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Competing land use in the reserve site selection problem

Frank van Langevelde[1*], Alex Schotman[2], Frits Claassen[3] & Gerard Sparenburg[1]
[1]*Department of Environmental Sciences, Land Use Planning Group, Wageningen Agricultural University, Generaal Foulkesweg 13, 6703 BJ Wageningen, The Netherlands*
[2]*Department of Landscape Ecology, Institute for Forestry and Nature Research, PO Box 23, 6700 AA Wageningen, The Netherlands*
[3]*Department of Mathematics, Operational Research Group, Wageningen Agricultural University, Dreijenlaan 4, 6703 HA Wageningen, The Netherlands*

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Abstract

The objective of this paper is to present an approach that addresses competing land uses in the reserve site selection problem. This approach is implemented in a spatial optimization model for conservation planning in human-dominated landscapes: MENTOR. This model allocates new sites as stepping stones between existing sites. We illustrated the model by a case with competition for space between wildlife habitat and agriculture as it occurs in the Netherlands. We focused on deciduous forests with the European nuthatch *Sitta europaea* as an umbrella species for forest birds. Suitability maps for deciduous forests and for agriculture were applied as input for the allocation model.

Effects on the landscape pattern, nuthatch populations, bird species richness and dairy farming were described. We can conclude that the application of MENTOR leads to an effective reserve network in De Leijen concerning the suitability of the land for dairy farming. The results show a doubling of the average proportion of occupied habitat, an increase in colonization probability of patches, a decrease in extinction probability of local populations, and an increase in bird species richness per patch. Whereas it results in a relatively small reduction in land currently used by agriculture.

Introduction

Developments in land use, especially in agriculture, transportation and urbanization, have led to a continuous decline in biodiversity due to habitat alteration, loss and isolation. Many species were not able to adapt to these changes and their numbers declined or they disappeared (Saunders et al. 1991; Andrén 1994). The need for preserving biodiversity through the selection and management of reserves has generally been recognized (Noss et al. 1997). However, the number and size of the remaining reserves have often become small and spatial claims of competing land use are high. Spatial planning can play a role in the preservation of biodiversity by selecting reserve networks. The effectiveness of selecting reserve networks in human-dominated landscapes depends on the extent to which the spatial claims and suitability of the land for competing land use are included (Van Buuren and Kerkstra 1993; Cook and Van Lier 1994; Nantel et al. 1998).

The reserve site selection problem (RSSP) has drawn increasing interest in conservation planning. A number of approaches has been applied to the problem of selecting sites that should be included in a reserve network (e.g., Margules et al. 1988; Bedward et al. 1992; Arthur et al. 1997; Csuti et al. 1997).

*Present address: Department of Environmental Sciences, Tropical Nature Conservation and Ecology of Vertebrates Group, Wageningen Agricultural University, Bornsesteeg 69, 6708 PD Wageningen, The Netherlands

The solutions for the RSSP have been concentrated on procedures to select existing sites that represent all species or each habitat type in the smallest number of sites. They focus on the selection of reserves based on the present distribution of species. However, the presence of a species in an existing site may depend upon stochastic processes. Especially in small and isolated sites, extinction may exceed colonization. When metapopulation dynamics are operating, only a fraction of the sites that contain suitable habitat is often occupied (Opdam et al. 1993; Hanski et al. 1996). Moreover, it appears that the present distribution of a species may deviate from the expected one due to fragmentation effects (Van Langevelde 1999). It has been argued that unoccupied sites with suitable habitat should also be explicitly considered in the RSSP (Opdam et al. 1993; Hanski et al. 1996). Enlargement of existing sites or addition of new sites may enhance biodiversity. The available space in these landscapes to enlarge habitat patches and add new habitat close to existing habitat is often limited due to competing land uses.

We defined the RSSP as a problem of selecting sites that both enhance biodiversity and minimize the disadvantages for the competing land uses. Therefore, we developed a spatial optimization model: MENTOR (*Model for Ecological Networks as Tool for Optimization of land use Reallocation*). We discuss the outline of MENTOR and illustrate it using a case in the region De Leijen with competition for space between nature and agriculture as it occurs in the Netherlands. The approach can be applied in situations where the RSSP deals with competing land uses, either in rural areas or in urban areas.

Outline of MENTOR

Objective

In human-dominated landscapes, networks of reserves may benefit biodiversity by facilitating exchange of individuals by stepping stones or corridors between the reserves (Opdam et al. 1993; Forman 1995; Hanski et al. 1996). The objective of MENTOR is to assign locations for stepping stones between existing sites. The assignment of the stepping stones is based on ecological guidelines derived from knowledge about population dynamics of the species concerned, and on the suitability of the land for habitat of the species and for other land uses.

