Multiple-species conservation planning for European wetlands with different degrees of coordination

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Abstract. Selection and establishment of reserves was often done unplanned and uncoordinated between regions. Systematic conservation planning provides tools to identify optimally located priority areas for conservation. Planning for multiple species promises adequate provision for the needs of a range of threatened species simultaneously. Several studies apply the set-covering problem by minimizing resources for given conservation targets of multiple species. We extend this method by also considering different degrees of coordination in multiple-species conservation planning and representing reserve sizes endogenously. A deterministic, spatially explicit programming model solved with mixed integer programming is used to represent minimum habitat area thresholds for all included biodiversity features. The empirical model application to European wetland species addresses five different scenarios of coordination in conservation planning, including taxonomic, political, and biogeographical coordination of planning. Our approach illustrates and quantifies the efficiency of multi-species conservation activities. We show that maximum coordination in conservation planning enhances area efficiency by 30% compared to no coordination. Furthermore, strong coordination in conservation planning does not only reduce the area requirement, but synergy effects even enable the conservation features to achieve higher conservation objectives. Spatial subdivision of planning, however, leads to highest area requirements and less conservation target achievement.

Keywords: systematic conservation planning, set-covering problem, representation, persistence, mixed integer programming, European environmental policies

1 Introduction

Protected areas are often established ad hoc without coordination between regions (Gonzales et al., 2003; Margules and Pressey, 2000; Pressey, 1994). In the European Union, the Natura 2000 network of protected areas currently covers about 17% of the total land area (European Commission, 2009). Hoekstra et al. (2005) identify the vast majority of the European continent's terrestrial area as crisis ecoregions with extensive habitat degradation and limited habitat protection. National governments in the European Union and the European Commission apply different strategies of conservation planning. There are protection plans for selected single species (Amstislavsky et al., 2008; Koffijberg and Schaffer, 2006; Tucakov et al., 2006), species groups (Goverse et al., 2006; Lovari, 2004; Papazoglou et al., 2004) as well as national conservation programs (Elliott and Udovc, 2005; Sepp et al., 1999; Vuorisalo and Laihonen, 2000). Transfrontier national parks covering characteristics of specific biogeographical regions are located for instance in mountainous regions (Oszlanyi et al., 2004; Williams et al., 2005b). Important pan-European initiatives (see Jones-Walters (2007) for a review on European ecological networks) are the Natura 2000 network based on the Birds and Habitats Directives (79/409/EEC; 92/43/EEC) and the Emerald's network based on the Bern convention (Council of Europe, 1979).

In light of increasing opportunity costs for land, questions on the efficiency of existing conservation strategies arise. The main question we address in this study is: How efficient in terms of area requirement are different strategies of coordination in conservation planning?

Systematic conservation planning (SCP) provides tools to identify priority areas for conservation (Margules and Pressey, 2000; Margules and Sarkar, 2007; Possingham et al., 2000). Formulated as minimization problem, SCP optimizes the allocation of conservation areas such that the total requirement of resources (typically, area or costs) under a given conservation target is minimized (McDonnell et al., 2002; Possingham et al., 2000; Williams et al., 2005a). Previous studies estimate the optimal arrangement of protected areas for exogenously given conservation targets (ReVelle et al., 2002; Saetersdal et al., 1993; Tognelli et al., 2008).

Several studies point out that the focus in reserve site selection lies on representation of biodiversity features whereas persistence is often inadequately addressed (Cabeza and Moilanen, 2001; Haight and Travis, 2008; Önal and Briers, 2005; Williams et al., 2005a). We extend the set-covering problem by: (i) combining representation and persistence requirements and (ii) representing the reserve sizes endogenously. As proposed by Marianov et al. (2008), we thereby account for species-specific habitat area needs to enable viable populations.

Whether setting definitive and measurable conservation targets is possible and reasonable has been discussed controversially (Soulé and Sanjayan, 1998; Tear et al., 2005; Wilhere, 2008). We do not determine a single representation target as sufficient for the long-term protection of the considered biodiversity features, but rather estimate a relationship between a relatively wide range of representation targets and their overall area requirement. There are three major reasons. First, we cannot endogenously determine the optimal conservation target because we do not estimate the benefits of conservation. Second, alternative target levels provide additional insight, which may help researchers and policymakers in finding the preferred conservation targets. Third, the costs of simulating additional targets are low and involve mainly computational costs. Justus et al. (2008) adopt a similar approach for representing biodiversity surrogates in five regions.

Multiple-species conservation planning has been discussed elaborately elsewhere (McCarthy et al., 2006; Moilanen et al., 2005; Nicholson and Possingham, 2006). However, most previous studies have neither explicitly examined different degrees of multiple-species conservation planning nor quantified the area reduction potential resulting from comprehensive coordination. First insights into efficiency gains from coordination in Europe give Strange et al. (2006) and Bladt et al. (2009). For North America, first studies on the impact of different spatial extents in planning provide Vazquez et al. (2008) and Pearce et al. (2008).

A deterministic, spatially explicit programming model solved with mixed integer programming is used to represent minimum habitat area thresholds for all included biodiversity features. Whether to prefer iterative heuristics or exact algorithms in reserve selection has been covered extensively (Pressey et al., 1996; Rosing et al., 2002; Vanderkam et al., 2007). In contrast to alternative methods, the chosen mixed integer programming with its branch-and-bound algorithm reveals at any time the quality of the solution with respect to a best possible integer solution. Our model quantifies area requirements for conservation under different assumptions of coordinated planning. We apply scenarios which mimic commonly used conservation strategies in Europe and globally. The analysis is done for European wetland species but is easily adaptable to other species, biodiversity features, or regions.

