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Using farmland prices to evaluate cost-efficiency of national versus regional reserve selection in Denmark

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ABSTRACT

The current study focuses on the influence of geopolitical coordination of conservation strategies on cost and efficiency in terms of species representation when selecting network of protected areas. Conservation policies in the EU are implemented at many different administrative levels: from the European Union and national levels, to regional or/county levels within member countries. This arise the question what size of efficiency gains could be achieved if planning of conservation priorities could be coordinated between geopolitical units. Using data for the nationwide distribution of 763 species, representing all Danish species within eight taxa, we compared illustrative costs for the addition of new areas to the existing conservation network in order to ensure full coverage of all species. We found that the cost of independent regional planning is 20-fold higher than an inter-regional and nationally co-ordinated strategy. We also found that substituting land prices for a simple land-area measure in our analyses increased the expected conservation costs differential significantly, without increasing coverage of species representations. We suggest that in economic and biodiversity terms it can largely be a win–win situation to set a common goal, to develop priority-strategies, and to coordinate actions at higher rather than lower levels of administration.

1. Introduction

In 2001, EU Heads of State and Government made a commitment at the EU's Spring Summit in Gothenburg to protect and restore habitats, and to halt the present decline in biodiversity by 2010. The EU Strategy on Biodiversity Protection (COM (98) 42) recognises that biodiversity in Europe has been subject to fluctuations throughout the preceding centuries. The European Environmental Agency cites intensive agriculture, accelerating urbanisation, pollution and tourism as the most important causes of the decline in biodiversity (European Environment Agency, 2004).

A variety of policy instruments have been adopted within the EU for improving biodiversity. The most common include legal instruments and policy frameworks such as directives, regulations, decisions, designations, strategies, EU Environmental law, as well as financial instruments (for instance, the Structural Funds Regulations, as well as state aid such as subsidies or tax relief). Generally, the EU's biodiversity policy has been rather weak, and the policy depends almost entirely on the member states to provide the means of implementation (Jordan, 1999). In contrast to other parts of the world, Europe has historically relied less on state-owned reserves than on land-use regulations and incentives for encouraging conservation action on private land to conserve biodiversity (for example, the decoupling in the CAP reform). Higher levels of funding as well as improved targeting of financial resources for the conservation of high biodiversity

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areas may make a significant contribution to slowing down biodiversity loss.

The choice of policy tools depends on the target itself, as well as the resources (funding) available. A clear set of priority objectives, policy tools and targets can help ensure that these limited resources are used to greatest effect in reducing the loss of biodiversity. These objectives, tools and targets can clarify, for decision-makers as well as the public, what needs to be done, and support the coordination of human and financial resources to address priorities.

The need to address the question of priorities has gathered increasing attention for at least two reasons. First, the implementation of conservation strategies is currently taking place in the member countries. Secondly, the existing reserve network in Europe will need to be enlarged, entailing the extension of the Birds and Habitats Directives as well as the establishment of Natura 2000, a network of protected areas throughout the EU, in new member states.

Biodiversity policies in the EU are implemented at many different administrative levels: from the European Union and national levels, to regional or/county levels within member countries. The increasing number of member countries in the European Union, and the implementation on different scales within these countries, indicates that geopolitical coordination will become increasingly critical in a European context. Only few studies have been conducted on the importance of geopolitical units (Pressey and Nicholls, 1989; Hunter and Hutchinson, 1994; Hull et al., 1998; Erasmus et al., 1999; Rodrigues and Gaston, 2002). A general conclusion is that increasing the number of geopolitical units decreases the efficiency of the network, as the number of areas required increases. Species that are rare within a unit on one scale play a disproportionate role in determining which areas to protect when operating on a broader scale (Erasmus et al., 1999). Thus, within a geopolitical unit a high priority may be given to species atypical of that unit, which in turn may affect conservation strategies. This suggests that increased efficiency may be achieved by geopolitical coordination between units, or diminished if coordination is reduced. Efficiency gains or losses can only be appropriately analysed by including appropriate cost estimates for conservation strategies. However, information on the costs involved in achieving protection goals is often lacking. Only a few studies have attempted to estimate the potential efficiency gains of different policy combinations. For example, Pence et al. (2003) and Frazee et al. (2003) estimate the costs of governmental purchase of land for conservation purposes, as well as the costs of long term maintenance for the protection of biodiversity. Pence et al. (2003) reveal that governmental purchase of private land may be an unduly costly means to secure protection goals. Furthermore, by assuming that similar protection goals may be achieved through the establishment of management agreements between governments and private land owners, together with tax relief, subsidies and reimbursements, it has been established that significant cost savings can be achieved.

In this study we follow up on these studies by determining the potential scale of efficiency gains from geopolitical coordination using illustrative cost data. That is, county-level data on farmland prices are used to assess the costs of governmental intervention involved in pursuing different protection strategies. We simulate the surrogate cost of regional planning conducted independently of other regions, and compare this with the cost of planning as part of an interregional, coordinated strategy. We discuss whether the multiple representations achieved in a non-coordinated strategy are more effective for maintaining species representation over time. While Denmark is used as a case study in this study, the problems described here are shared by many member countries within EU, it serves as an example of potential efficiency gains which could be achieved by increasing the coordination between member countries.

In order to determine the potential scale of efficiency gains, we asses the efficiency of the current network in Denmark using all Danish summer atlas data (grain-size 10×10 km) on the distribution of 763 terrestrial and freshwater species (orchids, crawling water beetles, click beetles, butterflies, large moths, amphibians and reptiles, birds and bats). We recognise that land use in Western European countries is often characterised by strong competition between agricultural needs and ecological requirements. Accordingly, we determine the most efficient extension of the current network, and assess the illustrative cost of including additional land in the existing network to ensure a more efficient coverage of species.

Finally, we assess the illustrative cost of independent regional planning, and compare this to a nationally co-ordinated strategy to identify whether efficiency gains can be obtained through the implementation of a national, rather than regional, strategy.

2. Data and methods

2.1. *Biodiversity data: species assemblages within each grid cell*

In this study we use geographically distributed data on terrestrial and freshwater species located in the 633 UTM (Universal Transverse Mercator) 10×10 km grid cells which provide a complete coverage of Denmark, including the island of Bornholm in the Baltic Sea. Information on species distribution (and species assemblages within each cell) is compiled as present/absent, based on all Danish summer atlas data providing complete coverage of all species within a given taxon. The species included represent 41 species of orchids (Orchidaceae: Wind, 2001), 18 species of crawling water beetles (Coleoptera: Haliplidae: Holmen, 1981), 23 species of click beetles (Coleoptera: species within Elateridae: Martin, 1989), 61 species of butterflies (Lepidoptera: Hesperioidea, Papilionoidea: Stoltze, 1994), 156 species of large moths (Lepidoptera: species within Hepialoidea, Cossoidea, Zygaenoidea, Tineoidea, Yponomentoidea, Bombycoidea, Geometroidea, Sphingoidea, Notodontoidea, Noctuoidea; Kaaber, 1982), 252 species of hoverflies (Diptera: Syrphidae: Torp, 1994), 19 species of amphibians and reptiles (Amphibia/Reptilia: Fog, 1993), 179 species of birds (Aves: Stoltze, 1994), and 14 species of bats (Chiroptera: Baagøe, 2001). The database thus comprises a total of 763 species of the "estimated" 30,000 species in Denmark (Stoltze and Pihl, 1998; see Lund and Rahbek, 2002; Lund, 2002 for use and further description of this database).