Spatial aspects of population dynamics

Many RSSP approaches are conducted as a multi-species approach (Margules et al. 1988; Bedward et al. 1992; Arthur et al. 1997; Csuti et al. 1997). Our model is based on a single-species approach, since species differ greatly in the space they need to complete their life cycles (see also Murphy and Noon 1992; Nevo and Garcia 1996; Hof and Raphael 1997). We used an umbrella species (*sensu* Simberloff 1998) that has such spatial requirements that many other species are assumed to benefit from the reserve network. The presented application of MENTOR is based on the European nuthatch *Sitta europaea*. The nuthatch is a songbird of mature deciduous forests. Deciduous woodlots form the majority of small reserves in the agricultural landscapes on the Pleistocene sandy soils in the Netherlands. The assemblages of forest bird species and the dynamics of the local populations of many bird species in these forest fragments are affected by the size of the fragments and the distance to other forest fragments (Van Dorp and Opdam 1987; Enoksson et al. 1995; Bellamy et al. 1996). Research indicates that populations of nuthatches are affected by fragmentation (Van Dorp and Opdam 1987; Verboom et al. 1991; Enoksson et al. 1995; Bellamy et al. 1998). From the group of birds related to mature deciduous forests, the nuthatch shows strong effects of area and connectivity on presence. If the landscape provides conditions for stable nuthatch populations, we can then also expect that most other forest birds are present (Van Dorp and Opdam 1987).

To derive spatial guidelines for the habitat network of the nuthatch, we examined if two generally accepted principles for reserve design, about habitat area and connectivity, could be applied for the habitat of the nuthatch at the observed spatial scale in the study region De Leijen.

(1) Large habitat patches that support large populations of the species will support this species for longer periods of time than small patches that support fewer individuals. Previous research has shown that the nuthatch occupation probability is higher and local extinction rate lower in large patches than in smaller patches (Van Dorp and Opdam 1987; Verboom et al. 1991; Bellamy et al. 1998). In De Leijen and surroundings, we also found an effect of habitat area on territory occupancy by nuthatches (Van Langevelde 1999). The relationship between the size of a habitat patch and population survival is also supported by Verboom et al. (1993). They simulated population de-

Table 1. Threshold distances for an acceptable probability on successful dispersal of nuthatches between the distinguished size classes of habitat patches.

From:	To: 1–3 ha	To: > 3 ha
1–3 ha	1 km	3 km
> 3 ha	3 km	3 km

velopment in different arrangements of habitat. The results show that the average proportion of occupied habitat by nuthatches increases when a given amount of habitat is distributed in larger patches. Also, the average time to extinction of the population is larger in large habitat patches than in small patches. Moreover, they found that large areas with large populations have a stabilizing role for the populations found in the surrounding fragments.

(2) Habitat patches that are sufficiently connected to allow dispersal support populations for longer periods than habitat patches that are less connected. The distance between the patches mainly determines the connectivity of habitat patches for nuthatches. We could not find any evidence that nuthatches use physical corridors between habitat patches. In regions with fragmented habitat, the connectivity of patches affects nuthatch occupation and colonization (Van Dorp and Opdam 1987; Verboom et al. 1991; Bellamy et al. 1998; Van Langevelde 1999). This can be explained by problematic dispersal of nuthatches in fragmented habitat (Matthysen and Currie 1996; Van Langevelde 1999).

Verboom et al. (1993) found that small nuthatch populations buffered the fluctuations in large populations and served as stepping stones between these large populations. In such situations, the frequency of colonization may be sufficient to minimize regional extinction. The effects of large populations on the colonization of the fragments (see above) and the effects of the populations in the fragments on the large populations diminish with distances between the patches.

Guidelines and strategy of the model

We used the following guidelines for the habitat network of the nuthatch, which were derived from the literature as reviewed above (Table 1). In the Netherlands, breeding pairs of nuthatches are found in fragments of 1 ha with high quality habitat. However, the occupation probability of these fragments is low (Van Dorp and Opdam 1987; Opdam et al. 1994). We assumed that habitat patches of at least 1 ha could act as ‘stepping stones’, since this is considered as the minimum territory size of nuthatches. Nevertheless, a size of at least 3 ha is preferred. The estimated occupation probability for patches of this size exceeds 0.6 (Van Dorp and Opdam 1987). The distance between patches may not exceed certain thresholds because of the necessary exchange of individuals. Empirical studies showed that the amount of habitat within a range of 3 km from the observed patch can significantly explain the patch occupancy and colonization by nuthatches (Verboom et al. 1991; Van Langevelde 1999). We applied 3 km as threshold distance for patches larger than 3 ha. For smaller patches that act as stepping stone (1–3 ha), the inter-patch distance should be at most 1 km since the occupation of these patches is highly dependent on dispersal from surrounding habitat.

