000). Some of these problems are related to the lack of integration between ecological and landscape assessments. Parallel to or in conjunction with ecological assessment, research fields such as ecological modelling and landscape ecology have developed rapidly. As an answer to the generally weak predictive nature of the ecology research filed (Treweek 1996), such developments and especially in combination with Geographic Information Systems (GIS) technologies have created new possibilities that allow qualitative as well as quantitative predictions.

The paper presents the need for improved quality of ecological assessment in the EIA and SEA processes through the integration of landscape-ecology-related concepts. It presents common shortcomings of ecological assessment and reviews literature on existing ecological models and other GIS-based methods that have the potential to address these shortcomings. The implementation of such methodologies would not only help to improve the quality of ecological assessments, but could also play a role in the integrative ambitions that characterize the EIA and SEA processes.

Main shortcomings of ecological assessments in the Environmental Impact Assessment process

Even though some improvements can be noticed, the overall quality of ecological assessment remains disputable. The results from different EIA reviews (Treweek et al. 1993; Thompson, Treweek and Thurling 1997; Atkinson et al. 2000; Byron et al. 2000) showed the main shortcomings in ecological assessment. The scope of ecological assessment and what it should include is often subject to misunderstanding, especially after the recent discussions initiated by the Convention on Biodiversity on the need to consider the different biodiversity levels (genetic, species and ecosystem levels) in ecological assessment. There is a general a lack of concern on biodiversity issues in today’s EIA process.

Ecological assessment is often characterized by its descriptive content and the lack of predictions (Byron et al. 2000). The descriptive content of today’s ecological assessment is a direct consequence of the qualitative methodologies used in the assessment whereas the use of quantitative methodologies remains absent. The vagueness of the information presented in EIA reports extends from basic information on the characteristics of the project (e.g. the size of the project) to the results of the survey presented (e.g. species inventories) and renders it difficult or impossible to undertake quantitative assessments. Ecological assessment tends to lack a range of tools and is mainly dependent on species or habitat inventories, showing the need to develop specific prediction tools. The use of inventories favours a focus on protected species and protected habitats and renders it difficult to develop a functional approach at the ecosystem or landscape level. The application of the EIA process on a project-by-project basis tends to lead to a fragmented pattern of protected areas (Rookwood 1995). This is strengthened by the poor integration between ecological and landscape assessments and translated by the fact that ecological assessments are often conducted at the local level and seldom consider impacts at the ecosystem or landscape levels.

As a consequence of assessments performed at the local level, it is difficult to assess cumulative and widespread impacts at the ecosystem or landscape levels. Other shortcomings of ecological assessments include difficulties in setting the time frame time frame for impacts, to distinguish between short-term and long-term impacts and especially to deal with long-term impacts in general.

GIS technologies and ecological modelling: potential tools for improvements in ecological assessments

The potential use of GIS in EIA in general (João and Fonseca 1996) and for ecological assessment in particular (Treweek and Veitch 1996; Geneletti 2002) has been recognized and advocated. However, in today's EIA reports, the use of GIS within ecological assessment is often limited to its display functions and seldom used for its analytical capacities. A broad definition of GIS is a computer system made up of hardware, software, data and applications for managing spatial data in the form of maps, digital images and tables of geocoded data items (Bonham-Carter 1994). In the research arena, there has been a fast development and acceptance for GIS technologies (Goodchild 2002) and its use in environmental modelling. The combination of GIS and environmental modelling offers new perspectives in integrated science (Clarke, Parks and Crane 2000). The next section describes some examples of potential improvements to ecological assessment through the use of GIS functions, applications and integration with ecological modelling.

