Opportunity costs in conservation planning

– of the case of European wetland species

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Abstract

Protected areas have often been designated ad hoc. Despite increasing conservation efforts, loss of biodiversity is still accelerating. Considering land scarcity and demand for alternative uses, efficiency in conservation strongly correlates with efficiency in land allocation. Systematic conservation planning can effectively prioritize conservation activities. Previous studies minimize costs for exogenously given conservation targets. However, these studies assume constant marginal costs of preservation. We extend this cost minimization approach by also considering an endogenous representation of marginal costs. The more land is allocated to nature reserves, the higher are opportunity costs, i.e. costs of forgone agricultural production. This increase in opportunity costs results from changes in the prices of agricultural commodities. We employ a deterministic, spatially explicit mathematical optimization model to allocate species habitats by minimizing opportunity costs for setting aside land for conservation purposes. We find that ignoring land market rent adjustments can lead to highly cost-ineffective solutions in reserve selection.

1 Introduction

Reservation has often been done ad hoc, leading to inefficient allocation of conservation areas (Pressey 1994; Margules & Pressey 2000; Gonzales *et al.* 2003). The selection of protected areas is biased towards economically marginal landscapes which leads to severe underrepresentation of species, habitats, and ecosystems (Pressey & Tully 1994; Araujo *et al.* 2007). Furthermore, existing reserves are often too small to support viable populations of wide-ranging species (Pullin 2002; Boyd *et al.* 2008). Thus, despite increasing conservation efforts, biodiversity loss is still accelerating (Myers *et al.* 2000; Baillie *et al.* 2004).

Considering land scarcity and demand for alternative uses, efficiency in conservation strongly correlates with efficiency in land allocation. Systematic conservation planning can effectively prioritize conservation activities (Margules & Pressey 2000; Possingham *et al.* 2000; Margules & Sarkar 2007). The set-covering problem detects how to achieve some minimum representation of biodiversity features while minimizing the resources needed (Possingham *et al.* 2000; Williams *et al.* 2005).

Addressing high competition for land especially in densely human-populated countries, the set-covering problem identifies the least required area. Previous studies minimize the number of reserve sites or their total area for given representation targets of biodiversity features (Saetersdal *et al.* 1993; ReVelle *et al.* 2002; Tognelli *et al.* 2008). However, finding the minimum area for reservation does not guarantee minimum costs for achieving the respective conservation target. Ando *et al.* (1998) show that the cost per conservation site under cost minimization can be less than one-sixth of that under the site-minimizing solution. Because marketable land values differ, regional priorities change under cost minimization (Balmford *et al.* 2000; Polasky *et al.* 2001; Naidoo *et al.* 2006). However, when appropriate data on land values are not available, conservation planning studies often use area as a proxy for costs (McDonnell *et al.* 2002).

When accounting for heterogeneity in land costs, previous studies assume marginal costs as being fixed and exogenous (Ando *et al.* 1998; Polasky *et al.* 2001; Stewart & Possingham 2005). However, Naidoo *et al.* (2006) argue that setting aside land for conservation itself could change land costs. Armsworth *et al.* (2006) explicitly consider land market feedbacks with respect to conservation planning. Assuming constant marginal land costs neglects land market effects and thereby may lead to underestimations of the real costs and thus non-optimal decisions on reservation. The main research question we address in this study is: How relevant is the effect on conservation planning results of taking the dynamic nature of land opportunity costs into account?

We employ a deterministic, spatially explicit mathematical optimization model, which allocates species habitats by minimizing total costs for setting aside land for conservation purposes. We apply mixed integer programming techniques. To illustrate the effect of incorporating the dynamic nature of opportunity costs into conservation planning, we compare exogenous and endogenous representations of costs in a multiple-species conservation planning exercise. The analysis is done for 69 wetland species across 23 European countries.

