A cost-efficient site-selection model for European wetland restoration

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1. Introduction

In this study, we concentrate on the area potentials to preserve, restore or create freshwater wetland ecosystems in the European Union in consideration of economic and bio-geophysical aspects. Expansion of settlements, agricultural areas and bioenergy plantations at the expense of wetlands and its corresponding fragmentation constitute a great challenge to nature conservation. Therefore, the understanding of how spatial patterns influence ecological processes at land use scale level as become an important factor in landscape management (EHRLICH 2007). Even though wetlands constitute valuable ecological resources, the number and size of wetlands in Europe has dramatically decreased over the last century. Main areas of wetland conversion include agriculture, forestry, peat extraction on fens and bogs, as well as urbanization and infrastructure measures (JOOSTEN & CLARKE 2002). Fens and floodplain forests have been opened up culturally since the early Middle Ages, but their major decrease has happened during the last few decades of the 20th century (RAMSAR COMMISSION), when private profit maximizing land use decisions resulted in drainage of wetlands and degradation. The diverse utilization demands lead to direct biotope loss and habitat fragmentation of the remaining wetlands in Europe. In spite of important progress made in recent decades, wetlands continue to be among the world's most threatened ecosystems, owing mainly to ongoing drainage, conversion, pollution, and over-exploitation of their resources.

Over the last decades concerns to the consequences of wetland degradation have been rising. Because the large-scale destruction of wetlands causes not only ecological damages but also negative economic externalities, as heavy floods in the vicinity of regulated rivers often illustrate. Subsequently, several conventions and directives and with them a range of natural conservation and restoration action have been adopted for the protection of wetlands (e.g. Natura 2000 sites, Water Framework Directive, Ramsar Convention). In this study, the term restoration includes an improvement in degraded wetlands as well as re-creation on sites where similar habitat formerly occurred and also wetland creation in areas where wetlands are established for the first time within historical time span (MORRIS ET AL. 2006). Restoration and conservation management are increasingly viewed as complementary activities with restoration often now forming an important element of conservation management (YOUNG 2000; HOBBS 2005). The reason is that the size and structure of existing reserves are often inadequate to provide certain biodiversity benefits. It is therefore necessary to acquire additional land with habitat value or restoration potential (MILLER 2007). Ecosystem restoration has therefore become a vital tool in the maintenance and restoration of resilience (MANNING 2007) even if wetland restoration effect is debated vehemently (cf. MORRIS ET AL. 2006; RATTI ET AL. 2001; ZEDLER & CALLAWAY 1999; ZEDLER ET AL. 2001; HOBBS 2007). However, wetland regulations should be designed to conserve an array of wetland functions, and not be limited to water quality, waterfowl habitat or recreation. They should simultaneously address all major functions, and connectivity of wetland, aquatic and terrestrial resources, and be comprehensive enough to protect both, individual wetlands and the overall integrity of landscapes in which wetlands occur (CALHOUN 2007).

The value of restored wetlands depends on its size, structure, and the surrounding landscape (MARTIN ET AL. 2006; MC INTYRE 2007). Values increase if protected areas are integrated into wider landscape uses and are connected to other areas of similar qualities. During the last years, the emphasis of conservation has shifted from protecting species to preservation of entire ecological systems or functional landscapes (WIENS 2007). Thus, efficient conservation policies must take the landscape context and function into consideration (HOBBS 2007, WESTPHAL ET AL. 2007), where humans are considered as part of the environment and not only as the underlying problem (LINDENMAYER & HOBBS 2007). Especially in Europe, their influence on the environment over many thousand centuries should not be neglected. Different abiotic, biotic and landscape specific cultural interactions and conditions have led to the characteristic spatial heterogeneity in Europe (HABER 1979). A strategic coordination is important to achieve greater benefits, such as by integrated networks of habitat (BENNETT & MACNALLY 2004). The most appropriate targets for restoration and the most cost-effective means of achieving clearly stated goals should be evaluated. This includes that the ecosystems would be able to interact with current surrounding landscapes as well as that the solution would be accepted by human societies (NILSSON ET AL. 2007). The key question of this study is therefore what pattern is most suitable to achieve an effective habitat network across the landscape for target ecosystems, in this case wetlands.

The aim of this study is to develop a decision support tool that uses spatially explicit land-use data to identify priority areas for wetland preservation considering both ecological linkages at the landscape level and full costs under different policy scenarios. To achieve this aim, we use a landscape approach to determine an EU-wide wetland network that 1) gives priority to the preservation of existing wetlands over restored wetlands, 2) includes the value of connectivity among these wetland systems and processes, 3) facilitates the ability of the wetlands and its surroundings to function as dynamic systems, 4) allows the biota of these ecosystems and landscapes to adapt to future environmental changes (HOCTOR ET AL. 2000), and 5) accounts direct and opportunity costs of preservation.

Protected areas cannot be sustained in isolation from the economic activities in and around them. Resources available for conservation management have always been limited. In this context is it essential that management actions are prioritized and directed towards explicitly stated goals and targets. Socio-economic considerations and temporal restrictions limit the realization of a chosen restoration goal for a certain wetland or parts thereof. One aim of this study is to incorporate costs into the spatial wetland site selection model to demonstrate the tradeoffs between obtaining higher levels of a conservation target and the increase in cost necessary to obtain it. It is relatively inexpensive to achieve moderate levels of conservation but often quite expensive to achieve maximum levels (ANDO ET AL. 1998; POLASKY ET AL. 2001; NAIDOO & ADAMOWICZ 2005). In the past, costs have not received adequate consideration in designs aimed at expanding reserve networks (NEWBURN ET AL. 2005). In reality, economic constraints impinge upon any landscape planning or design problem, and different assumptions about economic costs can result in markedly different solutions. For landscape restoration, the economic costs would include acquisition costs, management costs, transaction costs, and opportunity costs (NAIDOO ET AL. 2006; WESTPHAL ET AL. 2007). We use the European Forest and Agricultural Sector Optimization Model (EUFASOM) (SCHNEIDER ET AL. 2008) to compute the corresponding economic potential of wetlands, its effects on agricultural and forestry markets, and environmental impacts for different policy scenarios. EUFASOM is a partial equilibrium model of the European Agricultural and Forestry sector, which has been developed to analyse changing policies, technologies, resources, and markets (SCHNEIDER ET AL. 2008). The main purpose is to make possible consistent analysis of abatement cost curves for greenhouse gas emissions, and how changing policies, technologies and market conditions influence these costs. The model is scaled at EU country level but considers variation in natural conditions within countries. EUFASOM's objective function maximizes total agricultural and forestry sector surplus.