The threatened (red-listed) species represent 3% of the available atlas data. However, investigations carried out in Denmark by Lund and Rahbek (2000) reveal that red-listed species are unable to identify suitable networks of priority areas capable of representing all species efficiently. Thus, the analyses presented in this study are based on all species, irrespective of whether they are red-listed or not. Fourteen species are registered only once, which may introduce an increased risk of local extinction, and consequently extinction on a national level (Fig. 1). More than 30% of the species are represented in less than 5% of the grid cells while the most wide-spread species is represented in 630 cells. The geographical density of species is presented in Fig. 2a.

2.2. *Stratification of land within each grid cell*

Denmark consists of one large peninsula and hundreds of islands, and is as such both surrounded by, and intersected with salt/brackish water. Denmark covers an area of 43,000 km^2 of which approximately 65% is cultivated, while 20% are urban areas. The human population density is 124 per km^2 (Danish Statistics, 2003). The landscape is very fragmented. Typically, each of the 633 UTM 10×10 km grid cells contains a mosaic of smaller biotopes within a matrix of arable land (Lund and Rahbek, 2002). About 40% of the total area of land is publicly owned (Danish Statistics, 2003).

For each of the 633 UTM cells we calculated the actual amount of land area, as well as the percent land area within the following three categories: (a) protected land (b) non-protected land and (c) urban areas. This was done using data from The Danish Area Information System, which contains 40 detailed data layers, with area information based on more than two million polygons and with a precision of ±25 m (Danish Ministry of Environment and Energy, 2000).

Land classified as protected land consists of the following three areas:

(1) The European Economic Community (EEC) NATURA2000 network which consists of areas designated according to the EEC 'Birds' Directive (79/409/EEC) and the EEC 'Habitats' Directive (92/43/EEC). Typically, the management objective for these areas is to maintain and preserve the habitats and species populations in their existing condition, and to improve their biodiversity value over time.
(2) Conservation areas protected under Danish law, based on landscape amenity, cultural heritage and biodiversity values, as well as scientific and educational purposes. At present it is not possible to distinguish between these types of protected areas in The Danish Area Information System, nor is this information available in electronic format or accessible via a hardcopy compilation.
(3) Six biotopes (streams, lakes, bogs, heaths, meadows and salt marshes), if covering an area larger than a specified size (for example, lakes >100 m^2), receive a general protection under the Danish Conservation Act, irrespective of whether publicly or privately owned. The state of the biotopes must not change while current land use practices continue (for example, the use of fertilisers or pesticides). Many of these areas are, however, undergoes rapid succession. The need for extensive management, such as grazing management, is not addressed in the Act (Wilhjelm Committee, 2001). These areas are typically small and dispersed.

The type and level of "protection" of these three areas differs. However, all share some degree of regulation or restriction with regard to land use that either directly protects or, through restriction on land-use practice, favours current habitats and/or species within these areas. During the processing of area shares we avoided geographical overlap. The percentage of protected land inside the 633 cells varies, with 253 cells containing at least 10% protected land, whereas only 118 cells contain more than 30% protected

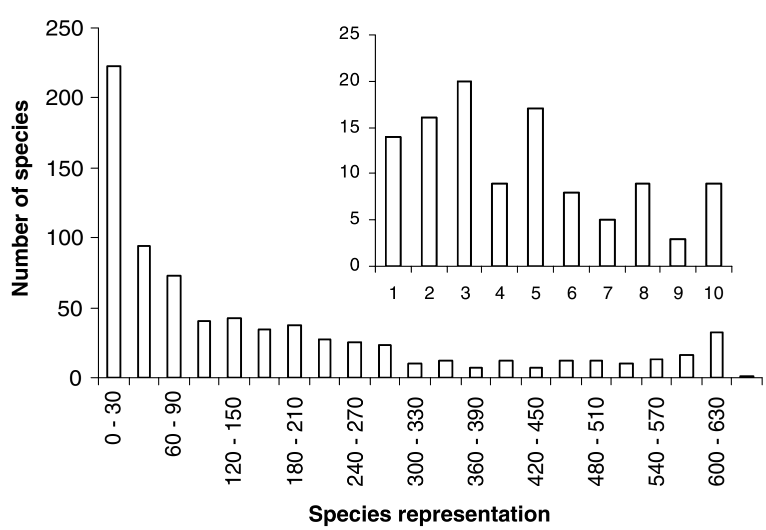

Fig. 1 – The frequency distribution of range sizes (number of 10 × 10 km grid cells occupied) of the 763 species comprising all species of orchids, crawling water beetles, click beetles, butterflies, large moths, hoverflies, amphibians, reptiles, birds and bats breeding in Denmark. Inserted histogram highlights the distribution among species with a range-size of 10 cells or less.

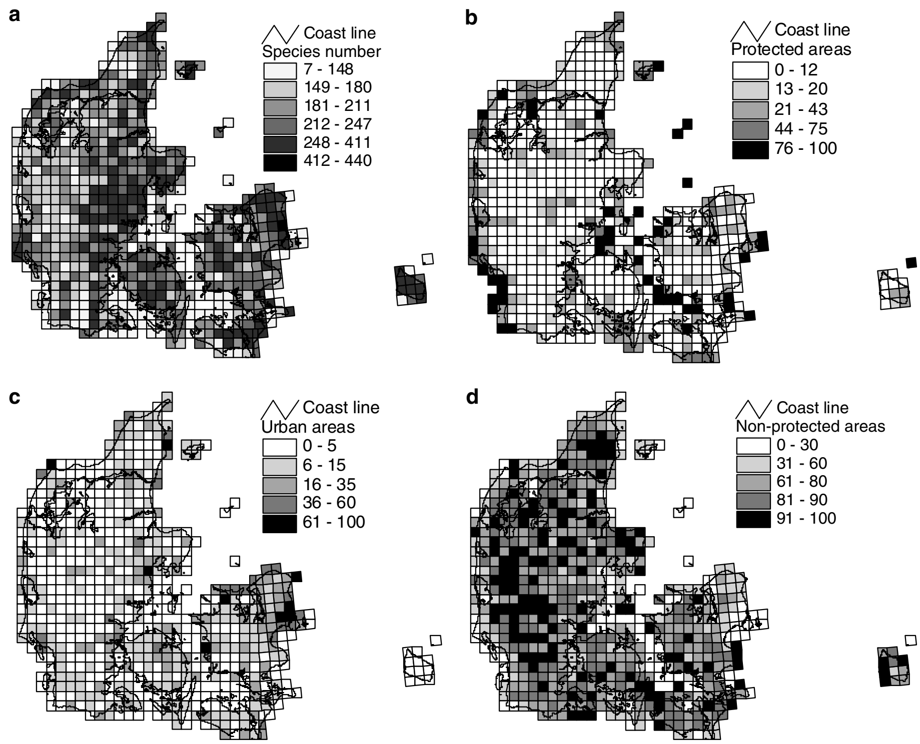

Fig. 2 – Species distribution and stratification of land-use in Denmark at a spatial grain size of 10 × 10 km grid cells. (a) Species density of the 763 species included in the analysis, (b) percent coverage of protected land, (c) urban areas and (d) non-protected land.

land (Fig. 3). Fifty-two cells (8%) are mainly urban areas and contain no protected land.