2 Methods

2.1 Conservation target

Effective biodiversity conservation requires simultaneous consideration of representation and persistence conditions (Margules & Pressey 2000; Sarkar *et al.* 2006). In our model, each species is subject to exogenously assigned representation targets. We assume the persistence criterion to be fulfilled when two conditions are met. First, each individual species' representation corresponds to one viable population. A population is considered viable when the allocated land area meets the minimum critical area which is a species-specific measure based on density data and minimum viable population sizes. To account for different habitat quality (Foppen *et al.* 2000; Riley 2002) and potential bias in sampling effort (Schwanghart *et al.* 2008), we solve the model for different density data. We do not explicitly portray competition between species and assume that they do not affect each other in terms of density. The second condition for the persistence criterion refers to habitat type requirements. In our model, each species requires specific habitat types which are either necessary for the species' survival or optional habitats. The land area that corresponds to the minimum critical area of a species is allocated to the relevant habitat types.

2.2 Planning units

We use a spatially explicit model based on planning units that differ in shape and size. The dedicated habitat area is determined for each planning unit. Available options are either to use the total planning unit area, a fraction of the planning unit, or real or estimated data on potential reserve areas. There are two possible states of each planning unit; it is either occupied by a species (1) or not (0). Occupation is only possible if the species was historically observed in this planning unit or in close proximity. We assume that habitat suitability for a species is constant across all possible planning units. Parts of planning units necessary to fulfill conservation targets are selected as priority area for conservation. If a species' minimum area requirement cannot be fulfilled within a single planning unit, we allow the model to choose further habitat area in adjacent planning units.

2.3 Land markets

When purchasing or renting large areas for conservation, the equilibrium between supply and demand in regional land markets is distorted and land rental rates will adjust. This feedback from land markets affects the economic feasibility and the marginal costs of conservation efforts (Armsworth *et al.* 2006). The more land is allocated to reserves, the higher are its opportunity costs, i.e. costs of forgone agricultural production. This increase in opportunity costs results from price adjustments in agricultural commodity markets. According to economic theory, a competitive land supply curve is equal to the marginal cost function of land. Mathematically, the marginal cost function is expressed as the derivative of the total cost function with respect to quantity.

2.4 Mathematical model structure

The formal framework used here expands the set-covering problem. We use the following notation: $c = \{1,\ldots,C\}$ is the set of countries; $p = \{1,\ldots,P\}$ is the set of planning units; $t = \{1,\ldots,T\}$ is the set of habitat types; $q = \{1,\ldots,Q\}$ is the set of habitat qualities; and $s = \{1,\ldots,S\}$ is the set of species. We employ several set mappings, which contain possible combinations between two or more individual indexes. In particular, $u(s,t)$ identifies the mapping between species and required or optional habitat types and $k(s,p,t)$ possible existence of species and habitats in each planning unit. The objective variable O represents total opportunity costs. The variable Z_c represents opportunity cost per country *c*. The variable $Y_{p,t,q}$ determines the habitat area per planning unit *p*, habitat type *t*, and habitat quality *q* in hectares. $X_{s,p}$ is a binary variable with $X_{s,p} = 1$ indicating species *s* is represented in planning unit *p*, and $X_{s,p} = 0$ otherwise. r_c denotes the annual land rent per hectare and country *c*. $a_{p,t,q}$ contains the maximum available area per planning unit *p*, habitat type *t* and habitat quality *q*. $d_{s,q}$ represents species- and habitat quality-specific density data. m_s is a species-specific proxy for minimum viable population size. $h_{t,s}$ determines which habitat types *t* are required by species *s*. t_s is the representation target per species *s*. v_s specifies deviations from the representation target based on exogenous maximum occurrence calculations.