The methods and mechanisms by which wetland restoration sites could be identified differ (cf. BURNSIDE AT AL. 2002). Often habitat suitability models determine the required habitat content or context for single or multiple species and restore landscape accordingly (VILLARD

ET AL. 1999; PRESSEY ET AL. 1997; HAIGHT ET AL. 2004; WESTPHAL ET AL. 2007). The underlying methodology mainly relies 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; TREPEL & PALMERI 2002). Another approach to model site-selection is the construction of decision-modelling frameworks, as described for example in POSSINGHAM & SHEA (1999) and POSSINGHAM ET AL. (2001). Several site-selection studies utilise GIS to map the modelled geographic distribution of individual species (POWELL ET AL. 2005; BAYLISS ET AL. 2005, CHEFAOUI ET AL. 2005). However, all of these studies rely on the modelling of environmental envelopes of one or multiple selected species and not on whole differentiated ecosystems as represented in this study by wetlands. LONKHUYZEN ET AL. (2004) evaluated the suitability of potential wetland mitigation sites using GIS and TREPEL & PALMERI (2002) modelled the nitrogen retention of wetlands at landscape scale. They state that the success of wetland restoration is dependent on the site-selection to achieve specific restoration goals. The aim of the spatially explicit wetland site-selection model presented here is to allow a flexible modelling process that is able to accommodate these different and multiple planning goals simultaneously.

2. The wetland site-selection model – a methodological introduction

The wetland restoration site selection model is part of an integrated modelling system, which comprises three main components:

The first component is a spatially explicit GIS-based distribution model of Europe (SCHLEUPNER 2008) with a spatial resolution of 1 km² that uses several spatial data (Corine land Cover, European Soil Database, Bioclim, Worldclim, Gtopo30, and Potential Natural Vegetation) and its combination concerning specified wetland characteristics. It differentiates between existing wetlands and potential restoration sites. SWEDI currently distinguishes five wetland types.

The highly resolved wetland areas of the SWEDI model are upscaled to EU country levels and passed to the second component, the European Forest and Agricultural Sector Optimization Model (EUFASOM, SCHNEIDER ET AL. 2008). EUFASOM is used to estimate the economic wetland potential expressed in hectare wetland area per EU-country and wetland type. The model is a fully dynamic, partial equilibrium model with endogenous commodity prices. Possible land exchanges and competition between agriculture, forestry, bioenergy, and nature reserves are represented. EUFASOM can be subjected to different policy settings, technological progress assumptions, and environmental change scenarios.

The third component involves a GIS-based site-selection model, which downscales the country-based, scenario specific results from EUFASOM to a higher spatial resolution. In the following exposition, we focus only on the geo-ecological development of the site-selection model. Figure 1 gives an overview of the methodological structure.

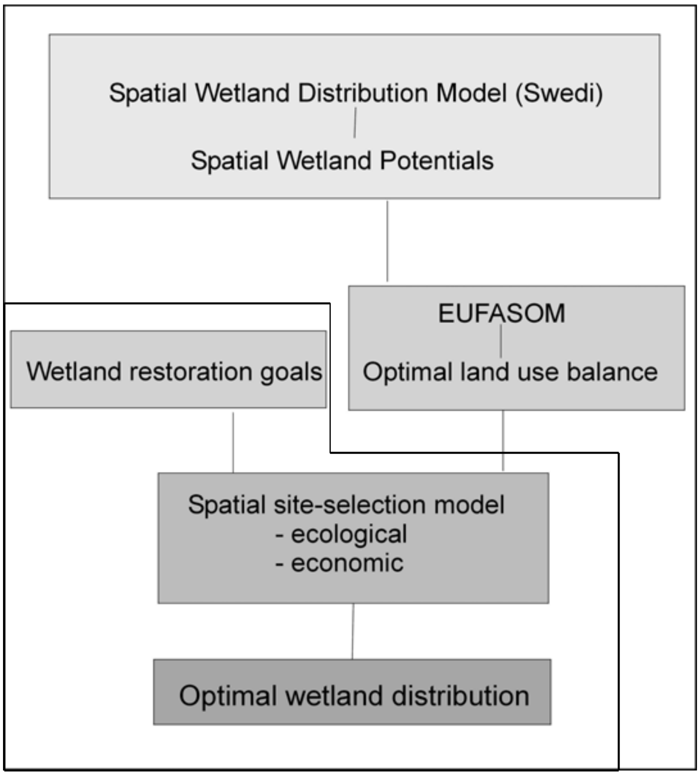

Fig 1 Overview of the methodology

The wetland location is often important in terms of ecological functions and values to people. These wetland functions and values do not only depend upon size, shape, type, and other characteristics of a wetland, but also upon proximity and connections with other waters, water quality, adjacent buffers, threats, and a broad range of other factors (KUSLER & KENTULA1990).

Site selection also depends on the specified goals. For the spatially explicit modelling of optimal wetland distribution it is necessary to formulate goals to identify and prioritise potential wetland restoration sites (KUSLER & KENTULA 1990, HOBBS 2007; SCOTT & TEAR 2007). These objectives may differ between regions, countries, or wetland types. The combination of several objectives or targets depending on its country and on the wetland type makes the formulation of a number of scenarios possible. The pre-defined potential goals may be applied separately as single objective but also combined in multiple objectives. In the following table (1), we define the potential ecological targets for the site-selection analysis as well as list its underlying evaluation methods that are explained below.

Table 1 Environmental goals and its evaluation methods

Restore the potential wetland sites that	**Evaluation method**	**abbr.**
lie within certain range to existing wetlands/conservation areas	spatial join	**DIST**
are directly attached to existing wetlands/open waters/rivers/lakes	spatial join	**Att**
build biotope complexes; improve connectivity among existing wetlands	proximity	**PX**
enlarge existing wetlands to a certain size	spatial join, area	**En**
are of certain size	area	**A**
are potential convertible to peatland/wetforest/wetgrassland sites	wetland type	**W**
lie on extensively used grassland/arable farmland/forest	land use	**LU**
are ranked after geophysical site-suitability	suitability assessment	**SUIT**
are prioritized after area quality	hemeroby assessment	**AQ**

Landscape metrics are the basis for the detection of each goal's spatial distribution. For each goal, a spatially distributed land attribute is calculated (TREPEL ET AL. 2000). Due to scale, these landscape attributes are more explanatory than patch-specific metrics. The analyses are conducted using *ArcGIS* as well as the analysis tools *V-late* and *Hawths Analysis Tools* (2006, TIEDE 2005, LANG & TIEDE, 2003). The wetland distribution of the SWEDI model is used as input parameter (SCHLEUPNER 2007). This model allows a detailed wetland type distinction in European scale for existing wetlands, but also for potential restoration sites. The other parameters used for the wetland site-selection assessment are extracted from CORINE Land Cover 2000 data (EEA 2000). In the following, the restoration goals are described in more detail:

a. Distance (DIST). Areas that lie within a certain range of existing wetlands or of conservation areas are detected by applying the spatial join function of ArcGIS and setting the match distance to the preferred range. The potential wetland restoration sites are in this case spatially joined with the existing wetland sites. All potential wetland restoration sites that fall - fully or partly - within this match distance are selected.

DIST = PCS *spatial join* (PEH *match distance* X) *b. Attachment (Att).* Wetland restoration sites that are directly attached to existing wetlands or open waters are evaluated by using the spatial join function as well (see a.). However, the match distance is set to a minimum of 10 m. 10 m are selected instead of 0 to allow for spatial or geometrically uncertainties in the SWEDI model.

