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Allocation of European wetland restoration options for systematic conservation planning

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ABSTRACT

Agricultural policies, urbanization and globalization processes can lead to profound land use changes. A strategic coordination for the areas that are allocated for agriculture and nature conservation, respectively restoration, is therefore important to achieve greater benefits for all parties, such as by integrated networks of habitat. In this regard the concept of systematic conservation planning provides methods for locating and designing new reserves to complement existing ones under consideration of competing land uses. This study evaluates both biophysical and economic potentials to preserve existing habitats, to restore formerly native habitats, and to create non-native managed habitats with respect to freshwater wetlands of the EU-25 countries. Spatially explicit wetland distribution data are aggregated to country level and integrated into the European Forest and Agricultural Sector Optimization Model (EUFASOM). For different policy scenarios, the optimization model computes the corresponding economic potential of wetlands, its effects on agricultural and forestry markets, and environmental impacts. The resulting scenario specific wetland area per EU-country is further assessed by a GIS-based site-allocation and selection model which uses environmental and economic constraints under consideration of the spatial context. The final result is a EUFASOM-scenario dynamic wetland suitability map that shows potential wetland restoration areas leveled after its suitability and dependent on defined restoration options. The model is useful to locate sites suitable for wetland restoration programmes, for the introduction of faunistic corridors considering the NATURA2000 network, and aims to favour success in regional conservation planning.

Introduction

For millennia European landscapes have been shaped by various human land uses. Different abiotic, biotic, as well as landscape-specific human interactions have led to the spatial heterogeneity characteristic of Europe, but have also caused the loss of natural areas, such as wetlands. Even though wetlands have been drained since the early Middle Ages, their decline has mostly occurred during the later decades of the 20th century, when private profit-maximizing land use decisions necessitated their drainage and caused their degradation (RAMSAR Commission).

In recent years concerns have grown regarding the consequences of wetland degradation, leading to the adoption of several conventions, directives, and an associated range of natural conservation and restoration actions for their protection (e.g. Natura 2000 sites, Water Framework Directive, Ramsar Convention). Although many reserves exist, their size and structure are currently not adequate enough to achieve the targets that have been set, and so nature restoration is increasingly viewed as an important element of conservation management (Young, 2000; Hobbs, 2005). Rounsevell et al. (2005) and Verburg et al. (2006) show that agricultural policies, urbanization and globalization processes have led to profound changes in land use changes throughout Europe. Therefore, a strategic coordination of areas that are allocated for agriculture or nature conservation is important to achieve greater benefits for all parties. In this regard, the concept of systematic conservation planning provides methods for locating and designing new reserves to complement existing ones, whilst also taking into consideration the factor of competing land uses (Margules and Pressey, 2000). Besides those systematic conservation planning studies that use a bottom-up approach, more and more efforts are also being undertaken to down-scale country-level data (Verburg et al., 2006; Dendoncker et al., 2006). This approach has been facilitated not only by improvements in data quality and availability, but also computing power.

The methods and mechanisms by which certain restoration sites might be identified differ (cf. Burnside et al., 2002). Often, habitat suitability models are used to determine the required habitat content or context for single or multiple species, and for assessing landscape features accordingly (e.g. Pressey et al., 1997; Haight

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et al., 2004; Westphal et al., 2007). The underlying methodology of these models relies mainly on weighted scoring approaches, where rankings for each attribute are used to calculate the geometric mean as a measure of overall suitability (Hoctor et al., 2000; Burnside et al., 2002). The construction of decision-modelling frameworks as an important element in habitat allocation analyses is described in Possingham et al. (2001). Several site-selection analyses utilize techniques involving Geographic Information Systems (GIS) to map the modelled geographic distribution of individual species (Powell et al., 2005; Bayliss et al., 2005; Chefaoui et al., 2005) or ecosystems (Lonkhuyzen et al., 2004). In addition, spatial optimization techniques that use mathematical programming are becoming increasingly accepted as a useful tool for land allocation measures. Sadeghi et al. (2009) provide a detailed overview of the literature on optimization applications. GIS-based optimization approaches using both mathematical programming and GIS techniques are still quite new. For example, recent papers by Frombo et al. (2009) and Alçada-Almeida et al. (2009) describe mixed-integer, multi-objective programming applications in combination with GIS-based interactive decision support systems.