I Conservation planning with constant exogenous land rents

Minimize $O = \sum_c Z_c$ [1]

subject to:

$$Z_c = r_c \cdot \sum_{p \in c,t,q} Y_{p,t,q} \quad \text{for all c} \quad [2]$$

$$Y_{p,t,q} \le a_{p,t,q} \quad \text{for all p,t,q} \quad [3]$$

$$\sum_q Y_{p,t,q} \ge h_{t,s} \cdot X_{s,p} \quad \text{for all p,t,s} \quad [4]$$

$$\sum_{p} X_{s,p} \geq t_s - v_s \qquad \text{for all s} \qquad [5]$$

$$\sum_{t,q} d_{s,q} \cdot Y_{p,t,q} \Big|_{k(s,p,t) \wedge u(s,t)} \geq m_s \cdot X_{s,p} \qquad \text{for all p,s} \qquad [6]$$

$$\sum_{p,t,q} d_{s,q} \cdot Y_{p,t,q} \Big|_{k(s,p,t)} \geq t_s \cdot m_s \qquad \text{for all s.} \qquad [7]$$

The objective function [1] minimizes total costs across all planning units. Equation [2] calculates the total costs per planning unit as product of habitat area and land rent. Constraint [3] limits habitat areas in each planning unit to given endowments. Constraint [4] forces the existence of required habitat types for all species chosen in a particular planning unit. Constraint [5] implements representation targets for all species but allows deviations if the number of planning units with occurrence data is below the representation target. Constraint [6] portrays minimum area requirements for all protected species in all planning units. The summation over habitat types depicts the choice between possible habitat alternatives. Constraint [7] ensures that the total population size equals at least the representation target times the minimum viable population size. This constraint is especially relevant for cases where the representation target is higher than the number of available planning units for conservation. For example, a representation target of ten viable populations with possible species occurrences in only nine planning units would under [7] require one or more planning units to establish enough habitat for more than one viable population.

II Conservation planning with endogenous land rents

To represent land rents endogenously, we alter the model formulation. r^0_c represents the initial land rent per hectare of land and differs by country. $a^0_{p,t,q}$ is the initially available area per planning unit. Land rents r_c rise according to function $f(Y_{p,t,q})$ [8].

$$r_c = f(Y_{p,t,q}) = r_c^0 + b_c \cdot \sum_{p \in c,t,q} Y_{p,t,q} \qquad [8]$$

We assume a linear marginal cost function with slope *b*. To determine *b* we introduce different price-elasticities of supply ε at a land supply level equal to the maximum conservation area. The elasticity ε measures the responsiveness of land supply to a change in land rent [9].

$$\varepsilon_c = \left| \frac{\partial \sum_{p\in c,t,q} Y_{p,t,q}}{\partial r_c} \cdot \frac{r_c}{\sum_{p\in c,t,q} a^0_{p,t,q}} \right| = \left| \frac{1}{b_c} \cdot \frac{r_c}{\sum_{p\in c,t,q} a^0_{p,t,q}} \right| \qquad [9]$$

The linear marginal cost function $f(Y_{p,t,q})$ is given by [10]:

$$f(Y_{p,t,q}) = r_c^0 + \frac{1}{\varepsilon_c} \cdot \frac{r_c}{\sum_{p\in c,t,q} a^0_{p,t,q}} \cdot \sum_{p\in c,t,q} Y_{p,t,q} \qquad [10]$$

The corresponding total cost function $F(Y_{p,t,q})$ is [11]:

$$F(Y_{p,t,q}) = r_c^0 \cdot \sum_{p\in c,t,q} Y_{p,t,q} + \frac{1}{2\varepsilon_c} \cdot \frac{r_c^0}{\sum_{p\in c,t,q} a^0_{p,t,q}} \cdot \left(\sum_{p\in c,t,q} Y_{p,t,q} \right)^2 \qquad [11]$$

In the model formulation, equation [2] is replaced with [2a]:

$$Z_c = r_c^0 \cdot \sum_{p\in c,t,q} Y_{p,t,q} + \frac{1}{2\varepsilon_c} \cdot \frac{r_c^0}{\sum_{p\in c,t,q} a^0_{p,t,q}} \cdot \left(\sum_{p\in c,t,q} Y_{p,t,q} \right)^2 \quad \text{for all c.} \qquad [2a]$$

The problem is solved with mixed integer programming using the General Algebraic Modelling System (GAMS) software version 22.9.