The classification of urban areas (such as town/city zones, as well as areas with holiday cottages) as opposed to non-protected land per se is based on the assumption that urban areas are incompatible with current and future protection goals for biodiversity. In contrast, "non-protected" land in non-urban areas can be transformed into "protected land", for example by governmental purchase. While non-protected areas are classified as agricultural land and forest, this classification does not distinguish between extensively or intensively cultivated land. In Denmark, cells containing a large degree of protected areas are primarily located near the coastline (Fig. 2b), while urban areas are mainly located in the eastern part of the country (Fig. 2c). Fig. 2d presents the distribution of non-protected areas.

2.3. *Economic cost: illustrative cost governmental within each grid cell*

We use county or regional-level data on farm estate sales, transformed to grid cell levels, as a surrogate to assess the economic costs of governmental intervention on privately owned farmland for conservation purposes.

County-level data on sales prices of farmland in 1992–2000 (in € per hectare) have been compiled by Statistics Denmark (Danish Statistics, 2001). These sales are organised in size classes of between 2 and 100 ha. The number of sales of areas

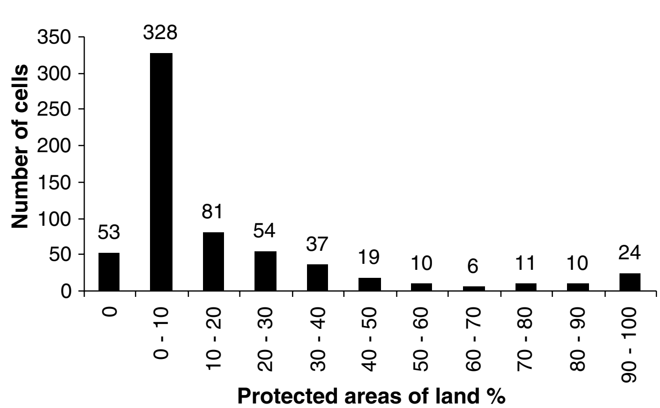

Fig. 3 – The frequency distribution of percent coverage of protected land within each 10 × 10 km cell.

over 100 ha are very few, and are therefore excluded from the assessment. In the other size classes, the number of sales in each size class is high, although sales may vary between counties and size classes and thus affect the average price considerably in a given county. Therefore, in this study we average all sales between 1992 and 2000. We estimate missing values, which occur in a few size classes with no sales, using values from previous size classes within the county (cf. Ando et al., 1998). We use a price index on agricultural farmland supplied by Danish Statistics (2003) to estimate the 2000 price level of all sales. The estimated average prices per hectare for all 14 counties are presented in Fig. 4. In cells located at the borderline of each county, farm land prices are estimated as average values of the bordering counties. For each grid cell, the economic cost is calculated using information about the percentage of non-protected area inside the grid cell. The cost is estimated by multiplication of the average land price at the county level with the number of non-protected hectares within the grid cells needed to protect a particular area share of the grid cell.

2.4. *Optimality and heuristics and implementation of cost*

The WORLDMAP software (Williams, 1998; Williams, 1999) makes use of a quantitative area-selection method to implement data-handling procedures. In order to identify the near-minimum set of areas capable of representing all species at least once, we use the heuristic progressive rarity algorithm based on the concept of complementarity (adapted from Margules et al., 1988). This simple algorithm has been demonstrated to give a close approximation to the mathematically optimal solution (Csuti et al., 1997; Moore et al., 2003) and is henceforth assumed to be effectively optimal. In this study, the algorithm is supplemented with additional procedures adapted from Williams et al. (2000) and Williams et al. (2003), respectively, in order to remove redundant grid cells from the network, as well as include cost parameters.

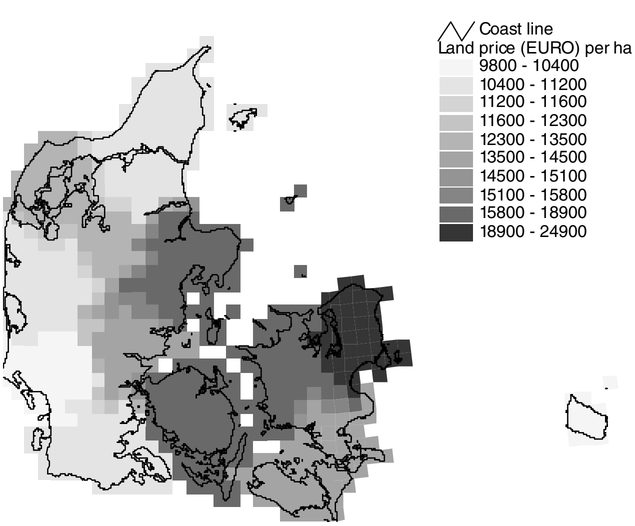

Fig. 4 – Estimated economic costs (in €/ha) of species conservation, estimated at the county (regional)level and based on the average real estate sales statistics of the period 1992–2000.

In the current study we explore two types of cost. First, all cells are assumed to be homogeneous with respect to cost. Alternatively, cells are assumed to be heterogeneous with respect to cost, and cost in each cell is set at land prices proportional to the size of the area protected within the cell. The cost function affects the solution space. When costs are similar in all cells the number of alternatives providing the same objective values is high. There is no unique global optimal solution, rather a number of optimal solutions, and one can effectively describe these solutions as a flat lowland of objective values.

While the adapted algorithm described above identifies a single approximate solution to the problem of identifying the near-minimum set of areas capable of representing all species at least once, there are often many possible solutions, all of which are equally efficient. Priority networks that have many equivalent solutions are considered to possess high flexibility, while those with fewer solutions possess lower flexibility. Various degrees of flexibility are possible. Some grid cells are considered irreplaceable, in that no alternative solutions exist to represent one or more of their species. Other grid cells are flexible, in that other alternative areas exist for representing the species. An area is considered to be fully flexible if it can be exchanged by another area while still managing to represent all species the required number of times within the same number of areas or the same total cost of areas. Partly flexible areas can be exchanged for a larger number of areas outside the network (Williams et al., 2003).