We considered two classes of habitat quality, high and low quality habitat. This distinction is made based on vegetation characteristics, especially the trunk diameter of the deciduous trees (Van Langevelde 1999). We assumed that breeding pairs in low quality habitat need twice the amount of area than in high quality habitat based on the nuthatch density in low and high quality habitat, see the densities of breeding pairs as given in Nilsson (1976) and Bellamy et al. (1998).

As shown by Verboom et al. (1993), there should be some large populations in the network that act as a source for dispersing individuals. We assumed that populations of at least 20 reproductive females could be source populations, provided there is an exchange of at least a few individuals per generation with other populations (Quinn and Hastings 1988; Kalkhoven et al. 1995). From the literature, source populations can be found in areas of 30-50 ha mature deciduous forest or 40–200 ha mixed forest (Kalkhoven et al. 1995).

To obtain a reserve network that supports viable populations, the model allocates a path of habitat patches between pairs of selected patches. These selected patches are the ‘pegs’ on which the network hangs. We selected patches, called sources areas, which may support source populations and act as a dispersal source for surrounding patches. When the existing reserves are separated by a distance that exceeds the threshold, adding new sites then connects the reserves. The location of these new sites should be near the existing sites, preferably adjacent to existing sites, but within the threshold distance to existing sites. The final paths contain sets of habitat patches, among which stepping stones are included, that are located within the threshold distances and connect each pair of source populations.

Minimizing competition with other land uses

The problem of competition between the allocation of land for a reserve network and for other land uses can be understood as an optimization problem. Sites with high suitability for wildlife habitat, in our case deciduous forest, should be part of the reserve network. However, they can also have a high suitability for other land uses, in our case agriculture. What should be preferred in these sites: agriculture or wildlife habitat? To address this question, sites with high suitability for habitat and low suitability for agriculture should be included in the reserve network, whereas sites with low suitability for habitat and high suitability for agriculture would remain agriculture. The final decision about the size and configuration of the reserve network depends on the ecological guidelines and the maximum amount of farmland to be transformed to deciduous forest.

We constructed suitability maps for deciduous forest and agriculture. These were the input for MENTOR. Therefore, we divided the landscape into gridcells of 1 ha. The size of the gridcells refers to the minimum area of a nuthatch territory. For each gridcell, the suitability for agriculture and habitat should be known. The position of each gridcell g_{ij} is represented by its coordinates (i, j) in which $i = \{1, \ldots, m\}$ and $j = \{1, \ldots, n\}$. The set of gridcells G is defined as $G := \{g_{11}, \ldots, g_{mn}\}$.

We defined the following coefficients:
Sh_{ij} – the suitability of gridcell g_{ij} for habitat,
Sa_{ij} – the suitability of gridcell g_{ij} for agriculture.
To balance the interest between habitat and agriculture, the suitability of both can be weighted by coefficients. These weights can be interpreted as the priority given by society to agriculture and nature conservation. We used the parameters *Wh* and *Wa* as weighting coefficients:
Wh – the interest of nature conservation,
Wa – the interest of agriculture.
The decision variables are defined as:
x_{ij} – a binary variable indicating whether gridcell g_{ij} is assigned as reserve site ($x_{ij} = 1$) or not ($x_{ij} = 0$).

Now, the allocation problem can be formulated as

$$\text{Max}\left\{Z = \sum_{i=1}^{m}\sum_{j=1}^{n}(Wh \cdot Sh_{ij} \cdot x_{ij} + Wa \cdot Sa_{ij} \cdot (1 - x_{ij}))\right\} \qquad (1)$$

subject to

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} \leq T, \qquad (2)$$

$$x_{ij} \in \{0, 1\} \;\; \forall i, j. \qquad (3)$$

Distances between the stepping stones connecting existing reserve sites may not exceed the threshold distances (see Table 1) (4)

in which T is the maximum available area (i.e., the number of gridcells) of farmland for new habitat, restricted due to, e.g., economic, legal or political constraints.

$$Wh,\ Wa > 0,$$

$$Wh + Wa = 1.$$

Without the constant $\Sigma\Sigma(Wa \cdot Sa_{ij})$, the objective function of equation (1) can be rewritten as:

$$\text{Max}\left\{Z' = \sum_{i=1}^{m}\sum_{j=1}^{n}(Wh \cdot Sh_{ij} - Wa \cdot Sa_{ij}) \cdot x_{ij}\right\}. \qquad (5)$$

For each gridcell g_{ij}, the term $(Wh \cdot Sh_{ij} - Wa \cdot Sa_{ij})$ in equation (5) can be calculated in advance and is called the subtracted value SV_{ij} of gridcell g_{ij}. In MENTOR, the SV_{ij} is used as the optimization criterion for minimizing the competition between allocating new habitat and agriculture. The solution technique to maximize SV_{ij} has been described in Van Langevelde (1999).