2 Methods

2.1 Integrating representation and persistence: the conservation target

Successful conservation requires consideration of both representation and persistence (Margules and Pressey, 2000; Sarkar et al., 2006). Each species in our model has to achieve exogenously assigned representation targets which can differ across species. The persistence criterion is subject to two conditions. First, each species' representation corresponds to one minimum viable population (MVP). A population is considered viable when the allocated land area equals smallest the minimum critical area (MCA) which is defined as follows:

MCA = density * MVP size for all species.

The species-specific measure of MCA depends on density data and proxies for MVP sizes. Density data can differ substantially depending on habitat quality (Foppen et al., 2000; Riley, 2002) or due to bias in sampling effort (Schwanghart et al., 2008). To account for that variability, we solve the model for different density data. We assume that species do not affect each others densities. Also, we do not explicitly portray competition between species. The second persistence condition requires that the land area that corresponds to a species' MCA is allocated to appropriate habitat types. We therefore classify the included habitat types species-specific as either necessary for its survival, as optional habitats, or as unsuitable.

2.2 *Planning units*

Our model is spatially explicit with planning units differing in shape and size. There are two possible states of each planning unit; it is either used as a species' reserve (1) or not (0). Status (1) is only achievable if a species was historically observed in a planning unit. The potential reserve areas are determined for each planning unit. However, using a planning unit for conservation does not necessarily allocate the entire planning unit's reserve area. Only those fractions of planning units are selected which are necessary to fulfill the respective conservation target. On the other hand, the potential reserve area within a single planning unit may not be sufficient for wide-ranging species. These species are therefore allowed to inhabit further habitat in adjacent planning units. This procedure allows easy implementation of planning units with varying sizes. Persistence criterions can be addressed regardless of the planning unit's size. We assume constant habitat suitability across all possible planning units.

2.3 *Mathematical optimization model*

The formal framework follows and expands the set-covering problem. We use the following notation: $p = \{1,\ldots,P\}$ is the set of planning units; $t = \{1,\ldots,T\}$ is the set of habitat types; $q = \{1,\ldots,Q\}$ is the set of different habitat qualities; and $s = \{1,\ldots,S\}$ is the set of species. In addition we employ several set mappings, which contain possible combinations between two or more indexes. In particular, $u(t,s)$ identifies the mapping between species and required or optional habitat types and $k(p,t,s)$ possible existence of species and habitats in each planning unit. The objective variable Z represents the total habitat area in hectares. The decision variable $Y_{p,t,q}$ determines the habitat area per planning unit p, habitat type t, and habitat quality q in hectares. $X_{p,s}$ is a binary variable with $X_{p,s} = 1$ indicating species s is protected in planning unit p, and $X_{p,s} = 0$ otherwise. $a_{p,t,q}$ is the maximum available area to be selected per planning unit p, habitat type t and habitat quality q. $d_{q,s}$ represents species- and habitat quality-specific density data. m_s is a species-specific proxy for MVP size. $h_{t,s}$ determines which habitat types t are required by species s. r_s is the representation target per species s. v_s specifies deviations from the representation target based on exogenous maximum occurrence calculations.

Minimize $Z = \sum_{p,t,q} Y_{p,t,q}$ (1)

subject to:

$Y_{p,t,q} \le a_{p,t,q}$ for all p,t,q (2)

$\sum_{t,q} d_{q,s} \cdot Y_{p,t,q} \big|_{k(p,t,s) \wedge u(t,s)} \ge m_s \cdot X_{p,s}$ for all p,s (3)

$\sum_{q} Y_{p,t,q} \ge h_{t,s} \cdot X_{p,s}$ for all p,t,s (4)

$\sum_{p} X_{p,s} \ge r_s - v_s$ for all s (5)

$\sum_{p,t,q} d_{q,s} \cdot Y_{p,t,q} \big|_{k(p,t,s)} \ge r_s \cdot m_s$ for all s. (6)

The objective function (1) minimizes the total habitat area across planning units, habitat types, and site qualities. Constraint (2) limits habitat areas in each planning unit to given endowments. Constraint (3) ensures that the habitat area for the conservation of a particular species is large enough to support viable populations of that species. The constraint 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 (4) forces the existence of required habitat types for all species which are chosen in a particular planning unit. Constraint (5) implements the representation targets for all species. This constraint allows deviations from the target if the number of planning units with occurrence data is below the representation target. Constraint (6) ensures that the total population size equals at least the representation target times the MVP 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 (6) require at least one planning unit to establish enough habitat for two viable populations.

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

3 Biodiversity conservation on European wetlands

Freshwater wetlands are of outstanding importance for biodiversity conservation (Bobbink et al., 2006; Mitsch and Gosselink, 1993; Schweiger et al., 2002). They also play prominent roles in carbon storage (Belyea and Malmer, 2004; Zhou et al., 2007) and provision of water-related ecosystem services (Brauman et al., 2007). However, wetlands are severely threatened by human disturbances

(Bobbink et al., 2006; Bronmark and Hansson, 2002). Recognizing their significance for conservation and related environmental objectives, we apply our model to freshwater wetlands.