3 Application to European wetland biodiversity

3.1 *Ecological and spatial data*

Due to their relevance for conservation and related environmental objectives, we apply our model to freshwater wetlands. Species dependent on freshwater wetlands serve as surrogates for biodiversity. We include 69 tetrapod species listed in the appendices of the birds and the habitats directive (79/409/EEC; 92/43/EEC) which encompass 15 amphibian, 4 reptile, 41 breeding bird, and 9 mammal species. Recorded occurrences from species atlases (Hagemeijer & Blair 1997; Gasc *et al.* 1997; Mitchell-Jones *et al.* 1999) identify their potential distribution in Europe. Species' density data were compiled through literature review; we use the maximum observed density. Proxies for minimum viable population sizes are based on Verboom *et al.* (2001). We adapt their proposed standards for minimum population sizes depending on species' body sizes and life expectancy. Particularly, a viable population in our model requires 120 reproductive units (pairs/territories/families; depending on species group) of long lived or large vertebrates and 200 reproductive units of other vertebrates. Data on habitat type requirements also result from literature review. We include five broad wetland habitat types in our dataset, namely mires, wet forests, wet grassland, water courses, and water bodies. A further type "open water" is applied to species that either require water courses or water bodies. See supplementary material for the included ecological data for the 69 species.

Figure 1 about here

Geographically estimated data from Schleupner (2007) provide information on existent habitat areas in Europe. To enable the most area-demanding species to fulfill their area requirements, they are allowed to inhabit a certain share of non-wetland habitat. The dataset comprises the European Union with 23 out of 27 member states (see Figure 1). Cyprus, Malta, the new member states Romania and Bulgaria, and Macaronesia were excluded due to data deficiencies. The planning units coincide with the resolution of the species occurrence data. The atlases use the Universal Transverse Mercator (UTM) projection with grid squares of about 50 km edge length. We considered the terrestrial parts of all 1996 grid cells belonging to the selected European countries as planning units.

3.2 Economic data

Country-specific data on current agricultural land rents are taken from European land statistics (see Table 1). To address the uncertainty of the price-elasticity of additional land supply, we use values of 0.1, 0.3, and 0.5. In future studies, we plan to take land prices directly from the European Forest and Agricultural Sector Optimization Model (Schneider *et al.* 2008).

Table 1 about here

3.3 Empirical Results

Figure 2 shows annual land opportunity costs for conservation targets ranging from 1 to 25 for 69 wetland species. The model simulations with constant exogenous land rents result in substantially lower total costs when compared to simulations that include land market feedbacks. For the medium price-elasticity of land supply (ε=0.3), the endogenously determined costs are on average about 19 percent (range: 2.0 to 27.9 percent) higher than the exogenously calculated costs. Note, however, that the cost differences in Figure 2 only represent a fraction of the total cost error resulting from incorrect assumptions about land markets. Specifically, the distance between the individual lines identifies the minimum cost error for misspecified land rents.

Figure 2 about here

The true cost error is likely to be higher because misspecified land rents are likely to result in inefficient land allocations. This is illustrated in Figure 3, where we correct the land opportunity costs estimated under constant land rents (lower line) to account for land market feedbacks (upper line). We re-calculate national land rents but keep the size and locations of the conservation areas as determined under the setup with constant land rents. Note that the resulting cost function (upper line) is about three to five times higher in magnitude than the endogenous land rent based cost function for the same elasticity (middle line). This indicates that the cost error due to inefficient land allocation may be substantial, especially if there is a large heterogeneity in land prices (see Table 1).

Figure 3 about here

The total area requirements for achieving a given conservation target and the corresponding habitat shares are shown in Figure 4 and Figure 5. For the highest simulated conservation target of 25 viable populations, the total habitat requirements equal 35 to 40 million hectares. This value is about 10 percent of the terrestrial land area and about 20 percent of the current agricultural area of the considered countries (see Table 1). Furthermore, the comparison of Figure 4 and Figure 5 reveals that different assumptions about land rents have little impact on the total conservation area requirements. However, the regional reserve allocation between European states differs across alternative land market representations (Figure 6).