One main function of a GIS is to gather data that will result in the creation of a database. This database can then be the starting point for further manipulation and analysis of the data. For ecological assessment, such a database could consist of a land-cover map, a topographical map (digital elevation model), a conservation or protected-areas map, a soil map, a geology map and a climate map depending on the availability of these data. Data on climatic variables could also be relevant to perform the assessment further. The quality and accuracy of the land-cover map will be the limiting factor for the rest of the ecological assessment. At the baseline level of the EIA process, the display functions of a GIS can be used to produce background ecological maps. In addition, a wide range of functions is usually built into GIS software and directly available. Some of these functions such as the *buffer* command can find some relevance in ecological assessment. For example, to buffer protected areas can be very relevant in order to look at potential impacts from noise or air emissions on sensitive species. This buffer could also take into consideration the influence of the wind pattern or topographical parameters in order to improve its accuracy.

A more advanced analysis could be a connectivity or fragmentation analysis. In a simplified way, connectivity and fragmentation analysis can be performed by analysing the degree of physical contact or distance between predefined habitat patches that represent selected ecological entities within the study area. As a result, such analysis can show the level of fragmentation or can help to identify important corridors for species movements. The connectivity analysis can be conducted at different scale levels. The development of three-dimensional visualization technologies when used in a GIS environment renders possible the visualization of ecological barriers resulting in habitat fragmentation (Krisp 2004). Three-dimensional visualization is based on the combination of geographic data and simulation programs (Krisp 2004). Such techniques offer potential for the comparison of impacts between different development scenarios or alternatives as required in the EIA process. GIS in general and three-dimensional visualization in particular are powerful tools that can serve the communication objectives in EIA, SEA and physical planning in general even though accuracy and interpretation of visual data raise problems of subjectivity.

Other methods based on more advanced processing of land-cover data involve the production of ecosystem or biodiversity maps. For example, a biotope map of the greater Stockholm area was produced by Löfvenhaft et al. (2002) based on the interpretation and classification of colour infrared aerial photographs. Geneletti (2003) proposed a modelling method based on ecosystem rarity in order to introduce criteria for protection and preservation of nature and apply it to compare the impact of different alternatives for a road project. Biodiversity maps constructed using biodiversity indices derived from criteria such as the number of species, their rarity or their sensitivity to specific disturbances. Another land-cover-based assessment is provided by Treweek and Veitch (1996), who looked at the spatial distribution of land-cover categories and their proximity to existing or planned developments.

Ecological modelling has found its core developments and applications in both conservation biology and landscape ecology, where the latter tends both to integrate knowledge and to orientate itself toward a problem-solving discipline (Tress and Tress 2002). Ecological modelling is not restricted to GIS applications but its usefulness and potential implementation in physical planning almost make some form of spatially referenced system a requirement. The development of predictive habitat distribution models (Guisan and Zimmermann 2000) and other predictive models in ecology have rapidly increased, and many of them could theoretically be relevant for ecological assessment within the EIA or SEA processes. From an ecology perspective, a model for biodiversity assessment would ideally be precise, ecologically sensible, interpretable, general and fully data-defined and should be expressed in a spatial framework (Lehmann, Overton and Austin 2002). Within ecological modelling, prediction models try to establish a relation between species occurrences and environmental variables in an attempt to characterize the habitats suitable for specific species (Mörtberg 2004).

Even though the development of new models and modelling techniques often reflects the needs of society (Scott et al. 2002) the contribution of ecological modelling to the EIA and SEA processes remains in practice insignificant. To gain an overview on the different streams of development within predictive modelling and the existing models, methods and areas of application is somewhat of a challenge. Decoursey (1992) suggested a classification based on the potential use of the models that would distinguish between screening, research and assessment models. Even though many ‘research-orientated’ models have great relevance for the topic, their potential implementation will require more experience of their use in practice. Here follow a few examples of methods, models and software that have tried to go a step further towards practical application in physical planning and which are therefore relevant for EIA and SEA processes. Although a classification of the different models and methods may be difficult, a distinction can, however, be made between expert-based models and empirical models (even though combinations of these two also exist).