3.1 Data

Freshwater wetland dependent species serve as surrogates for biodiversity. We consider 70 tetrapod wetland species which appear in the appendices of the Birds and the Habitats Directive (79/409/EEC; 92/43/EEC). The species assemblage includes 16 amphibian, 4 reptile, 41 breeding bird, and 9 mammal species. Recorded occurrences identify their European distribution. These data originate from the Atlas of Amphibians and Reptiles in Europe (Gasc et al., 1997), the EBCC Atlas of European Breeding Birds (Hagemeijer and Blair, 1997), and the Atlas of European Mammals (Mitchell-Jones et al., 1999).

Density data for all 70 species are equal to the maximum observed densities from a comprehensive literature review. In addition, we use the proposed standards for minimum population sizes from Verboom et al. (2001) as proxies for MVP size. These population sizes depend on species' body sizes and life expectancy. One MVP in our model represents 120 reproductive units of long lived or large vertebrates and 200 reproductive units of other vertebrates. Reproductive units correspond to pairs, territories, or families of a species.

Five broad wetland habitat types appear in our dataset, namely mire, wet forest, wet grassland, water course, and water body. "Open water" as a sixth type is assigned to species that either require water courses or water bodies. Information on species' habitat type requirements are also taken from the literature. We distinguish required and optional habitat types. See Appendix A for the ecological data of the 70 wetland species

The dataset covers 25 out of 27 European Union member states (see Figure I-1). Cyprus is excluded from the analysis due to the lack of comprehensive atlas data of all species; Malta is eliminated as none of the considered species have records in the used data sources. Furthermore, the Macaronesian islands are excluded due to general lack of data.

The resolution of the planning units is consistent with that of the species occurrence data. The Universal Transverse Mercator (UTM) projection results in grid squares of about 50 km edge length. The terrestrial parts of all 2235 grid cells belonging to the selected European countries serve as planning units. In this model version we allow the allocation of the entire unsealed land area in each planning unit to the five relevant habitat types. As we restrict habitat establishment to those planning units where a species was observed historically, we implicitly integrate the necessary natural conditions for the existence of these habitats.

Figure I-1: Spatial scope of empirical model application. The scope includes 25 of 27 European Union member states. Malta, Cyprus, and Macaronesia are excluded due to lack of biodiversity data.

3.2 Conservation planning scenarios

We define coordination of conservation planning as solving the set-covering problem simultaneously for different species. Five broad categories of coordination are distinguished which contain one or more independent planning entities. Within each entity, the model minimizes the habitat area requirements of all associated species jointly.

There are two reference scenarios delineating the lower and upper boundaries of possible solutions for scenarios without spatial segregation of planning within the European Union. The most uncoordinated scenario assumes that preservation of each of the considered 70 species is planned independently. Hereafter, we refer to this scenario as **no coordination in conservation planning**. The other extreme scenario involves the case of **maximum coordination in conservation planning**. This ideal scenario represents the maximum possible simultaneous conservation for our model. We assume completely coordinated planning for all included wetland species.

Furthermore, we analyze three intermediate scenarios to simulate the impacts of political, biogeographical, and taxonomic coordination limits. Political and biogeographical region based coordination implies dividing the European Union into sub-units. In the first scenario, we apply **coordinated conservation planning within countries**. Each European member state jointly protects all species which occur in large parts on its territory (see Appendix B); thus we have a political division of planning. However, there is no coordination between countries. The second intermediate scenario examines **coordinated conservation planning within biogeographical regions**. There are seven biogeographical units in the European Union which include the Alpine, Atlantic, Black Sea, Boreal, Continental, Mediterranean, and Pannonian region (see Appendix C). Finally, the third intermediate scenario coordinates conservation planning only within tetrapod classes. We consider the four taxon groups amphibians, reptiles, birds, and mammals as entities for each of which independent plans are developed. Hereafter, we refer to this scenario as **coordinated conservation planning within taxonomic groups**. For no coordination across species or coordination within taxonomic groups, we use a special algorithm to make the individually obtained solutions compatible. In particular, we first determine the order in which protection plans for the different species or taxonomic groups are established. To guarantee that the individual solutions can be combined without violating land endowments, we require that the allocated habitat areas under each established protection plan remain fixed for all subsequent plans.

4 Results

The habitat allocation model minimizes the total area of protected habitats for different conservation targets. Figure I-2 shows the total wetland area requirements and the optimal allocation of reserves to alternative wetland types under maximum coordination in conservation planning across 70 species. The area is shown in million hectares for conservation targets ranging between 1 and 20 population representations. The optimal share of habitat types varies between different targets. The highest amount of land is allocated to water bodies and wet grasslands for most displayed targets.

Figure I-3 compares the total area requirements of all five conservation planning scenarios. Spatial subdivision of the planning scope into countries or biogeographical regions implies highest area requirements. However, coordinated planning within biogeographical regions falls behind for the upper displayed targets. Maximum coordination results in the lowest area requirement throughout the targets. This scenario saves on average 42 percent relative to the most area-intensive one and 25 percent relative to the scenario without any coordination. Note that we show mean values from five model runs for the scenario without coordination.