Figure 4, Figure 5, and Figure 6 about here

4 Discussion

Conservation is costly and available land resources are scarce. As Cullen *et al.* (2005) point out, failure to apply economic tools to decision-making in conservation problems may lead to errors in project selection, wasted use of scarce resources, and lower levels of conservation than possible to achieve from given resources. Newburn *et al.*'s (2005) review of reserve designs finds that land costs are often inadequately addressed. Applying economic concepts and tools becomes increasingly important for decision-making in conservation (Shogren *et al.* 1999; Naidoo *et al.* 2006; Waetzold *et al.* 2006). Our study shows that negligence of land market adjustments may lead to highly cost-ineffective reserve selection. Furthermore, the reported total costs would be misleading and substantially underestimate the true total costs.

Polasky *et al.* (2008) argue that assuming constant land prices is reasonable when the areas of conservation interest do not significantly impact agricultural and forestry commodity markets. However, current demand for nature reserves does not just regard a few local sites for a few species. Most of the demand can only be met by reverting a considerable portion of agricultural and managed forest sites back to nature areas. Since virtually all agricultural and forest production is directly or indirectly linked to regional and international commodity markets, there will be always a market feedback. For example, Armsworth *et al.* (2006) confirm that land market feedbacks can influence conservation efforts even at local scales.

Several important simplifications in our analysis need to be noted. First, we consider only the land opportunity costs from acquiring additional land and keeping existing land under conservation. Reality in conservation planning is more complex and there are important additional costs, i.e. costs related to reserve establishment and maintenance (Naidoo *et al.* 2006). Note that opportunity costs are also relevant in other conservation issues not included in our study. In some cases management practices of landowners change and are compensated for. For example, Barlow *et al.* (2007) estimate the foregone forestry potentials when managing forest for maintaining habitat of endangered species. Rondinini & Boitani (2007) analyse costs of antipredator measures associated with the conservation of large carnivores. Second, we do not account for spatial reserve design criterions like connectivity or compactness in our model and also do not consider spatio-temporal aspects of persistence. We apply only five coarse habitat classes with no quality differences. Note that the employed absolute values of species' pairs, territories or families serve as proxies for viable populations. They are not assumed to represent real minimum viable populations, but are used as working targets due to the lack of better data.

5 Implications for conservation planning

Biodiversity conservation is a declared objective of many national governments but also of the United Nations. Its realization may interfere with other objectives because of land competition between conservation areas, agricultural fields, bioenergy plantations, and intensively managed forests. Our study quantifies the cost implications of different conservation planning approaches for 69 species of European wetlands. We find that misspecified land markets may lower the reported cost estimates but increase the true costs of conservation by several orders of magnitude. Depending on how a misspecified conservation planning study is used, there are different degrees of errors. Moderate errors occur if a conservation assessment with misspecified land rents is used only to predict the costs of conservation efforts. In this case, the realization of the conservation plan will result in higher costs or reduced areas. However, if a misspecified assessment is also used to determine the optimal locations for conservation areas, additional costs arise from inefficient reserve allocations.

A meaningful implemention of opportunity costs in reserve selection models requires reliable data on the price-elasticity of land. Also, the approach is easily applicable only when using exact algorithms but not iterative heuristics to solve reserve selection problems.

Considering the dynamic nature of costs seems particular important in cases where (i) land rents or prices are comparably high, (ii) high competition for land occurs, or (iii) a great fraction of land is to be reserved within a region.

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Figure 1: Spatial scope of empirical model application