2.5. *Area-selection analyses performed in the study*

We use a near-minimum-area set analysis based on all 763 terrestrial and freshwater species to identify the set of areas that represent all species *at least once* while minimising the total cost measured as area (i.e., the minimum-area network *sensu* Williams et al., 2003). A random sample of 1000 potential networks is generated and their cost is estimated. The effectiveness of the existing reserve network, i.e., the number of species protected by the existing network, is estimated by selecting all grid cells with a share of protected land higher than 30% (coverage criteria *sensu* Fjeldså and Rahbek, 1997; Fjeldså and Rahbek, 1998, see also; Lund and Rahbek, 2000; De Klerk et al., 2004) This approach rests on the assumption that larger protected areas are more successful in securing long-term survival of species, and that all of the species in a single one grid cell are protected adequately if the share of protected areas exceeds 30%. The coverage criterion of 30% is arbitrarily chosen. To investigate the implication of this assumption we perform a sensitivity analysis at four levels of protection coverage: 10%, 20%, 30%, and 40%. The cost of completing the coverage of all species at least once within a network is investigated by running a gap analysis (*sensu* Scott et al., 1993), where the aim is to perform a near-minimum set analysis on those species identified as currently not covered by the existing reserve network (using the definitions of 10%, 20%, 30% and 40% protection coverage, respectively). Initially, we apply the traditional near-minimum-area analysis minimising the number of cells needed to meet the goal and calculating the distribution of costs for a sample of flexible sets. Subsequently, we apply a near-minimum-cost analysis, using figures on farmland prices per grid cell to calculate the cheapest purchase of non-protected land. The latter analysis provides figures for the total cost of a nationally co-ordinated strategy.

The illustrative cost of independent regionally- versus nationally-coordinated strategies is investigated by performing an independent gap analysis for each of the 14 Danish counties based on the existing network of reserves (and using 30% as criteria for protection coverage) with the aim of covering all species occurring within the unit of analysis (i.e. counties) at a minimum cost. The results and combined costs of this regional analysis are compared with those obtained when using the national entity Denmark as a single unit of analysis.

3. Results

3.1. *Efficiency of a national network*

A minimum of 39 of Denmark's 633 UTM 10 × 10 km grid cells are necessary to ensure at least one representation of each of the 763 species (Fig. 5a). The most costly reserve network in a sample of 70 minimum set solutions is estimated to be €640 million, with the least costly estimate being €476 million. The mean and standard deviation of the random sample are estimated to be €560 million and €35 million, respectively. The effectiveness of the existing reserve network is high, with 171 of 633 cells having 30% or more of their land area under a form of protection, providing coverage for 740 of the 763 species. The cheapest method of purchasing additional land meeting the 30% criterion, while ensuring that all 763 species are covered at least once, involves adding 16 cells to the existing network (Fig. 5b). The number of non-covered species in the existing networks, their average range size and standard deviation are reported for the 10%, 20%, 30%, and 40% criterion in Table 1. The illustrative cost of this network is estimated to be €286 million, while the cost of the most expensive network is estimated to be €442 million. The traditional near-minimum-area analysis also identifies the need for 16 areas, and the number of alternative solutions is estimated at 3600. Hence we estimated the mean and standard deviation of a random sample of 1000 alternative networks to be €343 million and €20 million, respectively. Thus, lacking or ignoring a priori information on land prices potentially increases the cost of conservation on average with approximately €57 million. However, whereas the near-minimum-*cost* analysis provides only one alternative solution, the near-minimum-*area* analysis provides a large number of alternative solutions. The extra €57 million cost of these alternative solutions may be considered to be a rough illustrative estimate of "opportunity cost". Fig. 5c shows that the cost of the minimum-set-cost strategy is way below the 2.5 percentile of the cost of the 1000 alternative minimum-set-area strategy, emphasising the efficiency potential in collecting cost information on the network strategies.

Table 1 shows the results of repeating the analyses using a criterion of 10%, 20% and 40% protection coverage, as opposed to 30%. The number of existing protected areas decreases with increasing demands for higher within-cell protection coverage. Setting higher demands also significantly increases the cost of governmental intervention when additional land is needed to meet the aim of repre-

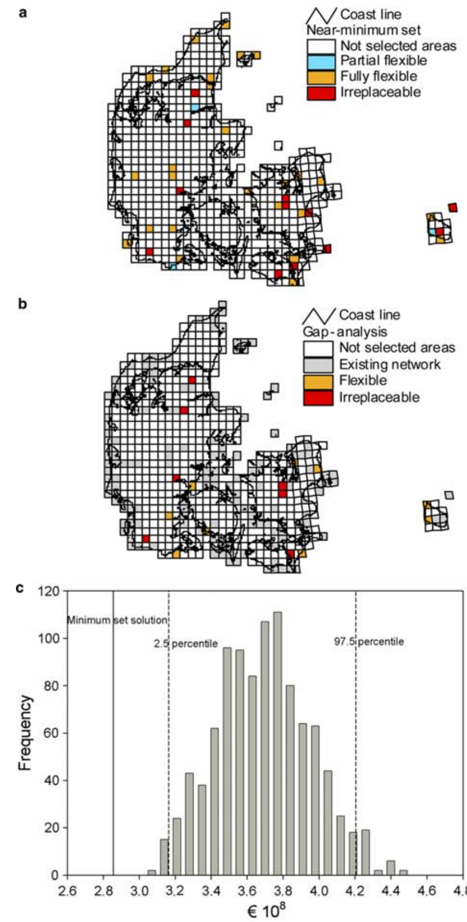

Fig. 5 – Area networks representing all 763 species within Denmark on a 10 × 10 km grain scale, using quantitative methods: (a) A near-minimum-area network of areas (39 areas), one of a number of possible solutions which ensures at least one representation of each species. Twelve areas are irreplaceable and have no alternatives, 13 areas are fully flexible and can be replaced by other areas and 16 areas are partial flexible and cannot be replaced without increasing the number of areas in the network; (b) A gap-analysis performed as a near-minimum-cost analysis using farmland prices per grid cell in order to calculate the cheapest purchase of non-protected land that ensures at least one representation of each species within the network. The illustrated network is based on the criterion that at least 30% of the land area inside a cell should be protected. The existing network consists of 117 areas to which 16 areas need to be added. Of these 16 areas, 7 areas are irreplaceable and 9 flexible areas can be replaced with other, more expensive areas and (c) 1000 random near-minimum-area networks of areas based on the criterion at least 30% of the land area should be protected.