Att = PCS *spatial join* (PEH *match distance* 10)

c. Proximity. The proximity index (PX) rates individual wetland patches according to its functional network with the surrounding wetland habitats (KIEL & ALBRECHT 2004). It analyses isolation or complexity of biotopes by distinguishing between space dispersal and clustered distribution of biotopes by considering the size as well as the distance of the patches (GUSTAFSON & PARKER 1992).

$$PX = \sum_{i=1}^{n} \frac{A_i}{d_i}$$

PX is calculated for patch *i* of a certain wetland class that is totally or partially situated within the defined proximity buffer. A_i is the patch size, and d_i is the nearest neighbor distance to a patch of the same class within the selected buffer.

The distribution of wetland sites of the SWEDI model serve as input for the PX evaluation and build the base of the subsequent PX scenario analyses of potential wetland restoration sites to allow comparability. The search radius is set to 2 km. To obtain reasonable results, the PX value needs to be transformed logarithmically (based on WEIS 2007). The PX decreases the smaller the area and/or the higher the distance to similar patches of land becomes. The value is highest if a patch is surrounded by and/or extending towards nearby biotopes of the same kind (LANG & BLASCHKE 2007). Table 2 shows the classification scheme of the PX for existing wetlands.

Table 2 Classification scheme

log (PX)	Description
-4.193 – -0.3497	small isolated wetlands that are not able to connect to other wetland systems
-0.3498 – 0.5905	spatially isolated wetlands of moderate size
0.5906 – 1.408	small to moderate wetlands with only moderate importance for connectivity
1.409 – 2.389	extending but spatially isolated wetlands or wetlands of any size that serve as important stepping stones between other wetlands
2.390 – 8.442	extending wetlands that build complexes with other wetlands

In a second step, the potential convertible sites were added to the existing wetland sites to repeat the PX evaluation under above described conditions. All wetland restoration sites with a PX above two thirds of the defined base PX of the existing wetland areas are assumed to reach the selected goal by building complexes.

d. Enlargement (En). Another goal is to enlarge the existing wetlands to a certain size. In this case the potential wetland restoration sites are selected through the attachment analysis (see b). Subsequently, the suitable areas of a defined minimum and maximum area of the combination of existing and selected convertible sites are evaluated by using SQL queries.

En = ((PCS spatial join PEH match distance 10) < x) AND ((PCS spatial join PEH match distance 10) > Y)

e. Size (A). The larger the habitat the less it is influenced by its surroundings and the higher is the probability for the establishment of viable populations (WULF 2001). For this reason, potential wetland restoration sites of a certain size may be selected. In this case, the desired minimum or maximum size of a potential wetland needs to be determined. With the help of SQL statements, the distributions of the potential wetland sites can be determined.

A = (PCS > X) AND (PCS <Y)

f. Wetland type (W). The Swedi model distinguishes five wetland types and six structures. Through SQL queries, the desired wetland types can be selected from the potential wetland restoration sites.

$W = W_{P,Wf,G}$

g. Land use (LU). Corine Land Cover data are used to identify the land use on the potential wetland restoration sites. The model is able to prioritize certain land use classes.

$LU = X_{LU}$

h. The suitability assessment. The wetland site suitability is assessed based on its potential restoration success and mainly dependent on ecological information. In addition, the surrounding land use, topography, and water quality can influence both technical and economical feasibility and hence the long-term success of a constructed wetland (PALMERI 2002). We use the wetland distribution of the SWEDI model (SCHLEUPNER 2007). The model assumes that the current land use on the potential wetland restoration sites and in its surroundings plays an important role in the restoration success. “Suitable” wetland restoration sites are further assessed with regard to its land use quality. The current land use at and around suitable sites is determined through Corine land cover 2000 data. Urban and other sealed off areas and their direct vicinity are assumed to be unsuitable for wetland restoration. All potential wetland restoration sites that fall within urban or other artificial areas including a 500 metre buffer are therefore extracted from the model. Furthermore, those sites that contain already existing conservation areas like salt marshes or valuable sparsely vegetated areas are also excluded as potential wetland restoration sites. Remaining potential restoration sites fall within agricultural areas and forests. Within these areas, wetland suitability is assessed by intersecting the potential wetland sites with extracted areas of potential wetland vegetation of the Potential Natural Vegetation map of Europe (BFN 2004). It is assumed that wetland restoration sites that match the potential natural wetland vegetation would be more easily restored than other sites which involve less conversion and management costs. Therefore, those potential wetland restoration sites that fall within the PNV wetland area are considered "suitable", whereas the remaining potential wetland restoration sites are considered "marginal". Figure 2 shows the distribution of suitable and marginal potential wetland restoration sites per country.