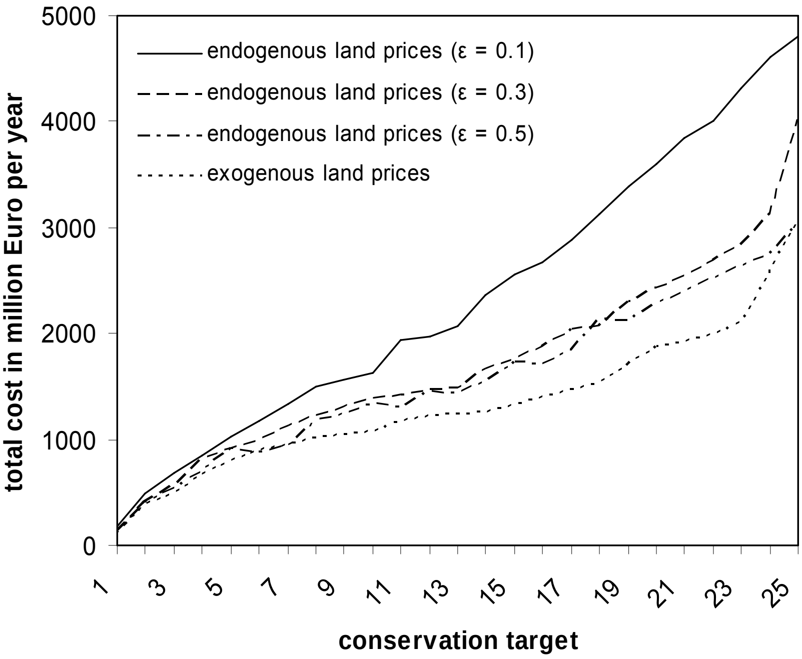

Figure 2: Total costs resulting from exogenous and endogenous cost representations