Table 1 – Gap analysis based on a near-minimum set analysis of the existing network of conservations areas with the aim of representing all 763 species at least once

Minimum protected share [%]	No. of cells in the existing network	No. of non-covered species in the existing network [average; st. dev.]	Average range size of non-covered species [st. dev. in brackets]	No. of cells added to the network	No. of alternative solutions	Costs (million €)
Minimise number of cells – minimum-set-area strategy						
10	339	4	1.50 [0.58]	4	4	32
20	252	11	1.55 [0.69]	9	24	154.6
30	171	23	2.78 [2.33]	16	3600	342.6[a]
40	117	55	5.05 [5.14]	26	254.600	761.6
Minimise cost – minimum-set-cost strategy						
10	339	4	1.50 [0.58]	4	1	19.2
20	252	11	1.55 [0.69]	9	1	114.0
30	171	23	2.78 [2.33]	16	1	285.6
40	117	55	5.05 [5.14]	28	0	556.1

"Minimise cost" is the near-minimum-cost analysis using a priori information on farmland price, to identify the cheapest purchase of non-protected land that meets the conservation goal. "Minimise number of cells" is the traditional near-minimum-area analysis, minimising the number of areas needed to meet the goal in absence of knowledge of actual cost. The cost of the "required" areas to be added to the existing network based on farmland prices ("Costs") is subsequently calculated for both approaches. The analysis is conducted where different levels (10%, 20%, 30%, and 40%) of minimum protected share of the land-area within a grid cell are assumed to be sufficient to consider a species "safe", and the area of occurrence can be considered a candidate for inclusion in the network.
a Represents the mean value of 1000 randomly chosen minimum set solutions. Standard deviation is estimated at € 20 million.

senting all species once. The minimum-set-cost ranges from €19 million to €556 million (Table 1, lower half). One important result presented in Table 1 is that the opportunity cost for alternative solutions also increases with an increasing demand for protection coverage. By applying the 10%, 20%, 30% and 40% protection coverage criteria, the illustrative opportunity cost is estimated at €12.8 million, €40.6 million, €57 million and €205.5 million, respectively (Table 1, comparing surrogate cost of minimum-set-cost and minimum-set-area). The number of non-covered species and average range sizes increase with increasing protection coverage.

3.2. *Efficiency of a regional network*

The results of conducting the gap-analysis and near-minimum-cost analysis independently for each of the 14 counties of Denmark (using the 30% protection coverage criteria) are shown in Table 2. The county-defined summed cost increases dramatically, when compared to the costs of applying a national priority scheme (Table 2). More than 331 cells are included in the regional network, as opposed to 187 cells in the national scheme. Applying regional conservation planning would produce an overall higher representation of species, while decreasing the risk of local extinction. Estimating the percentage of all 763 species that would be covered within each county when applying the regional protection strategy, we found the highest coverage (81% of all species) was achieved in Nordjylland county, with the lowest in Ribe county (43%). Vejle county is the most expensive (€748.4 million) though only covering 75% of all species. We found no significant correlation between cost at the county level and species coverage ($r_s = 0.43$ and $P > 0.05$ for $n = 14$; two-tailed).

4. Discussion

4.1. *Regional versus national conservation strategies*

Previous studies have addressed the question of efficiency of conservation planning using geopolitical units, which in turn has resulted in protection strategies based on areas progressively segregated into units of smaller geographic extent (see for example Pressey and Nicholls, 1989; Hull et al., 1998; Erasmus et al., 1999; Rodrigues and Gaston, 2002). This raises the question of how the level in the geopolitical hierarchy at which such planning is performed influences the economic and biological efficiency of areas that are designated as priorities for conservation.

Erasmus et al. (1999) find that the percentage of land required for conservation planning is smaller by a factor of three on the across-regional scale, compared to the within-regional scale. In addition, they find that the degree of spatial overlap between the specific areas identified on the two administrative scales is low. In the current study the number of cells needed in the regional strategy is about 15 times (248 cells/16 cells) the number of cells needed in the national (i.e. across-regional) strategy, where the share of protected areas is higher than 30%. When the illustrative cost is included, this efficiency gain is rescaled according to the heterogeneity of conservation cost across regions. We found that purchasing the additional land needed to meet the aim of representing all species once using the regional strategy totals €5.756 billion for all regions, or more than 20 times the cost of applying a national priority scheme (Table 2). This illustrates the variation in cost of networks and how it depends on the hierarchal level of conservation planning. Increasing coordination between multi-scale political units may increase the efficiency of the network accordingly.

Table 2 – Cost of conducting independently regional gap-analysis in each of the 14 Danish counties, capable of representing all species at least once at a regional or county scale ("Cost of a county-defined network")

County	Cost of a county-defined network (million €)	Coverage of species [%]	Cells added within each county in a county-defined network	Cost of a national-defined network (million €)
København	176.4	68	5	20.4
Frederiksborg	269.1	78	9	13.6
Roskilde	159.1	58	5	0
Vestsjælland	626.2	77	22	56.8
Storstrøm	452.2	79	21	42.9
Bornholm	72.2	66	7	22.5
Fyn	659.3	74	24	20.4
Sønderjylland	404.1	75	21	44.8
Ribe	431.5	68	19	0
Vejle	748.4	75	26	29.0
Ringkøbing	585.2	64	23	0
Århus	609.5	80	22	0
Viborg	563.1	73	24	13.1
Nordjylland	383.7	81	20	21.9
Total	5756.1		248	285.6

The column "Cost of a national-defined network" is the cost of areas per county if implementing a national coordinated strategy capable of representing all species at least once at a national scale. Costs is estimated using farm land prices based on the criteria that at least 30% of the land area inside a cell should be protected in order to consider its species "safe". "Coverage of species" is the proportion of all species covered within the county-defined, or regional, network.

This raises the question regarding the most appropriate decision making level. According to the Danish Act of Regional Planning and the Danish Act of Nature Protection, the regional counties in Denmark are currently responsible for the planning of biodiversity conservation. Thus, the results presented in Table 2 address the importance of coordinating such conservation strategies to increase efficiency. The political situation in Denmark calls for a new restructuring of such administrative units. The national government decided in 2004 to disband the counties and transfer the responsibility of conservation planning to the municipalities. This reform of environmental administrative units in Denmark indicates that loss of coordination may become even more critical with respect to conservation efficiency in the reserve network. On the other hand, areas recognised at the national level may differ significantly to areas identified at the regional level, such that areas regarded as being critical by national analyses may not be regarded as such by regional analyses. This issue emphasises that conservation requires collaboration between many levels, from land owners or managers at the local level, to politicians and administrations at regional, national, international and global levels.

While the larger number of additional selected areas needed in the regional strategy (248 cells vs. 16 cells needed in the national strategy) will ultimately produce a higher representation of species, this will not necessarily be implemented in a cost-effective manner (Fig. 6). The number of species with low coverage is actually fewer for the national strategy than the regional strategy (Fig. 6). Thus, the national strategy, which is the most cost-effective strategy, does not necessarily lead to an inherently inferior design characterized by a large number of sparsely covered species, as a consequence of lower cost (i.e., fewer areas selected). Rather it seems that the national strategy provides a better coverage of nationally rare species than the regional-defined strategies.