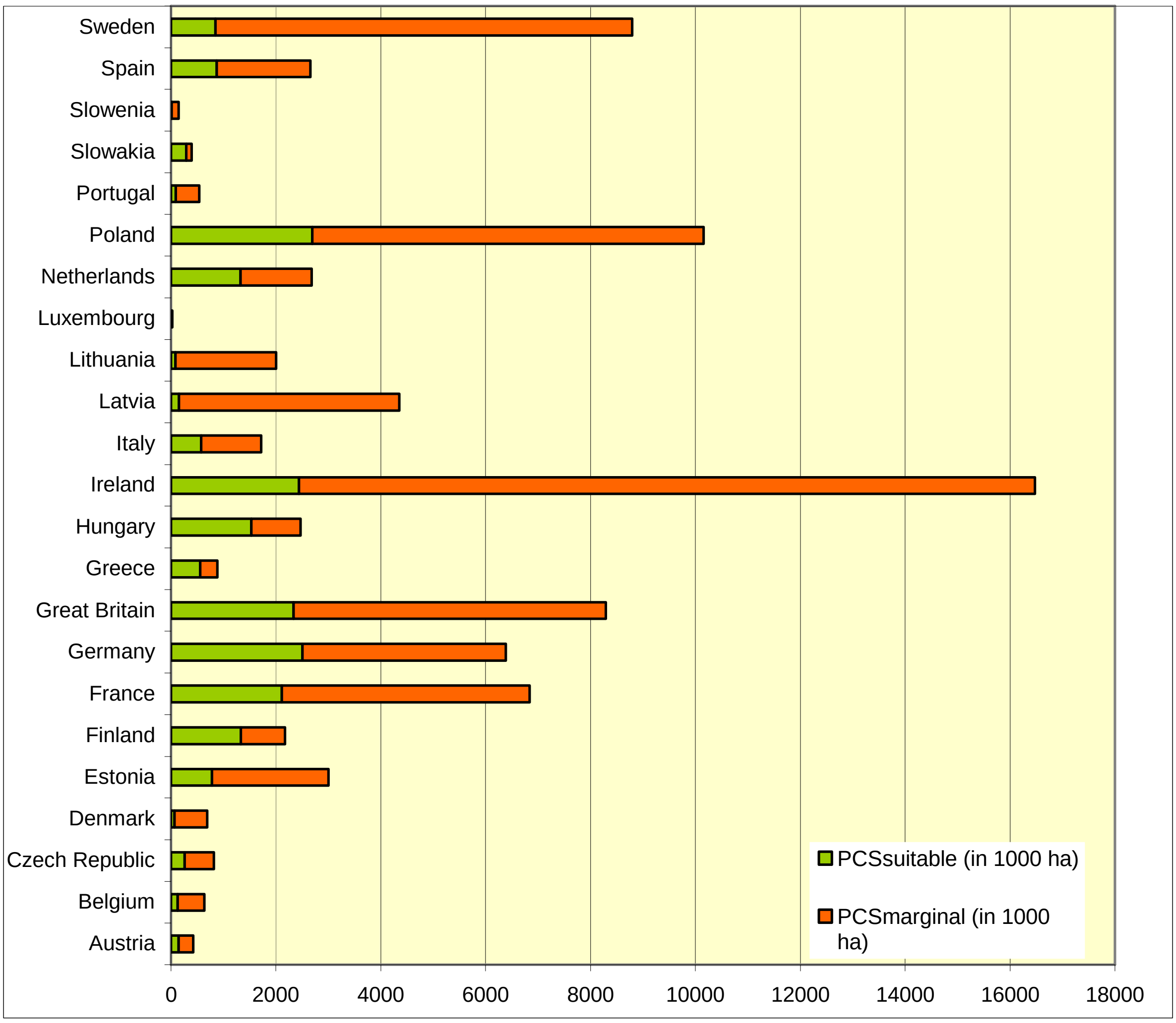

Fig 2 Results of the site-suitability assessment.

About two thirds of the potential sites for wetland restoration yield “marginal” sites. In Ireland, Greece, Hungary and Slovakia, “suitable” potential wetland sites dominate over the “marginal” sites. The Netherlands achieve nearly as many suitable sites as marginal ones. In comparison to the other EU-25 countries, France, Germany, Great Britain and Finland, as well as Poland have high amounts of “suitable” wetland restoration sites. As shown on the map in figure 8.6, the most suitable conversion sites are found within river valleys, next to open waters and other existing wetlands. In figure 6 in the appendix this distribution is illustrated in more detail through a map.

i. Area Quality. Neighbouring land use and the quality of the potential wetland restoration site can influence the long-term success of a constructed wetland. Therefore, the site-selection model considers the site quality as well as neighbourhood qualities of the surrounding areas of potential wetland restoration sites. Corine Land Cover data (EEA 2000) are assessed considering how close the respecting land use on potential restoration sites and their surroundings is to its original natural state, given the influence of anthropogenic cultivation present. This is expressed through the hemerobic index (*HI*). In general, the ranking follows the assessment by GLAWION (1999; see above). It is mainly based on vegetation but depends directly on human utilization intensity and pressure. The *HI* is closely connected to the biological regulation and regeneration capacity (SCHLÜTER 1987). The lower the *HI* is, the more limited is the regulation and regeneration potential of the biotope. This allows inferences about the ecological stability of assessed landscapes. The *Hawth’ analysis tools* (2006) are used to characterize the spatial context around the potential wetland sites within a 1 km neighbourhood (WESTPHAL ET AL. 2007). The area-relevant mean value of the *HI* including the *HI* of the potential wetland restoration site is determined for each patch (see also BASTIAN 1997; SCHLEUPNER & LINK 2007). It is expressed in six classes. Table 3 shows the classification scheme of the hemerobic index values of the potential wetland restoration sites and their application to Corine Land Cover data.

Potential wetland restoration sites are situated exclusively on sites with *HI* 2, 3, and 4. Figure 7 in the appendix illustrates the distribution of wetlands and their hemerobic ranking and gives an overview of the hemerobic classes applied to the EU-Corine land cover.

Table 3 Explanation of the hemerobie-index (*Hem class* after Glawion 1999, changed)

Hem class	**Corine Land Cover Classes**	**Describtion**	**HI**
I	open spaces with little or no vegetation wetlands water bodies	natural close to nature	1
II	forests shrub and/or herbaceous vegetation association	semi-natural	**2**
III	pastures heterogeneous agricultural areas	conditionally far off nature naturfern	**3**
IV	arable land, permanent crops	far off nature	**4**
V	mine, dump, and construction sites artificial non-agricultural vegetated areas	artificial	5
VI	urban fabric industrial, commercial and transport units	unnatural	6

Figure 7 shows that the largest areas for potential wetland restoration with the highest site qualities are found in Scandinavia, the west coast of Scotland, and the Baltic States. Fragmented sites are found in eastern Germany and Poland as well as in France and Hungary. Medium area qualities appear mainly along the North Sea states, in Ireland but also in the Baltic states. The low quality sites are scattered across entire Europe with the exception of Ireland.

The restoration goals described above are the basis for the spatial site-selection model. Out of these, specific algorithms are combined to integrative and complex statements as described below. Each raster cell of the SWEDI model that has been evaluated as potential wetland restoration site is attributed with the above stated goals. Consequently, one layer is produced for each restoration goal. Single or multiple goals determine the site-selection process. Single-goal selection makes no further analysis necessary, because the spatial model automatically chooses the selected attribute as “suitable” site. If the selected area of the restoration goals (S) exceeds the area determined by EUFASOM, the site-selection model chooses a sub area of the potential wetland restoration sites according to their quality. The area quality can also directly be applied for the site-selection equation. In this case, those sites with higher area quality are prioritised in the rank of its prioritisation goals.

Multiple goals depend on the analysis of logical connections between the layers using Boolean logic. The potential wetland restoration sites that are selected for each of the restoration goals receive a suitability value of “1”; the remaining wetland areas, which don’t fall into the categories, obtain a value of “0”. The site-selection model also integrates wetland sites of neighbouring countries into the analysis, to avoid adulterating results along the country borders.

For different search criteria, different potential site selection maps can be produced. These maps can be analysed through the summed irreplaceability algorithm (WESTPHAL ET AL. 2007) to identify those sites that are chosen more than randomly by the model in dependence of their EUFASOM wetland potentials. The summed irreplaceability *I* can be computed for each site *i* over all wetland restoration scenarios *r* as follows (after WESTPHAL ET AL. 2007):

$$I_i^{qr} = \frac{\sum_{i=1}^{r} S_i}{p_i^{qr}}$$

where *q* is the wetland potential based on EUFASOM and *p* is the probability that site *I* would be selected at random at a 95 % confidence interval. At normal distribution we assume an equal probability for each site to be chosen depending on the EUFASOM wetland potentials.

3. Results

We apply the EUFASOM scenario results shown in figure 3 to illustrate the wetland site selection. Wetland potentials are assessed simultaneously with and without European bioenergy targets (cf. SCHLEUPNER & SCHNEIDER 2008). The main assumption behind these scenarios is that the European Union has formulated bioenergy targets for the year 2020 that involve a 20% share of renewable energy in its total electricity consumption as well as a 10% bio-fuel share in its total fuel consumption. If the first target would be fulfilled through biomass based electricity, about 300 mio wet tons of biomass would have to be supplied. This would require significant impacts on land use. This is confirmed by EUFASOM scenario results which show that biomass production targets have substantial effects on wetland conservation and restoration potentials. As figure 8.3 illustrates, the wetland restoration area in scenarios without a biomass target, increases steadily for incentives up to 1000 Euro per hectare. On the other hand, a biomass target of 300 mio wet tons makes wetland restoration incentives below 1000 Euro per hectare ineffective. Only at very high incentives, some wetland becomes converted.