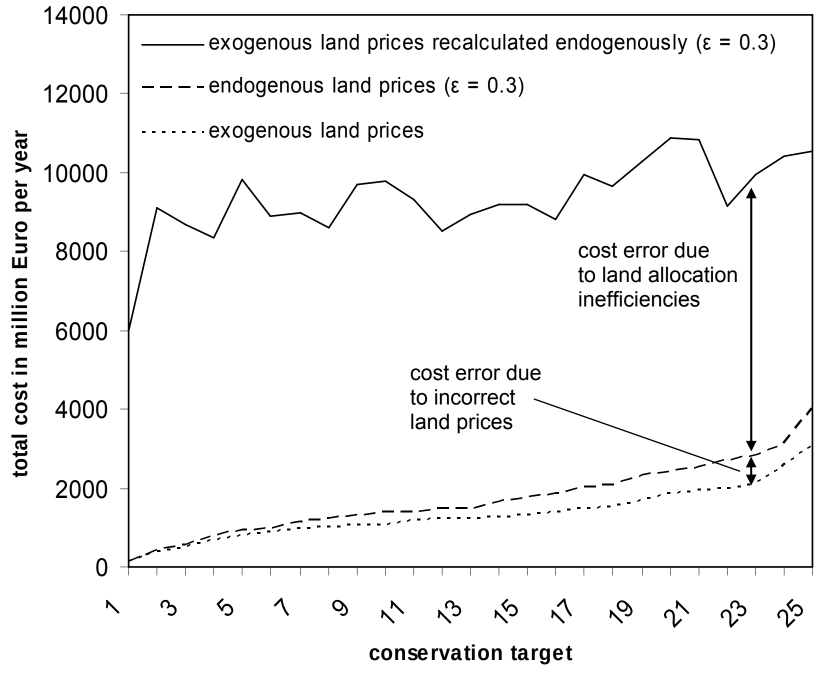

Figure 3: Cost errors related to exogenous land prices

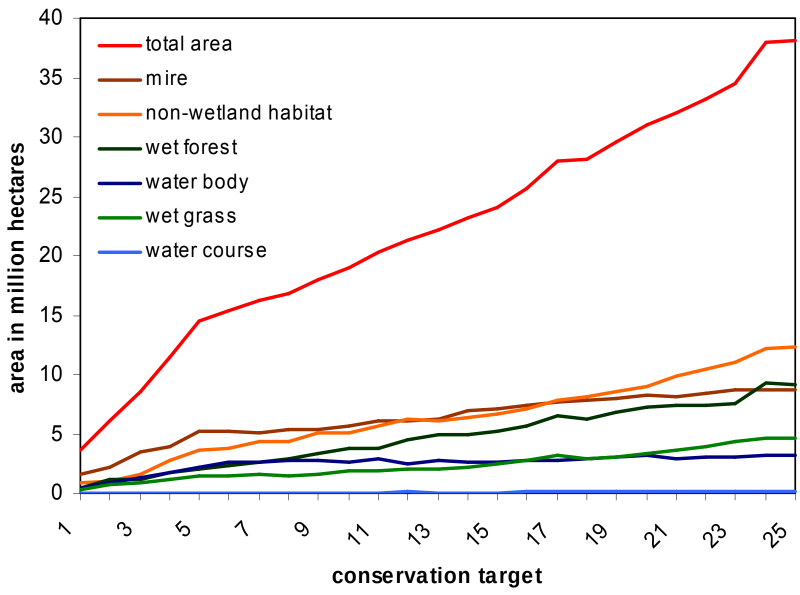

Figure 4: Exogenous land prices: allocation to wetland habitat types and total area requirement

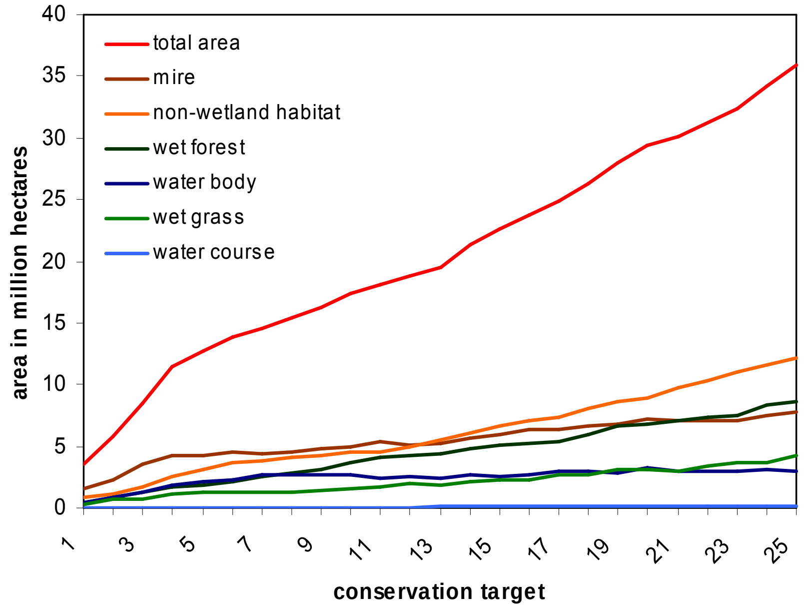

Figure 5: Endogenous land prices (ε=0.3): allocation to wetland habitat types and total area requirement