Our analysis is based on the assumption that species in a grid cell are protected if the share of protected areas is higher than a certain level, for example 30%. Species occurrences are related to a $10 \times 10\,\mathrm{km}^2$ grid cell, suggesting that we cannot be sure whether the species occur within, or outside, the protected areas. It is, however, unlikely to bias the results as the un-protected areas in Denmark is by and large heavily industrialised agricultural land and so species within cells are likely found in the protected areas of grid cells. It is also important to stress that the species may not be represented by a long-term viable population, even though they have been identified within a protected area of a given size. Given the heavily fragmented nature of the agricultural landscape of Denmark, the product of hundreds of years of development, these issues are less likely to bias our results than in other regions of Europe, where fragmentation of habitats is more recent. Compared to similar related conservation issues in, for example, the United States (Csuti et al., 1997; Dobson et al., 1997; Ando et al., 1998) there is also a considerable scale difference between grid dimension and the area of land available for conservation purposes (Pressey and Logan, 1998; Erasmus et al., 1999; Larsen and Rahbek, 2003, see also; Cowling et al., 2003 for discussion of scale-dependency on area selection). Even the largest Nature Reserve in Denmark, 'Lille Vildmose', (7700 ha) is smaller than the 10×10 km (10,000 ha) grid cell used to map the species distribution data.

A consequence of using the near-minimum-area analysis approach with the low requirement of only one representation of each species is that 10% of all species are represented less than 5 times. This low representation of species may invoke a significant risk of national extinction. Rodrigues et al.

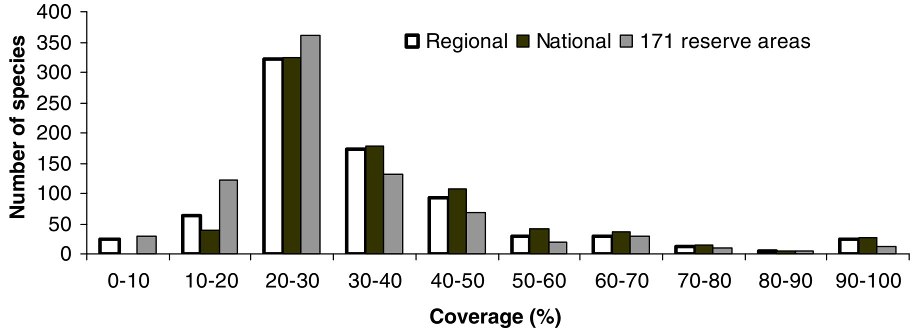

Fig. 6 – The efficiency of both a regional- and a national-defined strategy, in terms of species covered using the 30% land protection coverage criteria (see text) and given the existing 117 reserve areas. Coverage of species is defined as the proportion of their range represented within networks of areas compared to the maximum number of occurrences of the species.

(2000) argue that a larger network, where species are represented multiple times, could be more effective in maintaining species over time. Repeating our estimates based on different levels of minimum representation we find that the illustrative conservation cost increases approximately at the rate of €462 million for each required additional representation of all species. The estimated conservation costs at different levels of representation are presented in Fig. 7.

However, there has also been criticism of centralised management (Chambers, 1988), arguing that large, centralised and hierarchical organisations tend to simplify and standardise conservation solutions. Local management institutions must be included to minimise conflict, ensuring voluntary commitment, and what is more important to note is that local institutions may be most knowledgeable about the problems of local conservation. It is argued that more local-level institutions learn and develop capability to respond to environmental and economic feedbacks faster than do centralised agencies (Berkes, 2004). Thus, if control is too centralised, valuable information from the resource, in the form of feed backs may be delayed or lost because of the mismatch in institutional scale between the national, regional and local levels. We argue that there is a need to link the different institutional levels in order to pay attention to achieving larger efficiency gains in conservation management.

4.2. *Cost measures*

Appropriate estimates of conservation cost are crucial for the development of efficient protection strategies. Frazee et al. (2003) mention at least five components which are essential for determining a realistic conservation price, these being: estimates of the area of land and water required to represent and maintain biodiversity in a region; identification of a system of protected areas that will achieve these biodiversity-based targets; costs of acquiring and establishing the protected area system; annual expenditure required to effectively manage the system, and information on the costs of off-reserve conservation in the unprotected landscape. The purpose of the current study is to analyse the relative effects of decision-making at different geopolitical scales. We use county-level data on farm estate sales as a surrogate to estimate the economic costs of governmental intervention on farm land for conservation purposes. We use a composite cost measure for conservation including 2000-level prices for real estate sales compiled over the years 1992–2000. In similarity with earlier attempts to estimate the cost of effective conservation and its potential effect on priority setting (for example Ando et al., 1998; James et al., 2001; Balmford et al., 2000), our analysis cannot be used to estimate the financial costs of implementing conservation plans. One may suspect that the

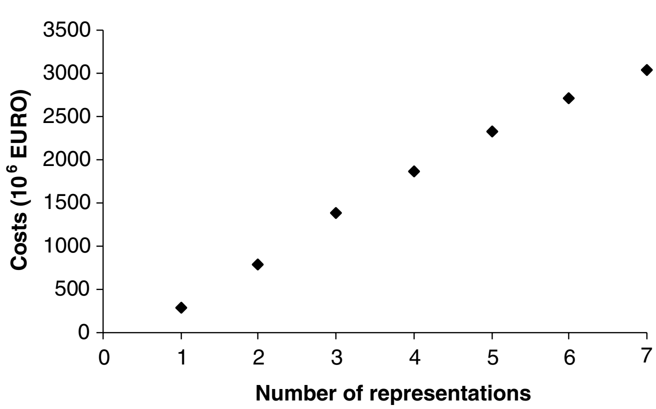

Fig. 7 – The cost of a near-minimum-cost network, with increasing requirements with respect to the minimum number of representations of each species within the network. The analysis is conducted using 30% of the minimum protected share of the land-area within a grid cell.

large relative differences in efficiencies between the regional and national strategies could be outweighed by differences in regional maintenance costs. However, available information on the maintenance costs of conservation areas reveals that there are only marginal cost differences between regions in Denmark (Danish Forest and Nature Agency, 2003; Amtsrådsforeningen, 2002). As a result of this, the relative cost difference between a national and a regional-based analysis may still be relatively large.

Although many factors influence the cost of conservation, we propose that many of these factors can influence the market for farm land, and are therefore reflected in the land prices on new conservation land. Varying conservation policy may also influence conservation costs differently. Biodiversity may be protected following outright purchase, by conservation easements (e.g. Crehan et al., 2005) supported by subsidy or tax relief schemes, by law enforcement or by other regulations, all of which invoke different costs. The effect of incentives as well as the design of agricultural policies have been studied intensively during recent years, in order to identify the economically most efficient policy (for example, Chambers, 1992; Wu and Babcock, 1996; Huth, 2000).