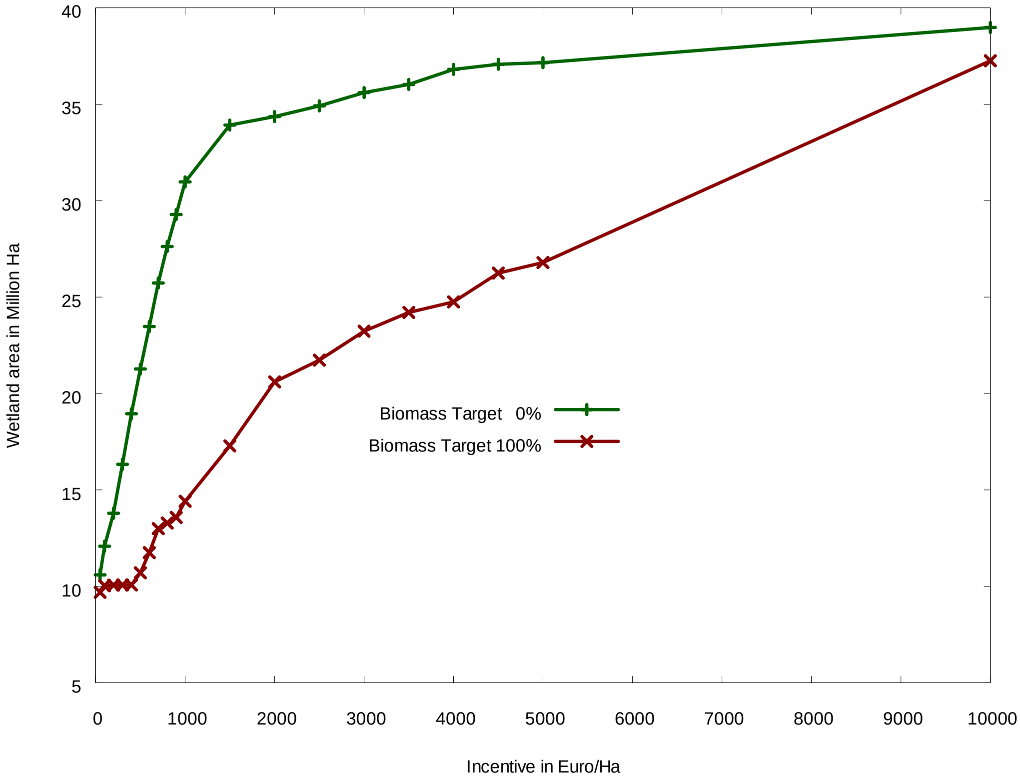

Fig 3 Wetland potentials with biomass target 100% and without biomass target.

The wetland potentials computed by EUFASOM scenarios give the optimal wetland area per EU-25 country for each given policy option. This area is then downscaled by optimising several restoration goals to find the most efficient sites to restore. The restoration goals are in this case ecological and geographical parameters determined through landscape metrics and spatial analyses as explained in chapter 2. In the following, we illustrate the downscaling of EUFASOM scenarios of figure 3 and their integration into two different multiple restoration goals in more detail by applying the model exemplarily to Germany. The multiple restoration goals are not static and always rely upon design and management objectives that might be regionally differentiated as well. In this example, we define the objectives as follows:

> *Select those sites that improve the connectivity among existing wetlands Prioritise areas that are directly attached to open waters. Of these, prefer "suitable" sites over "marginal sites".*

According to the restoration goals, the model chooses the three layers PX, Att, and SUIT and initially combines those using logical connections:

(SUIT) = 1 AND (Att) = 1 AND PX >= 1.4

The challenge is now not only to determine suitable wetland restoration sites in dependence of the restoration goals, but also to connect these with economic wetland potentials of the

EUFASOM scenarios. These determine the maximum area of potential wetland restoration per country. For this reason we need to extend the equation with a constraint for each scenario limiting the potential wetland area that varies:

WetlArea (type) (country X) <= Y (scenarioZ)

In case the resulting selection of potential wetland restoration sites exceeds the required maximum wetland potential, the site-selection model prioritizes the sites depending on its area quality (AQ) until the limit is reached. Because the PX changes with altered wetland areas for each individual wetland site, it is recomputed after each modelling step. If the selected wetland area remains below the maximum wetland limit, some criteria for certain parameters can be relaxed; in this case the PX value of 1.4 would be reduced until the wetland limit is reached. The results can be illustrated in dynamic maps depending on the wetland potentials of EUFASOM and restricted to the modelled wetlands of SWEDI. Figure 4 shows the results of our exemplary restoration goals for selected wetland potentials at incentives of 1000 and 3000 €/ha (see figure 3). In reality, these incentives are more than unrealistic but in this scale they make the differences of site-selection readily observable.

The four maps illustrate the differences in maximum wetland potentials and therefore also show the different distributions of selected wetland areas for restoration. The scenarios shown here assume protection of existing wetlands, so that the area of existing wetlands remains constant and only potential wetland restoration sites are allowed to change in area extent. In scenario A (Biomass target 100%, incentive 1000 €) no additional area is provided for wetland creation. The already very high incentive of 1000 €/ha is not sufficient to compete with the demands from biomass plantations. Without a biomass target the wetland area of Germany would at incentives of 1000 € per hectare even triple its extent to about 1.9 mio hectares. These wetlands are mainly distributed along river courses and in the low lying North Sea coastal region. In both scenarios, incentives of 3000 € per hectare result in a rise of wetland area. However, the wetland potential in scenario B (Biomass target 100%, incentive 3000 €) doubles in comparison to scenario A. It shows similar wetland selection as scenario C (no target, 1000 €) but only with less wetland area. Scenario D (no target, 3000 €) yields the highest wetland potentials of the four cases. According to the restoration goal to enhance connectivity, the potential wetland sites are distributed between other potential wetland restoration sites and consequently enlarge the biotope complexes.