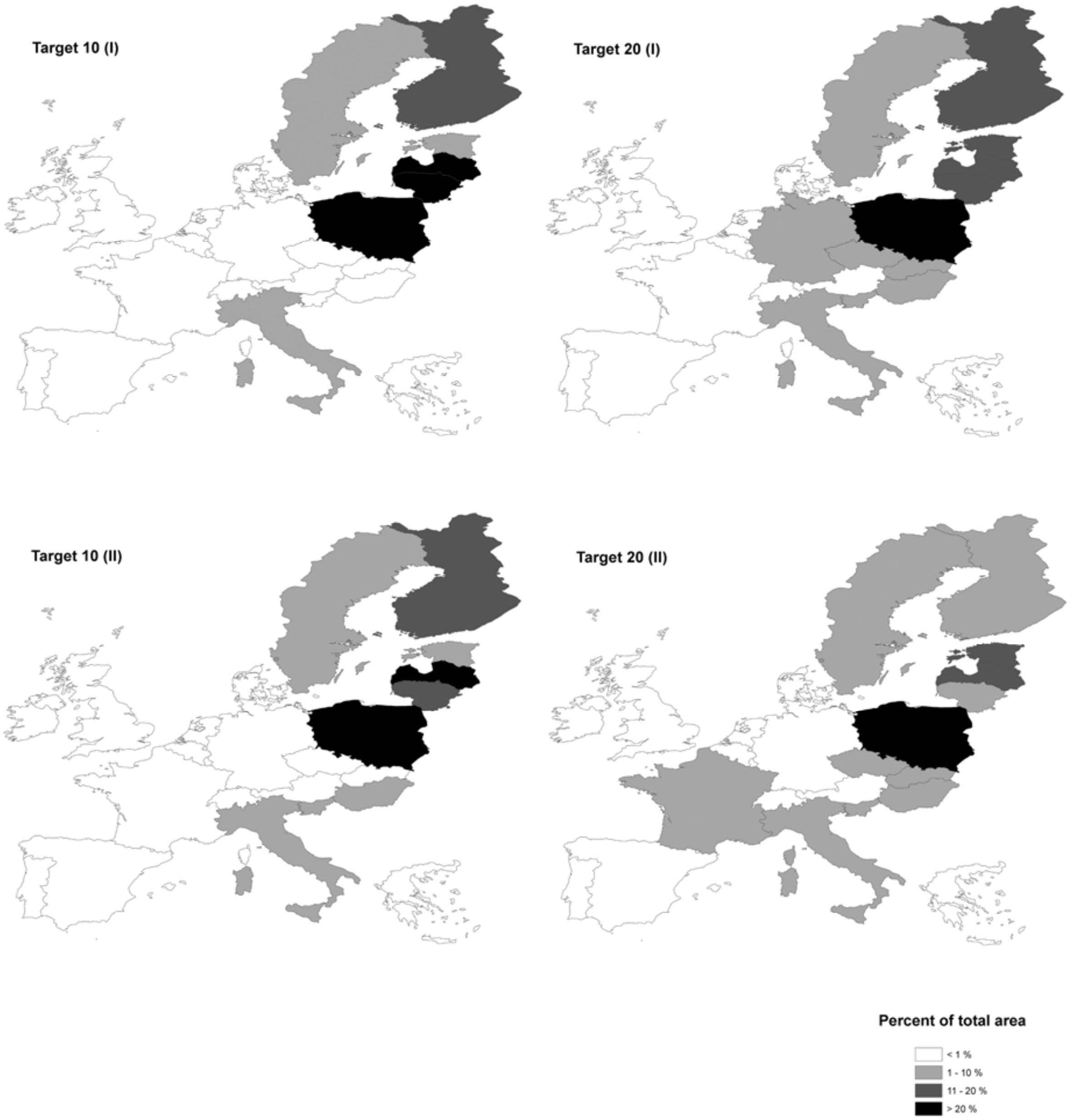

Figure 6: Regional allocation of total habitat area for exogenous (I) and endogenous (II) (ε=0.3) land prices and conservation targets 10 and 20

Table 1: Agricultural land area and rents for European countries

	Rent for agricultural land [€/ha*a]*	Agricultural land area [Mha]†	Total land area [Mha] †
Austria	244.53	3,240	8,245
Belgium	151.76	1,370	3,028
Czech Republic	23.17	4,249	7,725
Denmark	315.00	2,663	4,243
Estonia	15.76	823	4,239
Finland	152.08	2,295	30,409
France	109.35	29,418	54,766
Germany	156.32	16,950	34,877
Greece	402.98	8,280	12,890
Hungary	54.56	5,807	8,961
Ireland	212.76	4,276	6,889
Italy	248.42	13,888	29,414
Latvia	8.34	1,839	6,225
Lithuania	17.14	2,695	6,268
Luxembourg	150.38	131	259
Netherlands	396.01	1,914	3,376
Poland	68.08	16,177	30,425
Portugal	158.51	3,496	9,150
Slovakia	13.33	1,930	4,810
Slovenia	86.21	500	2,014
Spain	145.40	28,660	49,898
Sweden	98.12	3,136	41,033
United Kingdom	190.34	17,647	24,193
		171,384	**383,337**

* data derived from Eurostat (averaged data from 1985 to 2006 for Austria, Belgium, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Lithuania, Luxembourg, Netherlands, Poland, Slovakia, Spain, Sweden, United Kingdom) and Farm Accountancy Data Network (FADN) (data from 2004 for Czech Republic, Estonia, Italy, Latvia, Portugal, Slovenia)

† data taken from FAOSTAT (data from 2007)