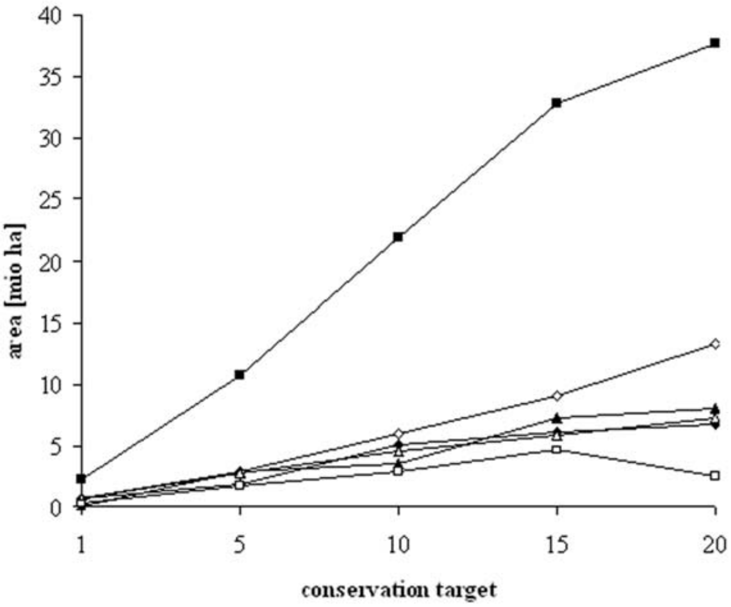

Figure I-2: Maximum coordination in conservation planning: allocation to wetland habitat types and total area requirement. The upper curve shows the minimum total area in million hectares needed to ensure the conservation targets 1 to 20. The lower curves display the shares of the five included wetland habitat types which add up to the total required area. The habitat types comprise water bodies (open diamonds), wet grasslands (solid triangles), water courses (solid diamonds), mires (open triangles), and wet forests (open squares).

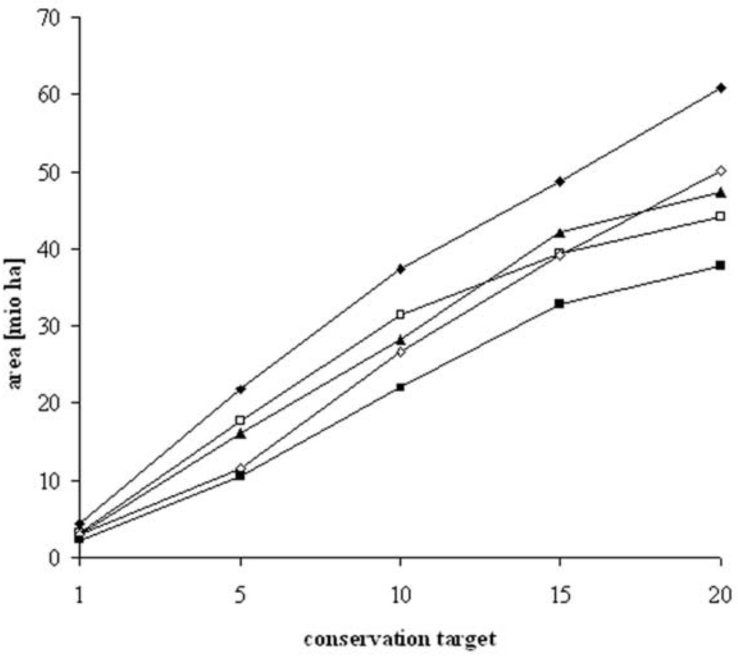

Figure I-3: Total area requirements for five scenarios of coordinated conservation planning. Shown is the wetland reserve area in million hectares that is required to represent 1 to 20 viable populations of the 70 included species in Europe. The curves indicate area requirements for the five scenarios of coordinated planning within countries (solid diamonds), coordinated planning within biogeographical regions (open squares), no coordination (solid triangles), coordinated planning within taxonomic groups (open diamonds), and maximum coordination (solid squares).

Table I-1 displays major results for the conservation targets 1, 10, and 20. The three spatially all-embracing conservation strategies – no coordination, maximum coordination, and coordination within taxonomic groups – are more area-efficient as they cover more species on less habitat area throughout the targets. However, the scenarios no coordination and coordination within taxonomic groups still fall far short behind the performance of the maximum coordination scenario.

Table I-1: Key results of scenarios of coordination. Shown are the numbers of planning units (P=2235) in which reserve area is allocated, average and maximum numbers of species that these planning units contain, as well as the total allocated area for selected conservation targets.

Scope of Coordination in Conservation Planning		Countries			Biogeographical Regions			No Coordination			Taxonomic Groups			Maximum Coordination		
Conservation Target		1	10	20	1	10	20	1	10	20	1	10	20	1	10	20
Selected Planning Units		46	329	602	40	292	504	86	335	524	55	292	499	25	215	346
Covered Species per Planning Unit	Average	1.8	2.2	2.2	2.5	2.5	2.6	3.6	3.5	3.5	2.4	3.5	3.6	3.8	4.0	4.4
	Maximum	9	10	11	12	13	20	18	21	23	14	20	21	23	23	23
Total Area (mio ha)		4.4	37.4	60.8	3.2	31.4	44.1	3.1	28.2	47.2	3.1	26.6	50.1	2.3	21.9	37.7

Target achievement differs substantially between the scenarios with and without spatial segregation (Table I-2). The higher the conservation target in the country- and biogeographical region-scenario, the fewer species are able to fulfill it. Also, only few species exceed the target. Target achievement does not differ remarkably between the three spatially all-embracing scenarios. The majority of species is represented according to the respective target. About one third of all species exceeds the conservation target by a factor of 2 or higher. Figure 4 shows the spatial distribution of selected planning units for all five scenarios exemplarily for conservation target 10.