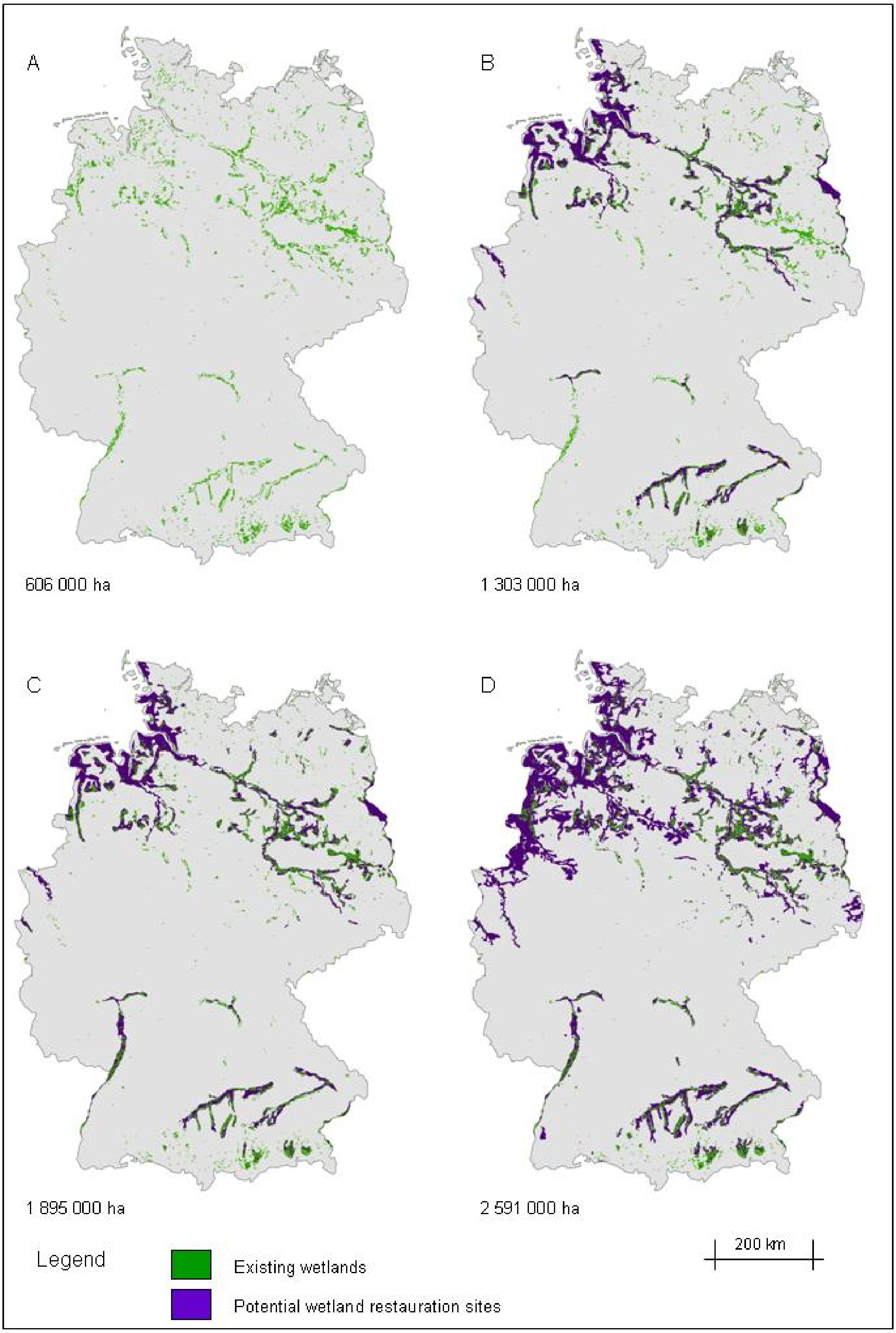

Fig 4 Exemplary wetland site selection for the defined restoration goals. A. 1000 € incentive with biomass target 100%, B. 3000 € incentive with biomass target 100%, C. incentive 1000 €/ha without biomass target, and D. 3000 € incentive without biomass target. Numbers indicate the respective maximum wetland potential including already existing wetland areas.

Via multiple combinations of restoration goals several different wetland site-selection scenarios can be obtained with each one showing unique wetland constellations also depending on the EUFASOM wetland potentials. These unique wetland solutions may be used to evaluate the summed irreplaceabilities after WESTPHAL ET AL. (2007). But whereas WESTPHAL ET AL. (2007) apply the irreplaceability algorithm for each scenario and budget size we utilize the summed irreplaceability equation to denote the number how often a site is selected in different scenarios depending on the same budget size after EUFASOM. This consistency is an expression of the priority or importance of the selected sites to be restored because it fulfils most of the restoration goals. Exemplarily we apply the summed irreplaceability algorithm to the wetland potential of 1 895 000 ha in Germany as given in scenario C in figure 4 (1000 € incentive without biomass target). Using the restoration goals, we construct 20 different site selection scenarios of wetland restoration. In figure 5 the summed irreplaceability is illustrated by a map.

The map visualizes priority sites for wetland restoration through summed irreplaceability analysis. The wetland restoration sites illustrated with red colour on the map are those sites that are chosen less often than the determined average probability. The potential wetland restoration sites with highest rates are found mainly in north-western Germany in river valleys of smaller water courses as the Aller or Leine rivers or the upper river course of the Ems. Other sites with high restoration priority are the river valleys of the Danube and Isar River in southern Germany, but also Elbe and Oder valleys in northern and eastern Germany. Weser and Ems river lower catchments areas show high selection rates as well.

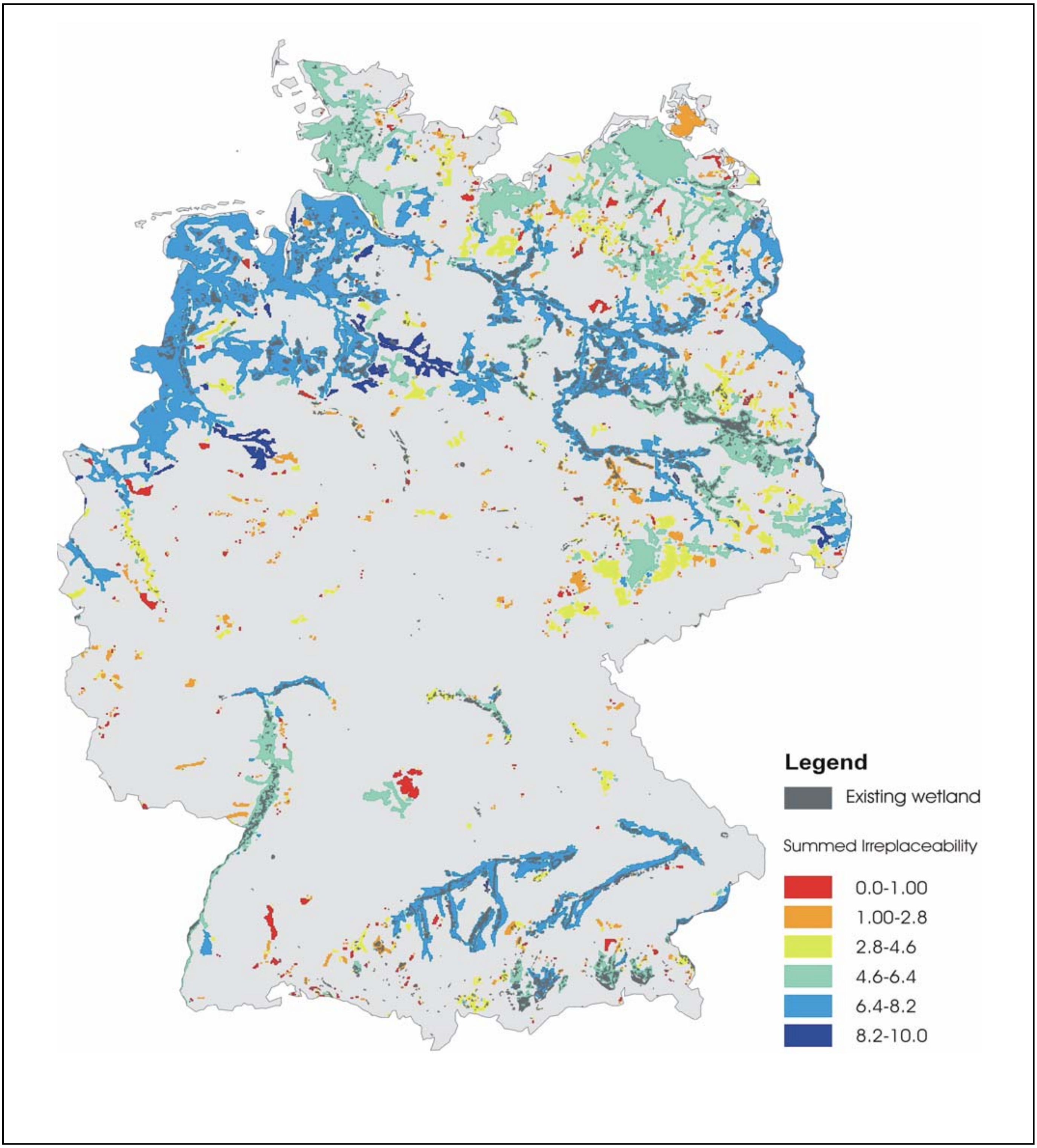

Fig 5 Summed irreplaceability of wetland restoration sites of Germany over 20 different scenarios.