In this paper, a GIS-based optimization method is presented and integrated into a mathematical land use optimization model. The aim was to identify priority areas for wetland preservation considering both spatial–ecological linkages at the landscape level, as well as costs under different policy scenarios. All wetland restoration incurs costs, which consist of (1) direct costs, i.e. the costs of restoration, maintenance management, and protection; and (2) opportunity costs. Direct costs are low where little restoration and maintenance is necessary. Opportunity costs are low where alternative land uses generally yield small profits. This leaves researchers, policymakers, and society with two important questions: (1) what degree of preservation is desirable, or rather financially or socially viable; and (2) which sites should be chosen for preservation? To answer these questions, a site-selection approach was used to determine an EU-wide wetland network that (1) gives priority to the preservation of already existing functional wetlands over wetland areas to be restored assuming that the first are more valuable for biodiversity conservation; (2) includes the value of connectivity among these wetland systems and processes; (3) is able to consider climate change impacts on freshwater wetlands; and (4) accounts for direct and opportunity costs of preservation underlying the assumption that the success of wetland restoration is dependent on site-selection to achieve specific restoration goals (Trepel and Palmeri, 2002). The objective of the methodology presented here is to allow a flexible modelling process that is able to accommodate multiple planning goals simultaneously by considering the interaction of natural, engineering, economic, and human sciences. In contrast to other studies that have applied the site-allocation procedure, this approach focuses on the regional scale, covering the EU-25 region. Additionally, it is spatially explicit and integrable into land use optimization and biodiversity conservation models (e.g. Jantke et al., 2011) by considering climate change impacts (Schleupner et al., forthcoming).

Methods

This integrated modelling approach consists of three main components (see also Fig. 1): (a) the compilation of wetland data provided by SWEDI (Spatial Wetland Distribution Model) into the European Forest and Agricultural Sector Optimization Model (EUFASOM) to obtain country-specific wetland restoration potentials (INPUT); (b) the development of a scenario-dependent site-allocation approach that selects wetland restoration sites according to their suitability in terms of location characteristics; and (c) an evaluation of priority areas for wetland restoration (OUTPUT). The study area comprises the whole EU-25 region, excluding Malta and Cyprus. Below, these three components (INPUT, site-allocation, OUTPUT) are described in more detail. Fig. 1 gives an overview of the methodological structure.

INPUT

SWEDI

For the allocation of wetland restoration sites, the spatial distributions of wetlands and suitable wetland areas are extremely important. Here, the wetland input data were derived from SWEDI, a spatially explicit, GIS-based wetland distribution estimation of Europe (Schleupner, 2010). SWEDI differentiates between existing wetlands and suitable sites for wetland restoration, and by doing so it is able to distinguish between three wetland types: wet forests (riverine and swamp), wet grasslands (like reeds and sedges), and peatlands (bogs and fens). Urban and other sealed-off areas and their direct vicinity are assumed to be unsuitable for wetland restoration and all potential wetland restoration sites that fall within urban or other built-up areas, including a 500-m buffer zone, are excluded from the analysis. Furthermore, sites that contain already existing conservation zones like salt marshes or valuable sparsely vegetated habitats are also set as not available for potential wetland restoration. In general, potential wetland restoration sites fall within agricultural land or forests.

Note: In this study, the term ‘restoration’ includes an improvement in degraded wetlands, re-creation at sites where similar habitat formerly occurred, and the creation of wetland in areas where they are being established for the first time within living memory (Morris et al., 2006). This includes artificial wetlands as well.

The wetland information provided by SWEDI is stored at a resolution of about 1 km. It was intersected with indexed vector grid cells of 5 km × 5 km, which divide the wetland areas into homogeneous parts. In total, this makes 83,047 grid cells, including 96,603 potential wetland restoration sites across the countries of the EU-25 region. Areas outside the SWEDI wetland distribution sites were set as zero.

The latest Version of SWEDI will include all European countries and is also able to account for climate change impacts on wetland distribution by using results from DWES, a fully coupled global dynamical model for wetlands (Stacke and Hagemann, 2012). This model identifies suitable areas for wetlands under changing climate conditions and their feedbacks to climate. However, DWES does not depict anthropogenic land use changes and adaptation in land management or nature conservation. But with integration of DWES into SWEDI and EUFASOM these changes are now included (described in Schleupner et al., forthcoming). Currently, the coupled modelling is in its implementation phase. Thus, future applications of the site-allocation tool presented here will be able to perform the analysis under several defined climate change scenarios.

EUFASOM

As a second component, EUFASOM (Schneider et al., 2008) was used to compute the corresponding economic potential of wetlands, their effects on agricultural and forestry markets, and the environmental impacts under different policy scenarios. EUFASOM is a fully dynamic, partial equilibrium model with endogenous commodity prices of the European Agricultural and Forestry sector. It has been developed to analyse changing policies, technologies, resources, and markets. Its main purpose is to make consistent analysis of abatement cost curves for greenhouse gas emissions possible, and how changing policies, technologies and market conditions influence these costs. The GHG emissions and emission reductions are accounted for all major sources, sink and offsets from agricultural, forest and ecological activities, for which data