Table I-2: Performance of scenarios in conservation target achievement. Shown are the numbers of species (S=70) that underachieve, fulfill, or exceed selected conservation targets. Note that target underachievements occur when species' area requirements for viable populations cannot be fulfilled according to the required target.

Scope of Coordination in Conservation Planning		Countries			Biogeographical Regions			No Coordination			Taxonomic Groups			Maximum Coordination		
Conservation Target		1	10	20	1	10	20	1	10	20	1	10	20	1	10	20
Number of species below, at, and above the specified target	< 100%		4	10		3	9									
	100%	**63**	**48**	**41**	**53**	**51**	**47**	**46**	**45**	**49**	**50**	**41**	**47**	**54**	**50**	**47**
	≤ 200%	4	15	17	11	14	13	5	11	13	8	20	18	10	16	19
	≤ 300%	2	3	2	3	1	1	4	5	4	6	5	1	3	2	2
	> 300%	1			3	1		15	9	4	6	4	4	2	2	2

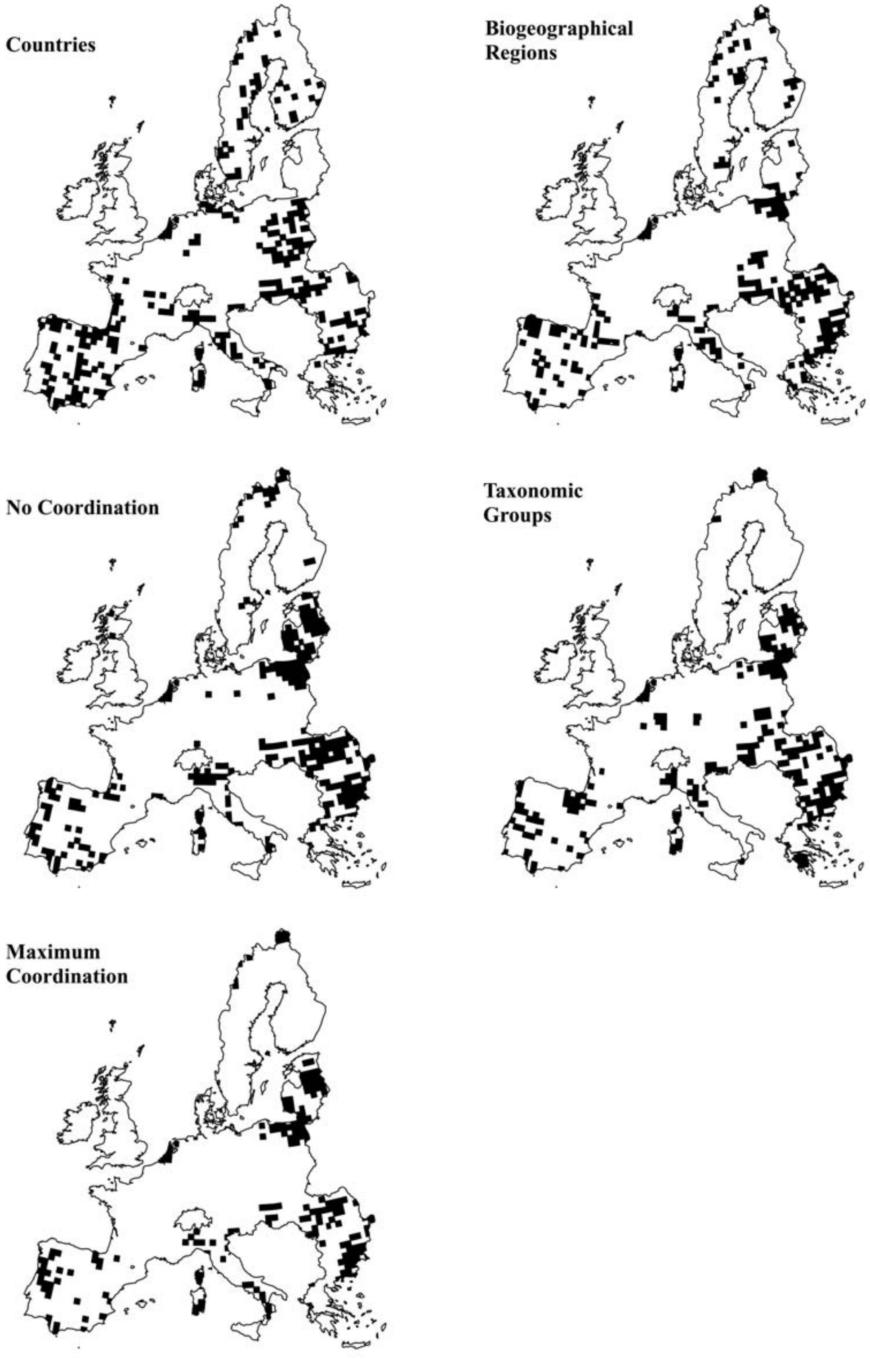

Figure I-4: Spatial distribution of selected planning units for conservation target 10. Shown are the planning units in which habitat area is to be established under the different assumptions of coordinated planning. The allocated habitat area per planning unit ranges between 10 ha and 250.000 ha.