The weighting coefficients can have a strong influence on SV_{ij}. However, the influence largely depends on the input data, i.e., the values for Sh_{ij} and Sa_{ij}. For example, a high preference for agriculture with high value for *Wa* will consolidate the value of agriculture in the calculation of SV_{ij}. Table 2 illustrates the impact of the weighting coefficients *Wh* and *Wa* on SV_{ij}. The SV_{ij} values of 4 gridcells were calculated with constant values for Sh_{ij} and Sa_{ij} and variable

Table 2. The impact of the weighting coefficients *Wh* and *Wa* on $SV_{ij} = (Wh \cdot Sh_{ij} - Wa \cdot Sa_{ij})$ [see equation (5)]. SV_{ij} is used as the optimization criterion for minimizing the competition between allocating new habitat and agriculture. SV_{ij} values for 4 gridcells were calculated with constant Sh_{ij} (the suitability of gridcell g_{ij} for habitat) and Sa_{ij} (the suitability of gridcell g_{ij} for agriculture) and different sets of *Wh* and *Wa* ($Wh + Wa = 1$). *Wh* and *Wa* represent the interest for nature conservation and agriculture respectively. For each set of *Wh* and *Wa*, the ranking order of the gridcells was determined from the highest SV_{ij} to the lowest SV_{ij} (between brackets). The values for Sa_{ij} and Sh_{ij} are between 0 and 5, where 0 represents the lowest suitability value and 5 the highest.

Wh	gridcell 1 $Sh_{ij} = 3$ $Sa_{ij} = 0.1$	gridcell 2 $Sh_{ij} = 4$ $Sa_{ij} = 2$	gridcell 3 $Sh_{ij} = 5$ $Sa_{ij} = 2$	gridcell 4 $Sh_{ij} = 5$ $Sa_{ij} = 3$
0.1	0.21 (1)	−1.4 (3)	−1.3 (2)	−2.2 (4)
0.4	1.14 (1)	0.4 (3)	0.8 (2)	0.2 (4)
0.5	1.45 (2)	1.0 (3.5)	1.5 (1)	1.0 (3.5)
0.6	1.76 (3)	1.6 (4)	2.2 (1)	1.8 (2)
0.9	2.69 (4)	3.4 (3)	4.3 (1)	4.2 (2)

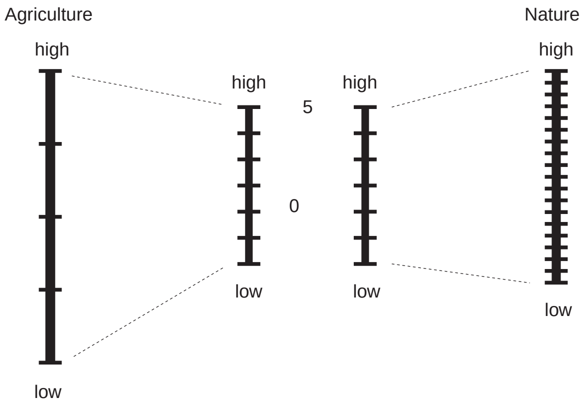

Figure 1. Transformation of the suitability values for agriculture and nature.

values for *Wh* and *Wa*. For each set of *Wh* and *Wa*, the ranking order of the gridcells was determined from the highest SV_{ij} to the lowest SV_{ij}. Due to the weighting coefficients, SV_{ij} and the ranking order of the cells change.

Regarding the principle of calculating the difference between the suitability values, the suitability values should be at one scale in order to make them comparable (in fact, we compare apples and oranges). Given that the suitability of gridcells for both agriculture and habitat varies from high to low values, the highest values may represent the best possible conditions for either agriculture or habitat and gridcells with the lowest values are hardly suitable. However, the nature of the criteria to determine the suitability for both may be very different and they are expressed in different units and scales. One way to make these values comparable is to transform the values (Figure 1). This procedure provides one scale for both the suitability of the land for habitat and agriculture with a fixed minimum and maximum value which represent respectively the lowest and highest suitability.