4. Discussion and Conclusions

Loss of natural ecosystems due to increasing land demands for other purposes is a major threat to many species but also to the sustainable development of the landscape in which the loss occurs. In general, ecosystem degradation constitutes social costs. This leaves researchers, policymakers, and society with two important questions: i) what degree of preservation is desirable, i.e. socially optimal, and ii) which sites should be chosen for preservation? Conservation planning needs to be weighed against other environmental and societal objectives (SCOTT & TEAR 2007; WIENS 2007). Therefore, conservation planning at global, broad ecoregional scales can help to identify areas or regions in which the payoff for conservation efforts is likely to be greatest (WIENS 2007).

We focus our study on European freshwater wetlands to evaluate the regional potentials of wetland restoration. During the last century more than 60% on average - in some countries even more than 80% - of all European wetlands were drained and converted to other land uses and the loss still continues despite several European conservation efforts. We distinguish between three preservation options: First, existing habitats can be protected from destruction. Second, on suitable sites, habitats can be restored. Third, on both existing and restored habitats, ecological management can increase the suitability and carrying capacity for certain species. Each of these options incurs costs. These costs consist of i) direct costs, i.e. the costs of restoration, maintenance management, and protection, and ii) opportunity costs. Direct costs are low where little restoration and maintenance is necessary. Opportunity costs are low where alternative land uses yield small benefits. Through the integration of the spatial wetland distribution model SWEDI into the economic optimization model EUFASOM it is possible to obtain statements of potential wetland areas per EU-country depending on different policy scenarios. EUFASOM considers also the effects of wetland conservation and restoration on agricultural and forestry markets. The location of the wetland in the landscape strongly influences its function. Knowledge about interrelationships between the wetland and the surrounding landscape is important for the success of wetland restoration projects as well as for the protection of natural, presently undisturbed wetlands (DAVIDSSON ET AL. 2000). Existing wetland areas and wetland restoration sites need to be integrated into wider landscape uses and be connected to other areas of similar qualities. Connected sites improve the survival chances of species in response to disturbances and climate change. The *Natura 2000* network can play a role in achieving such integration (EEA 2004). This study makes a contribution towards these goals by considering the interaction of natural, engineering, economic and human sciences. The site selection model uses SWEDI data to downscale the results from the economic analysis by utilising landscape metrics that analyse combinations of wetland restoration goals. These targets build the basis variables for the wetland site selection model that uses land-use data and information on significant ecological functions to identify potential ecological linkages. Potential wetland restoration sites might be used as buffer zones between existing wetlands and intensively used areas, they might also be important for the creation of corridors, step stones, or connections to other valuable existing wetlands. As result we obtain a spatially realistic, GIS integrated model (cf. LAUSCH 2004) that shows varying potential convertible wetland sites in the order of their restoration goals and dependent on the EUFASOM scenarios. By using the methodology of summed irreplaceability, we are further able to identify areas of ecological wetland priority and to make statements about large scale wetland conservation targets. The results indicate that wetlands along waterways and with a certain minimum extent are prioritized over smaller and fragmented wetlands. This result highlights the meaning of water-systems for the interconnectedness of greater ecosystems. However, the analysis has been conducted at country scale and therefore the assessment of potential wetland restoration sites as non-priority sites does not make any inferences about their landscape value.

As WIENS (2007) concluded conservation planning at large scales can help to identify the most suitable sites for conservation efforts. However, nature conservation must also be detected at broader scales of land use policies, which has often been neglected. Therefore, this GIS model was developed to depict the optimal distribution of wetlands at coarse geographic scale. This involves integrating a variety of GIS datasets and multiple iterations of interpretation. Despite the great opportunities that large-scale site-selection models offer, one always has to deal with spatial uncertainties and data limitations. In general, it is necessary to know the origin of the inflowing water, flow paths in the landscape and the fate of the water leaving the wetland. Information about the catchments, geology, geomorphology, vegetation and land-use are also needed. But often the available data are very general at this level of scale if available at all. Therefore, this site-selection model is primarily meant to show possible solutions in certain scenarios, and not to yield particular locations for wetland restoration at small scale. Moreover, it certainly is another challenge to facilitate and realise the technical and site-specific options to restore wetlands on local scale than simply select areas for restoration as done in this study at European scale. The model is useful to locate areas suitable for restoration programs, for the introduction of faunistic corridors considering the *Natura 2000* network, and favouring success in regional conservation planning. Additionally, an associated study is going to integrate area requirements of selected wetland species into the model. The results also give an overview of vital planning information for more detailed regional studies.

The site-selection model is considered to be extended to a decision making tool for identifying areas within a landscape where multiple utilisation demands overlap in geographic space. In a next step also economic constraints and relationships are going to be included as well. This module is in progress but has not provided sufficient base data for introduction into the site-selection model yet. The current model version excludes socio-economic constraints apart from EUFASOM data in terms of spatially explicit costs in the analysis. In future, the spatially explicit wetland site-selection model presented here will consider not only the costs of wetland conservation and restoration but also its spatial variability (e.g. BALMFORD ET AL. 2003; NEWBURN ET AL. 2005). It aims to come to more realistic solutions in optimal reserve design with the help of constraints of economic reality. As the site selection maps show, the most suitable wetland restoration sites are mainly found within river valleys of great agricultural value. Therefore, it is expected that the integration of spatially explicit costs will have enormous impacts on wetland site-selection. The impact of climate change to wetland restoration is another topic that might be investigated after expanding the site-selection model. The site-selection model is an attempt to effectively reduce human threats and biodiversity losses in Europe. The integration of both optimal wetland conservation options and economic land use allocations within a GIS environment is an important step forward in interdisciplinary cooperation in terms of land use management and the formulation of environmental policies.