As pointed out earlier, the price of farm land may depend upon its use, productivity, location, governmental payments to farmers or on quota systems. Several studies have examined the extent to which governmental payments, mandatory supply programs and other types of governmental regulation are capitalised into farm land values (Goodwin and Ortalo-Magne, 1992; Herriges et al., 1992; Barnard et al., 1997; Vukina and Wossink, 2000). Another relevant factor in land price is the ownership type. The Danish Agricultural Act allows non-professional farmers to buy a farm, if the total area of the farm does not exceed 30 ha. The real value of such farms has changed according to the real value of urban estates (Danish Ministry of Food, Agriculture and Fisheries, 2000). This has increased the demand for small farms within a reasonable distance of cities. Generally, the interaction of agricultural and urban land-market forces within those areas bordering central cities, or their surrounding suburbs and nearby towns, results in increased farm land values (Chicoine, 1981; Shi et al., 1997). Another important observation is that governmental expropriation may affect the supply and demand for farm land dramatically. Accordingly, changes in farm land prices depend on the elasticity of supply and demand.

5. Conclusion

Nationally and internationally, increasing importance is being attached to the preservation of the overall diversity of the landscape in terms of its biodiversity, as well as its aesthetics and cultural historic value. Recently, Denmark has been criticised for its lack of national strategies and clear priorities for the protection and management of biodiversity (OECD, 1999). Future goals for Denmark include the development of comprehensive, nation-wide area statistics for all protected areas, and the increased co-ordination of biodiversity knowledge and nature monitoring as part of a comprehensive nation-wide monitoring programme. From society's point of view, only limited economic resources can be redistributed from other sectors to maintain or develop habitats for biodiversity conservation. It is therefore critical that conservation resources are utilised in an economically efficient way, so that a maximum number of species and ecosystems can be represented within a network of natural reserves.

Reserve-selection algorithms and gap analyses have been shown to be cheaper in terms of minimizing the area needed to achieve a particular species-representation goal. As demonstrated in this study, the inclusion of illustrative cost, such as land-purchase prices, can further reduce the expected conservation costs substantially. We also show that the higher the administrative level at which strategies for common goals are co-ordinated (in this case national versus regional strategies), the greater the cost reduction that can be achieved. Finally, we demonstrate that the extra cost of lower level-strategies is only weakly countered by the improved coverage of species as a result of more land being protected.

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REFERENCES

Ando, A., Camm, J., Polasky, S., Solow, A., 1998. Species distributions, land values, and efficient conservation. Science 279, 2126–2128.

Amtsrådsforeningen, 2002. Amterne i naturen 2001 [The Counties and the nature]. Amtsrådsforeningen, Copenhagen, 21 pp. [In Danish].

Baagøe, H., 2001. Danish bats (Chiroptera, Mammalia): Atlas and analysis of distribution, occurrence, and abundance. Steenstrupia.

Balmford, A., Gaston, K.J., Rodrigues, A.S.L., James, A., 2000. Integrating costs of conservation into international priority setting. Conservation Biology 14, 597–605.

Barnard, C.H.G., Whittaker, G., Westenbarger, D., Ahearn, M., 1997. Evidence of capitalization of firect government payments into US cropland values. American Journal of Agricultural Economics 79, 1642–1650.

Berkes, F., 2004. Rethinking community-based conservation. Conservation Biology 18, 621–630.

Chambers, R., 1988. Bureaucratic reversals and local diversity. IDS Bulletin 19, 50–56.

Chambers, R.G., 1992. On the design of agricultural policy mechanisms. American Journal of Agricultural Economics 74, 646–654.

Chicoine, D.L., 1981. Farmland values at the urban fringe. An analysis of sale prices. Land Economics 57, 353–362.

Cowling, R.M., Pressey, R.L., Rouget, M., Lombard, A.T., 2003. A conservation plan for a global biodiversity hotspot – the Cape Floristic Region, South Africa. Biological Conservation 112, 191–216.