5 Discussions and conclusions

5.1 Efficiency of multiple-species conservation planning: conservation implications

Our analysis measures the area efficiency of simultaneous conservation planning. The magnitude of our results confirms that conservation planning should be coordinated at the largest possible spatial scale of an ecozone. These findings are in accordance with results of a study by Bladt et al. (2009) analyzing coordinated conservation efforts at a European scale. However, full coordination requires a high degree of collaboration between many organizations from different countries and incurs transaction costs. These costs are not included in our study. On the other hand, there may be economies of scale by avoiding the parallel development and maintenance of a large number of protection plans. Our simulations show that even small degrees of coordination can lead to substantial synergies. A study by Strange et al. (2006), comparing national and regional conservation strategies in Denmark, supports this conclusion also with respect to cost-efficiency. An additional advantage of joint conservation effort is according to our study that a lot of species are represented several times more than the respective conservation target enforces. The spatial scope of coordinated planning can greatly affect location and size of priority areas for conservation. These results agree with findings by Vazquez et al. (2008) who did a similar analysis in North America. EU-national coordination does not only yield the fewest target achievements but also requires the largest habitat area for the majority of conservation targets. Note that this argument is not to question the national responsibilities for species protection (see Schmeller et al. (2008) for a review). Still, according to our results, options for cooperation beyond the borders of countries should be exploited whenever these countries belong to the same ecozone. The same argumentation holds for conservation planning across different biogeographical regions.

The relatively simple case study quantifies possible advantages from multiple-species conservation planning in terms of area requirements. Reality in conservation planning is undoubtedly more complex. An application of SCP for actual policymaking requires great care in ensuring adequate representation of each species' specific needs. Constraints should be added to the SCP model to keep valuable existing reserves in place. Encouraging to imprudently lump together basically different species is not purpose of this study as such proceeding will most likely not favor conservation success. Also, in certain circumstances coordination in planning may not be the best option for action. In particular cases, e.g. when species are directly faced with extinction, urgent action is indispensable. Hence, time lags until reserve establishment associated with comprehensive planning would discourage coordination efforts in such cases. Highly coordinated conservation planning seems particular suitable in cases where on large spatial extent new reserve systems are to be established or current systems are to be enlarged.

5.2 Limitations in conservation planning

Applying SCP usually involves several simplifications. First, species are taken as surrogates for biodiversity. This may lead to non-optimal conservation decisions (Margules and Pressey, 2000; Rodrigues and Brooks, 2007). The necessity to include occurrence data as basic input parameter into reserve selection models leads to bias towards well-surveyed species such as vertebrates (Hazen and Harris, 2007; Kerley et al., 2003; Polasky et al., 2001). We furthermore assume that species do not influence each others' population densities, and treat each colonized planning unit as equally appropriate for a species.

In addition to these general shortcomings, two further simplifications were made. First, we do not directly account for spatial reserve design criterions such as connectivity or compactness in our model. This is especially critical for species with low dispersal abilities such as amphibians and reptiles. Polasky et al. (2008) show an approach to explicitly consider species-specific dispersal abilities within reserve selection models. Even so, simultaneous planning implicitly results in compact reserves. Also, the spatial configuration of potential reserves is of utmost importance mainly in the concrete delineation of habitats to be protected. Accurate matching of species and reserves (Araujo, 2004; Araujo et al., 2005) has to be considered carefully when downscaling our results, e.g. to propose an improved network of reserve areas. Ongoing work, however, is addressing this issue so that it may be possible to be more inclusive in the future (e.g., Schleupner and Schneider, 2008).
Second, we do not include existing wetland habitats but rather allowed the model to allocate the entire land area to the wetland habitat types which can lead to unrealistic high wetland fractions. However, preliminary simulations with geographically estimated wetland data (Schleupner, 2007) indicate that the range of results does not change markedly.

The importance of area-efficient conservation increases with the value of land. These values are heterogeneous and minimization of area requirements for reservation does not guarantee minimization of costs (Balmford et al., 2000; Naidoo et al., 2006; Polasky et al., 2001). Costs are an important factor not directly accounted for in our study as we minimize the overall habitat area instead of the land costs. However, when appropriate data on land costs are not available, conservation planning studies often use area as a substitute for costs (McDonnell et al., 2002).

5.3 Conservation target: integrating representation and persistence

Each conservation target does not just correspond to the presence of a biodiversity feature, i.e. a certain species, but rather to the establishment of a viable population. Unlike commonly done in conservation planning (Tognelli et al., 2008; Williams et al., 2005a; Williams and Araujo, 2002), our approach does not necessarily select the entire planning unit as a priority area for conservation. Instead, the identified habitat areas must meet the MCAs for all preserved species in each planning unit. Thus, their sum may fall short of a planning unit's total area. If the area needed for the establishment of a viable population for a wide-ranging species cannot be provided by a single planning unit, areas from adjacent planning units are added.

The above-described procedure seems reasonable when dealing with large planning units for which it is unlikely or impossible to reserve them entirely. This study, for example, uses relatively coarse species occurrence data which result in planning units with an edge length of about 50 km.

We make several simplifications to adopt the conservation target approach. First, although the model structure allows the determination of species-specific representation targets, we employ the same target for each species in our application. Main reason for it is the difficulty in consistently determining explicit targets for individual species (Kerley et al., 2003). Second, to account for persistence, reliable density data as well as proxies for MVP sizes are essential. However, density data from literature vary substantially or are biased towards regions with high population densities (Schwanghart et al., 2008). Whether using absolute numbers for viable population sizes seems appropriate is subject to further discussion (Nicholson et al., 2006; Traill et al., 2007). Note that we do not assume the utilized figures to represent real MVPs nor that defining explicit sizes for persistent populations is possible. This is particularly true for such a range of species with divergent habitat requirements. Given the lack of better data, we still use these figures as working targets in our conservation planning exercise. Similar proceeding can be found in Kautz and Cox (2001), Verboom et al. (2001), and Kerley et al. (2003). Polasky et al. (2008) use population viability thresholds to estimate the number of species sustained on a landscape. Note that we do not account for spatio-temporal aspects of persistence.