Estimation of population characteristics and bird species richness

To estimate the effect of the reserve design, we measured some population characteristics in the reserve network. Therefore, we used the spatially structured, stochastic population model METAPHOR (Verboom 1996). This model simulates year-to-year behavior of individual nuthatches in patches. In the model, the mortality, recruitment and dispersal are density dependent. These life history parameters are derived from literature (see Verboom 1996). The spatial location (in terms of *x*- and *y*-coordinates) and the area of the habitat patches form the input for METAPHOR. Based on this information, METAPHOR calculates the maximum number of breeding pairs that can be found in the patches based on the amount of habitat, as well as the probability of dispersal success between pairs of patches based on the distances between patches. The output of the model is the probability of extinction and colonization and the final number of nuthatch pairs in each patch. We simulated the population dynamics of nuthatches for a period of 100 years to determine effects of the number, size and configuration of patches on local populations. We compared the differences in extinction and colonization probability of habitat patches in the present situation and the modelled situations resulting from MENTOR. We used the set of gridcells that contains habitat in the present situation. The gridcells received the extinction and colonization probability of the underlying patches.

To predict the bird species richness in the sites of the reserve network, we used the regression model as presented in Hinsley et al. (1998)

$$N_s = 12.5 + 7.55 \cdot 10\log(A_s),$$

in which N_s is the expected number of forest bird species and A_s is the area (ha) of deciduous forest in patch *s*. This model is based on the data about forest

Box 1. Mapping the suitability of the land for dairy farming

Two criteria were used to map the suitability of the land for the farm types in scenario 1 and 2: the bio-physical and the spatial conditions. These criteria reflect the key processes for optimal production in dairy farming in the Netherlands (Kuijsters and Nieuw-Beerta 1989, Kuijsters and Sparenburg 1990). The bio-physical conditions based on soil type and groundwater level determine the potential yield of the land for grass and maize. Thus, poor bio-physical conditions reduce the potential yield. We used data about the yield reduction for each soil type and groundwater level as found in the Netherlands (Huinink 1993). For both farm types, the potential yield is expressed in economic terms of reduced profits per ha/year (with 0% reduction in potential yield as reference point). The spatial conditions for dairy farming concern the percentage of the acreage that each farm can realize adjacent to the farmstead. This percentage is critical for farm management to reduce the costs of transportation of dairy cows, milk equipment, manure, fertilizers, etc. To obtain this percentage, the number of farms was determined for both scenarios. The region provides space for 437 farms of type 1 (scenario 1) or 219 farms of type 2 (scenario 2). In our current data, 451 dairy farms were present. Therefore, we removed randomly 14 farms for scenario 1, and 232 farms for scenario 2. The reduction in the number of farms together with the enlargement of the remaining farms is in accordance with the trend of the last decades in farming in the Netherlands. This reduction is expected to be the autonomous development. In De Leijen, 332 so called farm units were distinguished. Farm units are areas of contiguous farmland that are bounded by 'permanent' landscape elements, such as roads, streams, urban areas, nature reserves. These elements are expected to be not removed in the future. For reasons of concentrated capital investments in and near the farmsteads, we assumed that the current location of the farmsteads will not change in the future. So, the size of each farm unit limits the possibility for individual farms to realize a certain percentage of the farm acreage adjacent to the farmstead. The percentage was calculated as the ratio of the size of the farm unit and the sum of the sizes of the farms within the unit. Dairy farms require a certain percentage of the farm acreage adjacent to the farmsteads, and the remaining acreage preferably close by. Below this percentage, the costs of transportation become very high. For the farm type with the highest intensity (scenario 1), the percentage is higher than for the less intensive type (scenario 2). When a higher percentage of the farm acreage is near the farmstead, the costs per hectare decrease, and therefore the total added value increases. However, the added value per hectare decreases. Thus, the suitability of these gridcells for new habitat is higher than the suitability of gridcells in a farm unit where the farms cannot realize this percentage. In other words, it is more difficult for farmers to go from 60% of the farm acreage to 50% than from 90% to 80%. The suitability Sa_{ij} of gridcell (i, j) for dairy farming was calculated as the sum of the profits due to the bio-physical and the spatial conditions. Figure 2b presents the values of the suitability of the land for the farm type in scenario 1. The highest suitability value (5.0) was assigned to gridcells with both no yield reduction (0%) and a small percentage of the farm acreage adjacent to the farmstead. The lowest value (0.1) was assigned to grids with 30% yield reduction (the highest percentage in the region) and 100% of the farm acreage adjacent to the farmstead. Value 0.0 in the suitability maps for agriculture was assigned to gridcells that contained urban areas, nature reserves, streams and roads. These gridcells cannot be used for agriculture.

birds by Van Dorp and Opdam (1987). For the bird species richness, we compared the set of gridcells of the patches in the present situation with the same set in the modelled situations. Each gridcell covered by a patch received the number of species that can be expected in the patch.