One group of models is found under the heading of Habitat Suitability (HS) models. These are applied mainly to individual species but can also be applied at the community level. Among habitat-suitability models, one main type are the Habitat Suitability Index (HSI) models developed at the beginning of the 1980s in the USA (U.S. Fish and Wildlife Service 1981), which are expert-based models. Examples of other habitat-suitability methods are the Generalized Linear Model (GLM) and the

Ecological Niche Factor Analysis (ENFA) (Hirzel, Helfer and Metral 2001), which both use empirical data. Verboom et al. (Verboom et al. 2001) have developed an approach combining species-distribution data, population-viability analysis and landscape indices using the Landscape Ecological Analysis and Rules for the Configuration of Habitat (LARCH) decision-support system. The latter is a landscape-ecological model designed as decision-support system (Reijnen et al. 1995). It claims to be a flexible and versatile tool that combines expert knowledge with empirical studies. Another type of expert-based ecological models is represented by the Landscape Ecological Decision and Evaluation Support System (LEDESS) model that has been developed for the evaluation of development scenarios at the landscape level (Knol and Verweij 1999). The use of ecological models in the EIA and SEA processes makes it possible to integrate a functional approach in the ecological assessment as well as to take into consideration impacts at the landscape level.

In addition to ecological modelling, research has been initiated on integrated assessment. Within that research area Clarke et al. (2000) advocate for the integrative capacities of combining environmental modelling and GIS. Aspinall and Pearson (2000) provide an example of that and use GIS and modelling as an instrument for integration, in an attempt to link landscape ecology, environmental modelling and GIS. Figure 1 shows how, apart from other consequences on the quality of EIA’s ecological assessment, the integration of landscape-ecology concepts through the use of ecological models and other GIS tools could influence the physical scale of the assessment. It also introduces the potential for integration of other landscape interests such as cultural or aesthetical values within the EIA process.

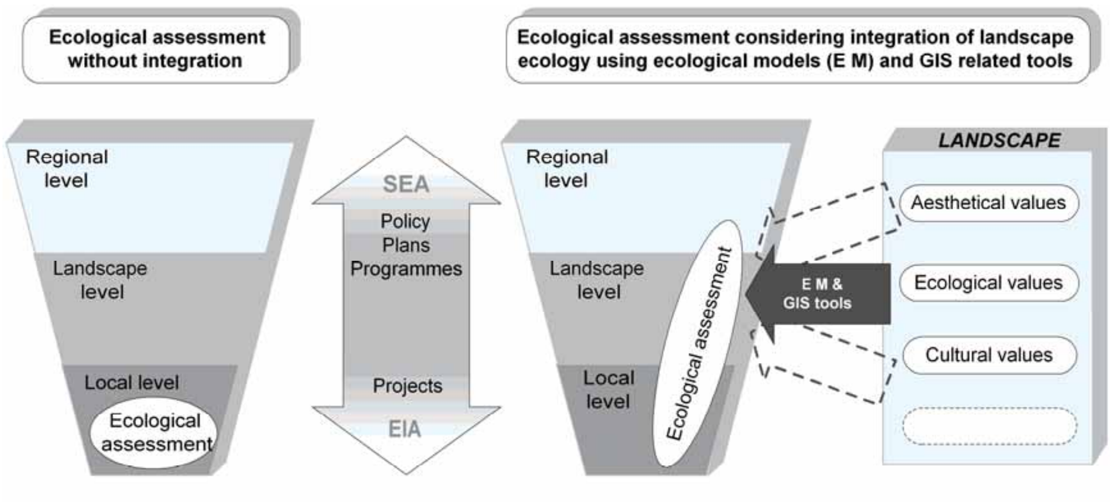

Figure 1. Schematic representation of the integration of landscape ecology using ecological models and other GIS tools in the ecological assessment and how it could affect the physical scale considered in the assessment