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Appendix A

Table I-A1: Wetland species of European conservation concern

Shown are the 70 included species with their proxies for MVP sizes (adapted from Verboom et al. (2001)), density data, and habitat types. The genus *Discoglossus galganoi* includes *Discoglossus jeanneae*. For *Castor fiber*, the Estonian, Latvian, Lithuanian, Finnish and Swedish populations are excluded (according to 92/43/EEC). Regarding the densities for colonial birds, we differentiate nesting and foraging areas. The foraging area is set to 5 ha per reproductive unit (RU). Regarding the densities of the amphibian species, we assume 10 RU per hectare for solitary species and 20 RU per hectare for gregarious species. X stands for a required habitat type; / stands for an optional habitat type. The category open water is introduced for species that need some type of open water habitat. Wide-ranging species are indicated with an asterisk.

Scientific name	Vernacular name	MVP (RU)	Maximum density (RU/ha)	Required (x) and optional (/) habitat types					
				Mire	Wet forest	Wet grassland	Water course	Water body	Open water
Amphibians									
Alytes muletensis	Mallorcan midwife toad	200	20				x		
Bombina bombina	Fire-bellied toad	200	20			x		x	
Bombina variegata	Yellow-bellied toad	200	20		/	/		x	
Chioglossa lusitanica	Golden-striped salamander	200	10				x		
Discoglossus galganoi	Iberian painted frog	200	10					x	
Discoglossus montalentii	Corsican painted frog	200	10				x		
Discoglossus sardus	Tyrrhenian painted frog	200	10					x	
Pelobates fuscus insubricus	Common spadefoot	200	10					x	
Rana latastei	Italian agile frog	200	20		x			x	
Salamandrina terdigitata	Spectacled salamander	200	10				x		
Triturus carnifex	Italian crested newt	200	10		/	/		x	
Triturus cristatus	Great crested newt	200	10		/	/		x	
Triturus dobrogicus	Danube crested newt	200	10			/		x	
Triturus karelini	Southern crested newt	200	10					x	
Triturus montandoni	Carpathian newt	200	10		x	/		x	
Triturus vulgaris ampelensis	Smooth newt	200	20		/	/		x	
Reptiles									
Elaphe quatuorlineata	Four-lined snake	120	2			/			
Emys orbicularis	European pond tortoise	120	15					x	
Mauremys caspica	Stripe necked terrapin	120	9						x
Mauremys leprosa	Spanish terrapin	120	9						x
Birds									
Acrocephalus paludicola	Aquatic warbler	200	1.09			x			
Alcedo atthis	Kingfisher	200	0.15						x
Anser erythropus	Lesser white-fronted goose	200	0.127		x				x
*Aquila chrysaetos**	Golden eagle	120	0.0002	/		/			
*Aquila clanga**	Spotted eagle	120	0.000055	/	x	/	/	/	

Ardea purpurea purpurea	Purple heron	120	0.19			x			x
Ardeola ralloides	Squacco heron	200	0.19			x		x	
Asio flammeus	Short-eared owl	200	0.1	/		/			
Aythya nyroca	Ferruginous duck	200	1			x		x	
Botaurus stellaris stellaris	Bittern	200	0.5			x			
Chlidonias hybridus	Whiskered tern	200	0.19			/		x	
Chlidonias niger	Black tern	200	0.19			x		x	
*Ciconia ciconia**	White stork	120	0.001415			x			*x*
*Ciconia nigra**	Black stork	120	0.00018		x				x
Crex crex	Corncrake	200	0.19	/		x	/		
Fulica cristata	Crested coot	200	10			x		x	
Gavia arctica	Black-throated diver	120	0.006					x	
Gelochelidon nilotica	Gull-billed tern	200	0.19			x	x		
Glareola pratincola	Collared pratincole	200	8			x		x	
*Grus grus**	Crane	120	0.00043	/	/	/		/	
Haliaeetus albicilla	White-tailed eagle	120	0.01273		x				x
Hoplopterus spinosus	Spur-winged plover	200	0.3846			x			x
Ixobrychus minutus minutus	Little bittern	200	1.97			x			x
Marmaronetta angustirostris	Marbled teal	200	0.19			x		x	
Milvus migrans	Black kite	120	1.2733						x
Nycticorax nycticorax	Night heron	200	0.19			x			x
Oxyura leucocephala	White-headed duck	200	1.5					x	
*Pandion haliaetus**	Osprey	120	0.0004		/			x	
Pelecanus crispus	Dalmatian pelican	120	0.19			/		x	
Pelecanus onocrotalus	White pelican	120	0.19			/		x	
Phalacrocorax pygmaeus	Pygmy cormorant	200	0.19		/	/		x	
Philomachus pugnax	Ruff	200	1	/		/			
Platalea leucorodia	Spoonbill	120	0.19		/	x		x	
Plegadis falcinellus	Glossy ibis	200	0.19		/	x		x	
Porphyrio porphyrio	Purple gallinule	200	3.3			x		x	
Porzana parva parva	Little crake	200	5			x		/	
Porzana porzana	Spotted crake	200	0.333	/		/			
Porzana pusilla	Baillon´s crake	200	3.5368			x			
Sterna albifrons	Little tern	200	0.19				x	/	
Tadorna ferruginea	Ruddy shelduck	120	10					x	
Tringa glareola	Wood sandpiper	200	0.12	x	/	/			
Mammals									
*Castor fiber**	Eurasian beaver	120	0.002		x				x
Galemys pyrenaicus	Pyrenean desman	200	13.89						x
*Lutra lutra**	European otter	120	0.00017						x
Microtus cabrerae	Cabrera's vole	200	57.5			x			
Microtus oeconomus arenicola	Dutch root vole	200	65	/		/	/	/	
Microtus oeconomus mehelyi	Pannonian root vole	200	65	/		/	/	/	
Mustela lutreola	European mink	200	0.083			/	x	/	
*Myotis capaccinii**	Long-fingered bat	200	0.0042						x
*Myotis dasycneme**	Pond bat	200	0.0042					x	