Case study De Leijen

To illustrate the model, we applied it for De Leijen in Noord-Brabant, one of the southern provinces of the Netherlands (Figure 2a). The region is 15×18 km^2 (27,000 ha). The current landscape is a mosaic of farmland with forests, roads and cities. The dominant land use is agriculture (13,200 ha). Approximately 90% of this farmland is used for dairy farming. Therefore, we considered the suitability of the land for dairy farming. The population density is about 450 persons per km^2 and the present land use is intensive. The use of the land has caused significant environmental stress and, as a result, the biodiversity has been decreased drastically (Van de Sande 1988, Prov. Noord-Brabant 1992). The actual suitable habitat for the nuthatch covers less than 3% of the total area.

The region and surroundings are expected to be important for the distribution of nuthatch populations in the south of the Netherlands (Post and Ongenae 1990). Based on the habitat map and the distribution of the nuthatch, we could identify 5 areas that are large enough to support a source nuthatch population provided that they are part of the network (Figure 2c). Two of them are located in the surroundings of De Leijen. Simulations showed that the forest areas in De Leijen are not large enough to provide adequate conditions for source populations without dispersal from the surroundings. Therefore, a habitat network may contribute to regional population survival.

To illustrate the model MENTOR, we studied the consequences of two existing land use scenarios (CPB 1992). The scenarios contain model farm types (the 'average farm') which can be expected in the future under the conditions of the scenarios (Table 3). Scenario 1 contains a highly productive type of dairy farming, whereas a farmtype with less intensive use is dominant in scenario 2. The two model farm types differ in the size of each farm, the number of dairy cows and their yearly milk production. Based on these characteristics, an index for the intensity of agricultural land use was calculated:

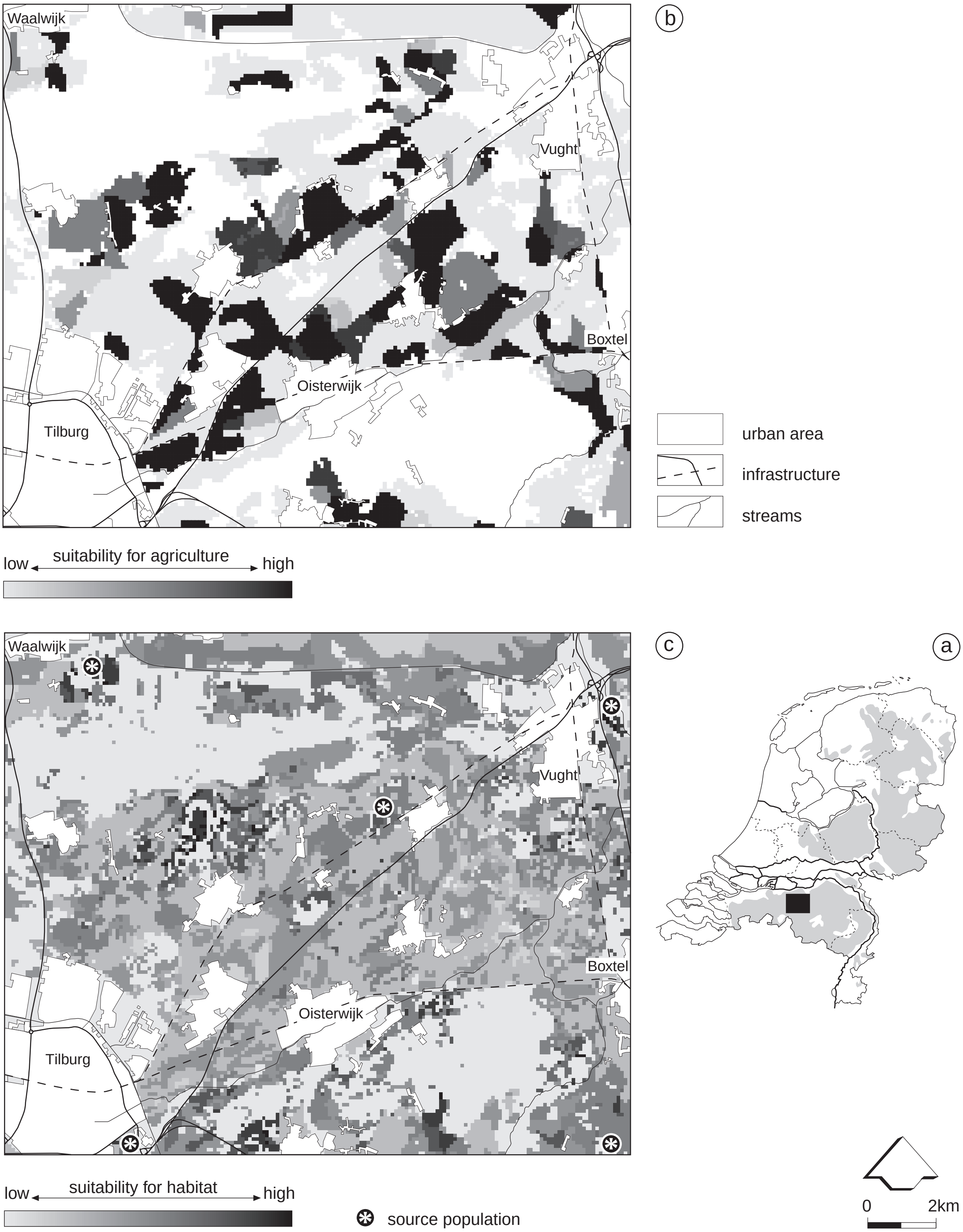

Figure 2. The location of the study region De Leijen on the Pleistocene sandy soils in the Netherlands (a), the suitability map for the highly intensive type of agriculture (dairy farming) in scenario 1 (b) and the suitability map for habitat of the nuthatch (deciduous forests) with the distinguished source areas (patches that can contain source populations) (c). The two markers in the south of the region indicate the locations for connections with source areas in the surroundings of the region.

Table 3. Some characteristics of the two types of dairy farming in scenario 1 (highly intensive) and 2 (less intensive) (see text for further explanation of these scenarios).

	Highly intensive farm type	Less intensive farm type
Farm size (ha)	30	60
Number of dairy cows	70	80
Milk production/cow/year (kg)	8500	7500
Index for the intensity of land use (%)	100	50

Box 2. Mapping the suitability of the land for deciduous forests

We used two criteria to determine the land suitability for deciduous forests: the quality of the actual forests as nuthatch habitat and the bio-physical conditions for potential habitat. The quality of the actual forests as habitat could be described by the dominant tree species and its average trunk diameter. Nuthatches prefer mature oaks (*Quercus robur*, *Q. petraea*, *Q. rubra*) and beeches (*Fagus sylvatica*) with large trunk diameter (Van Langevelde 1999). Data on the average trunk diameter were obtained from the Dutch national forest statistics (CBS 1984) and corrected for additional growth of the trees (Van Langevelde 1999). We applied a regression model that predicts the occupancy probability of nuthatch territories based on these habitat quality variables (Van Langevelde 1999). We used these predictions for the habitat suitability value of the actual forests F_{ij} of gridcell (i, j). The bio-physical conditions determine the potentials for habitat. We used data about the potential growth of deciduous tree species for each soil type and groundwater level as found in the Netherlands (Schütz and Van Tol 1990). Based on these data, the classes 'good potential', 'moderate potential' and 'poor potential' could be distinguished for the potential growth of oaks and beeches. These classes provided values for the biophysical conditions B_{ij} of gridcell (i, j) for the development of habitat. B_{ij} and F_{ij} were scaled between 0 and 5. Since we evaluated scenarios for future developments, the values F_{ij} and B_{ij} were summed as

$$Sh_{ij} = 0.3F_{ij} + 0.7B_{ij}.$$

For non-forested areas, $F_{ij} = 0$. The weights 0.3 and 0.7 were chosen following the relative importance in nowadays society regarding the actual and potential suitability. The final suitability map for nuthatch habitat is shown in Figure 2c. Gridcells that contained urban areas, streams and roads became value 0. These gridcells were excluded from the RSSP.

[(number of dairy cows × milk production per cow)/farm size]. The intensity of the farm type in scenario 1 was set on 100%. The scenarios varied also in the priority of society given to nature conservation. In scenario 1, a high preference is assigned to agriculture ($Wa = 0.9$ and $Wh = 0.1$). In scenario 2, a high preference is given to nature ($Wh = 0.9$ and $Wa = 0.1$). The scenarios may differ in the spatial claims for future agricultural land use. For both scenarios, we assumed that the maximum amount of habitat T added to the reserve network is 5% of the area currently used as farmland.