Crehan, C.L., Newman, D.H., Flick, W.A., Neuhauserz, H., 2005. Land trust activity and highest and best uses under conservation easements in Georgia, USA. Natural Areas Journal 25, 91–100.
Csuti, B., Polasky, S., Williams, P.H., Pressey, R.L., Camm, D.J., Kershaw, M., Kiester, R.A., Downs, B., Hamilton, R., Huso, M., Sahr, K., 1997. A Comparison of reserve selection algorithms using data on terrestrial vertebrates in Oregon. Biological Conservation 80, 83–97.
Danish Forest and Nature Agency, 2003. Budget økonomiske nøgletal [Budget Accounts]. Miljøministeriet, 55pp (in Danish).
Danish Ministry of Environment and Energy, 2000. Areal Informations Systemet–AIS. Miljø-og Energiministeriet, Danmarks Miljøundersøgelser, 110pp (in Danish).
Danish Ministry of Food, Agriculture and Fisheries, 2000. Landbrugets strukturudvikling. [The structural development of the agricultural sector]. Betænkning fra Udvalget vedrørende landbrugets strukturudvikling. Betænkning nr. 1351. Strukturdirektoratet, Ministeriet Fødevarer, Landbrug og Fiskeri (in Danish).
Danish Statistics, 2001. Danmarks Statistik databank. Available from: <http://www.dst.dk>.
Danish Statistics, 2003. Danmarks Statistik databank. Available from: <http://www.dst.dk>.
De Klerk, H.M., Fjeldså, J., Blyth, S., Burgess, N.D., 2004. Gaps in the protected area network for threatened Afrotropical birds. Biological Conservation 117, 529–537.
Dobson, P.A., Rodriguez, J.P., Roberts, M.W., Wilcove, S.D., 1997. Geographic distribution of endangered species in the United States. Science 275, 550–553.
Erasmus, B.F.N., Freitag, S., Gaston, K.J., Erasmus, B.H., van Jaarsveld, A.S., 1999. Scale and conservation planning in the realWorld. Proceedings of the Royal Society London. Biological Series 266, 315–319.
European Environment Agency, 2004. The state of biological diversity in the European Union. Paper prepared for the Stakeholders' Conference Biodiversity and the EU–Sustaining Life, Sustaining Livelihoods Grand Hotel, Malahide, Ireland, 25–27 May 2004, 30 pp. Available from: <http://www.eu2004.ie/templates/document_file.asp?id=17102>.
Fjeldså, J., Rahbek, C., 1997. Species richness and endemism in South American birds: implications for the design of networks of nature reserves. In: Laurance, W.F., Bierregaard, R.O. (Eds.), Tropical Forest Remnants: Ecology, Management and Conservation of Fragmented Communities. Chicago University Press, Chicago, pp. 466–482.
Fjeldså, J., Rahbek, C., 1998. Continent-wide conservation priorities and diversification processes. In: Mace, G.M., Balmford, A., Ginsberg, J.R. (Eds.), Conservation in a Changing World. Integrating Processes into Priorities for Action. Cambridge University Press, Cambridge, pp. 139–160.
Fog, K., 1993. Oplæg til forvaltningsplan for Danmarks padder og krybdyr. Skov-og Naturstyrelsen (in Danish).
Frazee, S.R., Cowling, R.M., Pressey, R.L., Turpie, J.K., Lindenberg, N., 2003. Estimating the costs of conserving a biodiversity hotspot: a case-study of the Cape Florisitc Region, South Africa. Biological Conservation 112, 275–290.
Goodwin, B.K., Ortalo-Magne, F., 1992. The capitalisation of wheat subsidies into agricultural land values. Canadian Journal of Agricultural Economics 40, 37–54.
Herriges, J.A., Barickman, N.E., Shogren, J.F., 1992. The implicit value of corn base acreage. American Journal of Agricultural Economics 74, 50–58.
Holmen, M., 1981. Status over Danmarks Haliplidae (Coleoptera) med bemærkninger om zoogeografi og autøkologi. Entomologiske meddelelser 49, 1–14 (in Danish).
Hull, H.E., Freitag, S., Chown, S.L., Bellamy, C.L., 1998. Identification and evaluation of priority conservation areas for Buprestidae (Coleoptera) in South Africa, Lesotho, Swaziland and Namibia. African Entomology 6, 265–274.
Hunter, M.L., Hutchinson, A., 1994. The shortcomings of parochialism – conserving species that are locally rare, but globally common. Conservation Biology 8, 1163–1165.
Huth, B., 2000. The goals of US agricultural policy: a mechanism design approach. American Journal of Agricultural Economics 82, 14–24.
James, A.N., Gaston, K.J., Balmford, A., 2001. Can we afford to conserve biodiversity? Bioscience 51, 43–52.
Jordan, A.J., 1999. The implementation of EU environmental policy: a policy problem without at political solution? Environment and Planning C (Government and Policy) 17, 69–90.
Kaaber, S., 1982. De danske sværmere og spindere. Geografisk udbredelse og fluktuationer 1850–1980. Dansk faunistisk Bibliotek, bind 3, Scandinavian Science Press (in Danish).
Larsen, F.W., Rahbek, C., 2003. Influence of scale on conservation priority setting - a test on African mammals. Biodiversity and Conservation 12, 599–614.
Lund, M.P., 2002. Performance of the species listed in the European Community "Habitats" Directive as indicators of species richness in Denmark. Environmental Science and Policy 5, 105–112.
Lund, M.P., Rahbek, C., 2000. A quantitative biological analysis of the efficiency of Danish nature management – with emphasis on biological diversity. Working Paper 2000:1. Economic Council, Denmark, 65 pp.
Lund, M.P., Rahbek, C., 2002. Cross-taxon congruence in complementarity and conservation of temporate biodiversity. Animal Conservation 5, 163–171.
Margules, C.R., Nicholls, A.O., Pressey, R.L., 1988. Selecting network reserves to maximise biological diversity. Biological Conservation 43, 63–76.
Martin, O., 1989. Smældere fra gammel løvskov i Danmark, Entomologiske Meddelelser, bind 57, 1–2 (in Danish).
Moore, J.L., Folkmann, M., Balmford, A., Brooks, T., Burgess, N., Rahbek, C., Williams, P., Krarup, J., 2003. Heuristic and optimal solutions for set-covering problems in conservation biology. Ecography 26, 591–601.
OECD, 1999. Environmental performance reviews (1st cycle). Conclusions and recommendations 32 countries. OECD, 299 pp.
Pence, G.Q.K., Botha, M.A., Turpie, J.K., 2003. Evaluating combinations of on-and off-reserve conservation strategies for the Agulhas Plain, South Africa: a financial perspective. Biological Conservation 112, 253–273.
Pressey, R.L., Logan, V.S., 1998. Size of selection for future reserves and its influence on actual vs. targeted representation of features: a case study in western New South Wales. Biological Conservation 85, 305–319.
Pressey, R.L., Nicholls, A.O., 1989. Application of a numerical algorithm to the selection of reserves in semi-arid New-South-Wales. Biological Conservation 50, 263–278.
Rodrigues, A.S.L., Gaston, K.J., 2002. Rarity and conservation planning across geopolitical units. Conservation Biology 16, 674–682.
Rodrigues, A.S, Gaston, K.J., Gregory, R., 2000. Using presence-absence data to establish reserve selection procedures which are robust to temporal species turnover. Proceedings of the Royal Society of London, Series B 267, 1–6.
Scott, J.M., Davis, F., Csuti, B., Noss, R., Butterfield, B., Groves, C., Anderson, H., Ciacco, S., D'erchia, F., Edwards, T.C., Ulliman, J., Wright, R.G., 1993. Gap analysis: a geographical approach to protection of biological diversity. Wildlife Monographs 123, 1–41.
Shi, Y.J., Phillips, T.T., Colyer, D., 1997. Agricultural land values under urbanizing influences. Land Economics 73, 90–100.

Stoltze, M., 1994. An Annotated Atlas of the Danish Butterflies. Ph.D. dissertation. Zoological Museum, Copenhagen, Denmark.
Stoltze, M., Pihl, S., 1998. Redlisted species of flora and fauna 1997 in Denmark. Ministry of Environment and Energy, Danish Environmental Research Institute and Danish Forest and Nature Agency, 219 pp. (in Danish).
Torp, E., 1994. Danmarks svirrefluer (Diptera: Syrphidae). Danmarks Dyreliv, bind 6, Apollo Books, Stenstrup (in Danish).
Vukina, T., Wossink, A., 2000. Environmental policies and agricultural land values:evidence from the Dutch nutrient quota system. Land Economics 76, 413–429.
Wilhjelm Committee, 2001a. En rig natur i et rigt samfund. Danish Forest and Nature Agency, Denmark, 123 p. (in Danish).
Williams, P.H., 1998. Key sites for conservation: area-selection methods for biodiversity. In: Mace, G.M., Balmford, A., Ginsberg, J.R. (Eds.), Conservation in a Changing World. Cambridge University Press, Cambridge, pp. 211–249.
Williams, P.H., 1999. WORLDMAP 4 WINDOWS: software and help document 4.1. London: distributed privately and from http://www.nhm.ac.uk/science/projects/worldmap/.
Williams, P.H., Moore, J.L., Kamden Toham, A., Brooks, T.M., Strand, H., D'Amico, J., Wisz, M., Burgess, N.D., Balmford, A., Rahbek, C., 2003. Integrating biodiversity priorities with conflicting socio-economic values in the Guinean-Congolian forest region. Biodiversity and Conservation 12, 1297–1320.
Williams, P.H., Burgess, N.D., Rahbek, C., 2000. Flagship species, ecological complementarity, and conserving the diversity of mammals and birds in Sub-Saharan Africa. Animal Conservation 3, 249–260.
Wind, P., 2001. Printout from the orchid monitoring database, updated May 2001. Department of Coastal Zone Ecology, National Environmental Research Institute, Kalø, Denmark.
Wu, J., Babcock, B.A., 1996. Contract design for the purchase of environmental goods from agriculture. American Journal of Agricultural Economics 78, 935–945.