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6. Appendix

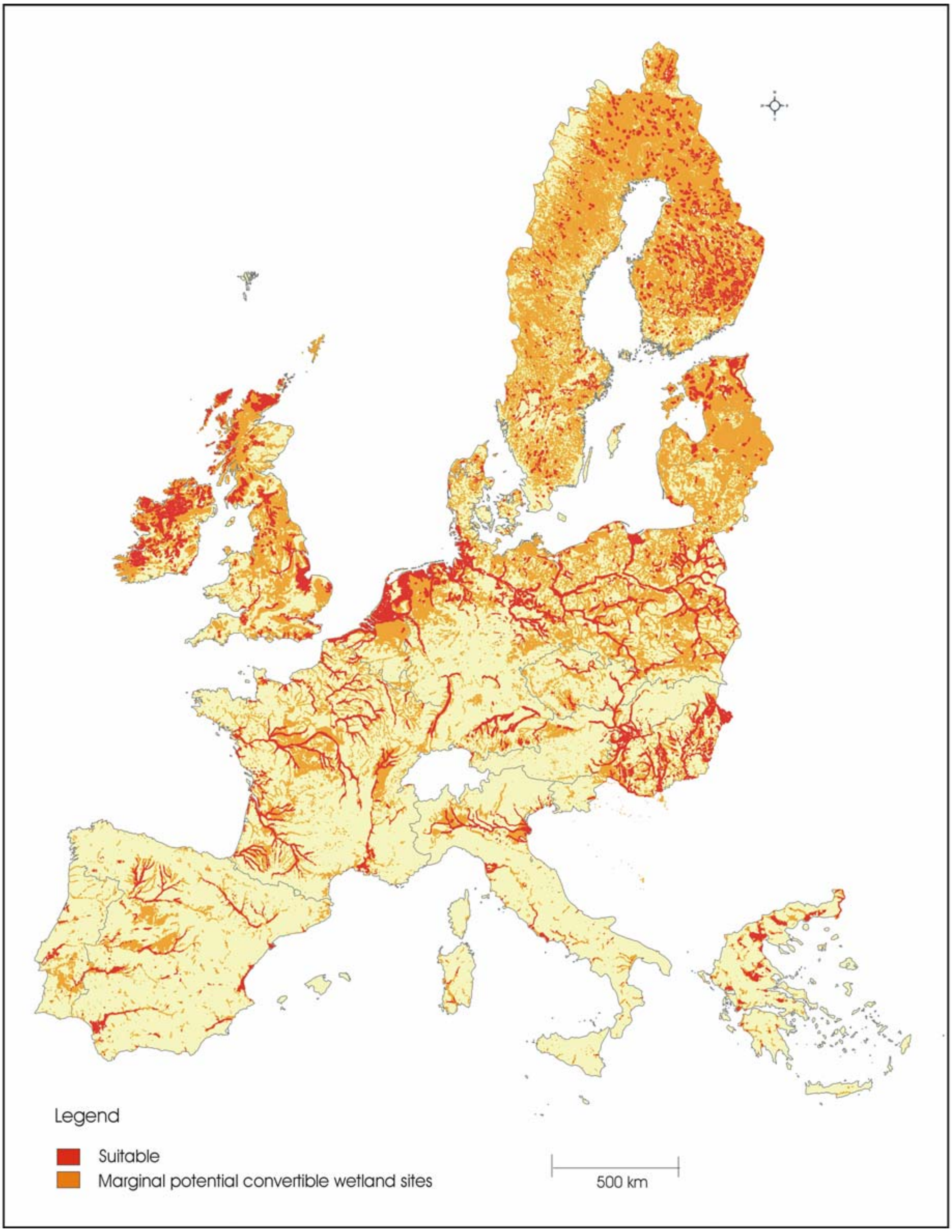

Fig. 8.6 wetland site suitability assessement of potential convertible sites**.**

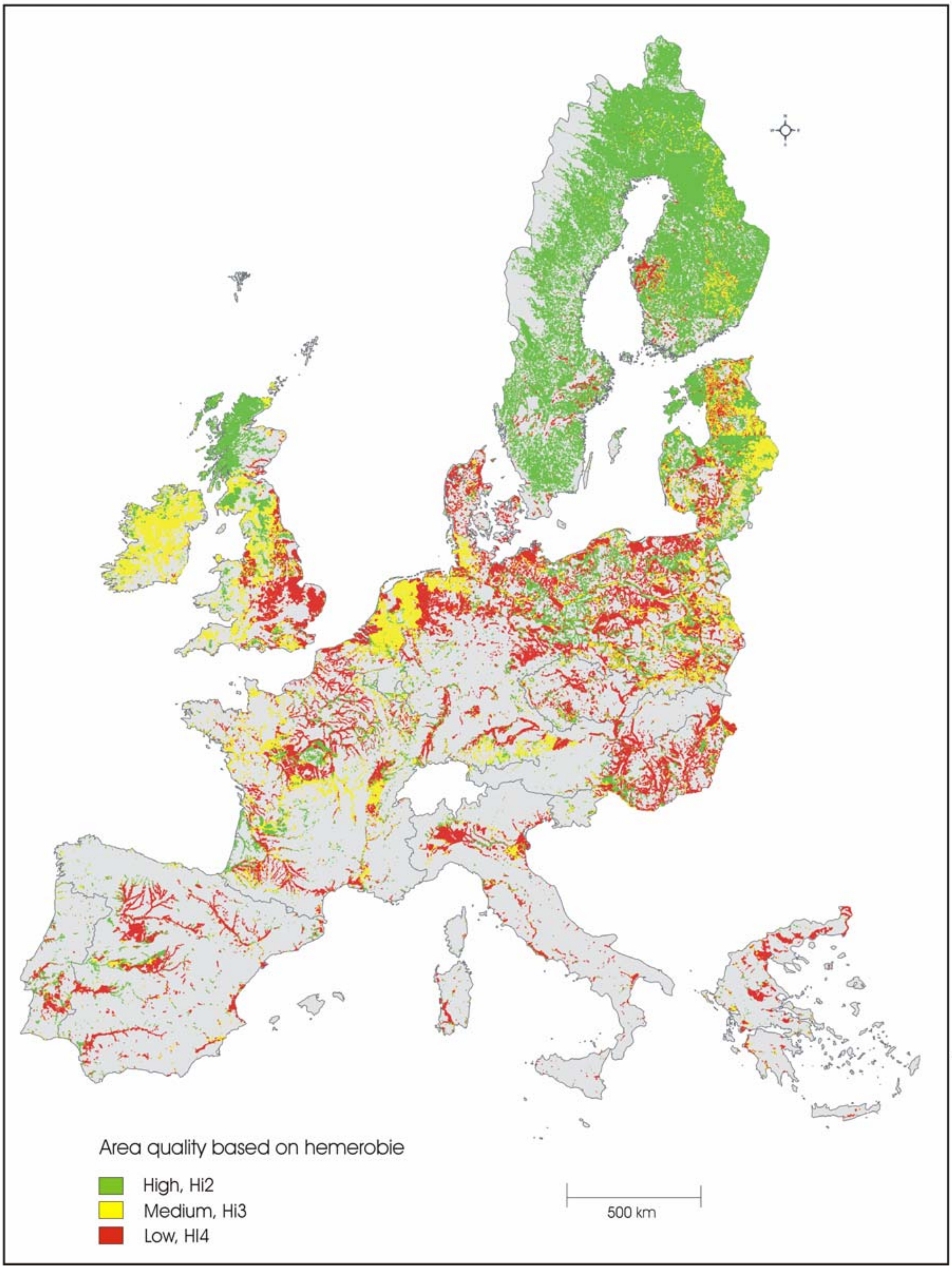

Fig. 8.7 Area quality of potential wetland restoration sites.