Problems and limitations to implementation of GIS and ecological modelling

The accuracy, resolution and the size of GIS databases and the hardware necessary to handle or combine such data were previously limiting issues that have been substantially improved through technological advances in recent years (e.g. Lehmann, Overton and Austin 2002; Krisp 2004). However, access to data remains a major barrier to the use of GIS and modelling tools. Efforts need to be made to provide a more open and technically easier access to existing data such as species inventories that would assist the implementation of ecological models. More generally, the harmonization of databases at the national and international level (for transboundary projects) is a key issue to the successful use of such methodologies. In Europe the development of the Corine Land Cover (CLC) database is an example of such harmonization. The complexity of ecological modelling and problems related to its reproducibility and robustness remain the main obstacles (Goodchild 2002) for its further implementation in EIA and SEA. Although GIS analyses and ecological models are now recognized as powerful tools for predicting the impacts of developments, the results need to be interpreted with a full understanding of their limitations. The fact that some of these methods have been used and tested for many years but are still seldom applied in an EIA or SEA context shows the need for further capacity building outside research environments.

Conclusion

One of today's challenges consists in bridging the gap between ecology and physical planning (Opdam, Foppen and Vos 2001). The EIA and SEA processes are two main regulation tools available to integrate ecological and biodiversity issues in physical planning and landscape management. Within the EIA process, one problem is linked to the definitions and scopes of ecological and landscape assessments and the lack of integration between these two. A partial answer to that problem might be found in the implementation of GIS technologies and ecological modelling. However, the advances initiated more than 20 years ago in the GIS and ecological-modelling fields still move only slowly towards implementation in EIA or SEA. One problem lies in the way this knowledge tends to be applied, at short notice and for a fixed budget within the framework of a specific project development in the case of EIA, and for plans, programmes or policies in the case of SEA. A successful integration of existing ecological tools and models developed in a GIS interface in the regulated EIA and SEA processes could be a key factor in working towards sustainable landscape management. The work conducted in landscape ecology illustrates a move from a descriptive approach of the environment to a more functional approach that has potential to be translated into practice (Gutzwiller 2002; Vägverket 2002).

The integration of landscape ecology concepts in EIA's ecological assessment brings most importantly the discussion to the need to consider the spatial dimension of our ecological environment. Ecological models and GIS technologies are the tools that allow the implementation of the concepts into practice. The potential change of the spatial scale considered in EIA's ecological assessment resulting from the use of ecological models and GIS tools might help to overcome problems related to fragmentation. Moreover, the implementation of the SEA process will as well offer possibilities to discuss scale-related issues.

However, integrating landscape-ecological concepts in the EIA's and SEA's ecological assessment is not the only challenge. EIA and SEA have the ambition to be integrated processes. Other landscape interests such as recreational or cultural aspects are also part of their scopes (Figure 1). But in order to reach the integration objective, EIA and SEA have to face the challenge of moving from a multidisciplinary approach to a transdisciplinary one. In other words, it requires not only that the different disciplines are part of the same process but also that cooperation and exchange are achieved beyond the discipline boundaries in order to reach a common goal. Research is performed on the integration of cultural, ecological and/or recreational values in the landscape (Suter 1999; O'Rourke 2005), but is confronted with the lack of specific tools. Other landscape interests as, for example, recreational and cultural values are to some extent incorporated in a number of ecological models, where they act as disturbance factors for the ecological environment, but without the ambition to perform an integrated assessment. The development of GIS technologies and predictive modelling make it technically possible to compare different interests that can be characterized spatially. GIS, more generally, form a platform where different landscape interests can be spatially confronted with each other. The integration of landscape-ecology concepts in the ecological assessment is therefore only one step on the way to the integration objective of the EIA and SEA processes. The recent development and application of SEA does not yet allow us to draw conclusions on its efficiency, but it opens the way for increased consideration of impacts at the landscape and regional levels. It will however face the same challenges as the EIA process concerning the need for predictive tools. But it remains that it will play a central role in landscape management by assessing impacts from entire activities of sectors such as road planning or agriculture.

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