Appendix B

Table I-A2: Allocation of species to countries (scenario: coordinated conservation planning within countries)

Each species is allocated to the country in which most occupied planning units of the species are located; the twelve resulting countries encompass 79% of the considered land area.

European country	Species
Bulgaria	*Triturus karelinii, Pelecanus crispus, Pelecanus onocrotalus, Phalacrocorax pygmaeus, Plegadis falcinellus, Tadorna ferruginea*
Finland	*Asio flammeus, Philomachus pugnax*
France	*Bombina variegata, Discoglossus montalentii, Emys orbicularis, Alcedo atthis, Ixobrychus minutus minutus, Milvus migrans, Nycticorax nycticorax, Mustela lutreola*
Germany	*Triturus cristatus, Myotis dasycneme*
Greece	*Mauremys caspica, Hoplopterus spinosus*
Hungary	*Platalea leucorodia, Microtus oeconomus mehelyi*
Italy	*Discoglossus sardus, Pelobates fuscus insubricus, Rana latastei, Salamandrina terdigitata, Triturus carnifex, Elaphe quatuorlineata, Myotis capaccinii*
Netherlands	*Microtus oeconomus arenicola*
Poland	*Bombina bombina, Triturus montandoni, Acrocephalus paludicola, Aythya nyroca, Botaurus stellaris stellaris, Chlidonias niger, Ciconia ciconia, Ciconia nigra, Crex crex, Haliaeetus albicilla, Porzana parva parva, Porzana porzana, Sterna albifrons, Castor fiber*
Romania	*Triturus dobrogicus, Triturus vulgaris ampelensis, Aquila clanga, Ardeola ralloides, Chlidonias hybridus*
Spain	*Alytes muletensis, Chioglossa lusitanica, Discoglossus galganoi, Mauremys leprosa, Aquila chrysaetos, Ardea purpurea purpurea, Fulica cristata, Gelochelidon nilotica, Glareola pratincola, Marmaronetta angustirostris, Oxyra leucocephala, Porphyrio porphyrio, Porzana pusilla, Galemys pyrenaicus, Lutra lutra, Microtus cabrerae*
Sweden	*Anser erythropus, Gavia arctica, Grus grus, Pandion haliaetus, Tringa glareola*

Appendix C

Table I-A3: Allocation of species to biogeographical regions (scenario: coordinated conservation planning within biogeographical regions)

Each species is allocated to the biogeographical region in which most occupied planning units of the species are located; the seven resulting regions encompass 99% of the considered land area.

Biogeographical region	**Species**
Alpine	*Triturus montandoni, Anser erythropus*
Atlantic	*Chioglossa lusitanica, Microtus oeconomus arenicola, Mustela lutreola*
Black Sea	*Pelecanus onocrotalus*
Boreal	*Asio flammeus, Gavia arctica, Grus grus, Pandion haliaetus, Philomachus pugnax, Tringa glareola, Castor fiber*
Continental	*Bombina bombina, Bombina variegata, Pelobates fuscus insubricus, Rana latastei, Triturus carnifex, Tritutus cristatus, Triturus karelinii, Triturus vulgaris ampelensis, Acrocephalus paludicola, Alcedo atthis, Aquila clanga, Ardeola ralloides, Aythya nyroca, Botaurus stellaris stellaris, Chlidonias niger, Ciconia ciconia, Ciconia nigra, Crex crex, Haliaeetus albicilla, Ixobrychus minutus minutus, Milvus migrans, Pelecanus crispus, Phalacrocorax pygmaeus, Porzana parva parva, Porzana porzana, Sterna albifrons, Lutra lutra, Myotis dasycneme*
Mediterranean	*Alytes muletensis, Discoglossus galganoi, Discoglossus montalentii, Discoglossus sardus, Salamandrina terdigitata, Elaphe quatuorlineata, Emys orbicularis, Mauremys caspica, Mauremys leprosa, Aquila chrysaetos, Ardea purpurea purpurea, Chlidonias hybridus, Fulica cristata, Gelochelidon nilotica, Glareola pratincola, Hoplopterus spinosus, Marmaronetta angustirostris, Nycticorax nycticorax, Oxyra leucocephala, Plegadis falcinellus, Porphyrio porphyrio, Porzana pusilla, Tadorna ferruginea, Galemys pyrenaicus, Microtus cabrerae, Myotis capaccinii*
Pannonian	*Triturus dobrogicus, Platalea leucorodia, Microtus oeconomus mehelyi*