We mapped the suitability of the land for dairy farming and for deciduous forest based on simple models. These maps represent the key processes for both dairy farming in the Netherlands and the population ecology of the nuthatch in fragmented habitat. Several map layers that contained information about characteristics of the land (soil types, groundwater level, vegetation cover, land use, roads, cities) contributed to an overall value per gridcell. We assumed that the suitability within gridcells is uniform. The procedures we used to obtain the suitability maps for nuthatch habitat and dairy farming are enumerated in Box 1 and 2.

Results of the case study

Effects on landscape pattern

As a result of the allocation of the reserve network in De Leijen, the amount of deciduous forest would increase from 741 ha in the present situation to 1029 ha for scenario 1 and 1036 ha for scenario 2 (Table 4). In the scenarios, deciduous forests cover about 4% of the total area. The total number of habitat patches increases in both scenarios. Figure 3 shows the number of patches in area classes. Due to the addition of new patches, the number of small patches increases. As a result of the combination or enlargement of existing sites, there is a small increase in larger patches. The changes in amount and configuration of habitat should have consequences for the populations of the nuthatch and species richness in both scenarios.

Effects on population response and species richness

Figure 4 shows the average occupation degree of patches in the present situation and for scenario 1 (with the highly intensive farm type). The average

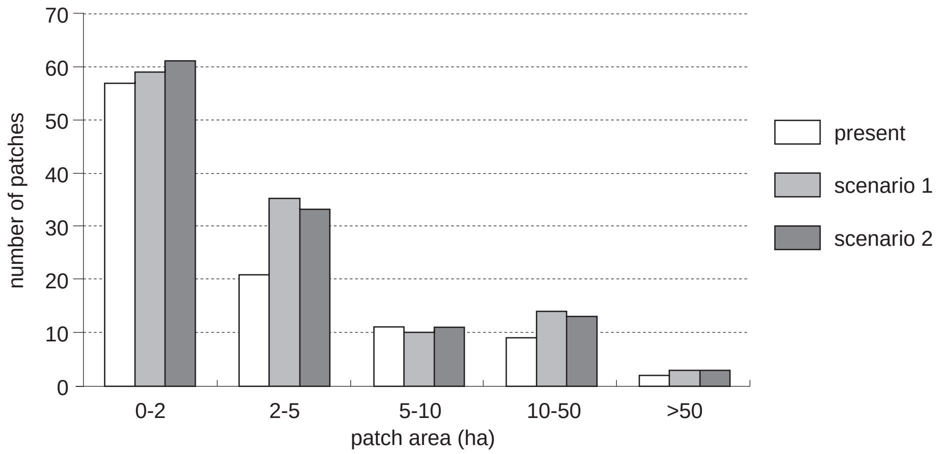

Figure 3. Number of patches per area class for the present situation and the modelled situations under the conditions of the two land use scenarios (see text for explanation of these scenarios).

Table 4. Summary of the results of the allocation of the reserve network in De Leijen based on the two land use scenarios related to the present situation (see text for explanation of these scenarios).

	Present	Scenario 1	Scenario 2
Effects on landscape pattern			
Amount of deciduous forests (ha)	741	1029	1036
Number of habitat patches	100	121	121
Effects on nuthatch populations			
Proportion of occupied habitat (%)	23	38	38
Effects on dairy farming			
Area currently used for dairy farming and assigned as habitat (ha)	0	194	204
Estimation of the reduced yields for dairy farming (%, scenario 1 was set on 100%)	0	100	50

occupation degree per patch is calculated as the ratio between the simulated average number and the maximum number of breeding pairs in each patch. The average proportion of occupied habitat is 23% in the present situation. Due to the planning of new habitat, the average proportion of occupied habitat increases to almost 40% (Table 4). As is argued, there is a clear relationship between the average proportion of occupied habitat and the survival of nuthatch populations. Decreased extinction probability (Figure 5a) and increased colonization probability (Figure 5b) can explain the increase in occupation degree. These figures show the change in number of gridcells with a certain probability value. Especially the colonization probability of the selected set of gridcells changes due to the allocation of the reserve network. The average colonization probability for the set of gridcells increases from 0.23 (s.e. 0.11) in the present situation to 0.64 (s.e. 0.23) in scenario 1 and 0.62 (s.e. 0.24) in scenario 2. We also calculated the expected bird species richness in the patches (Figure 6). High numbers of forest birds can be found in more patches due to the addition of new forest.

Effects for agriculture

We assessed the effects for the agricultural use in terms of the number of farms and of the suitability of the land on which new habitat is planned. Based on the area that can be used for agriculture and the average sizes of the farm types (Table 3), we calculated the number of farms that can be expected in the future. The planning of new habitat required 194 ha for scenario 1 and

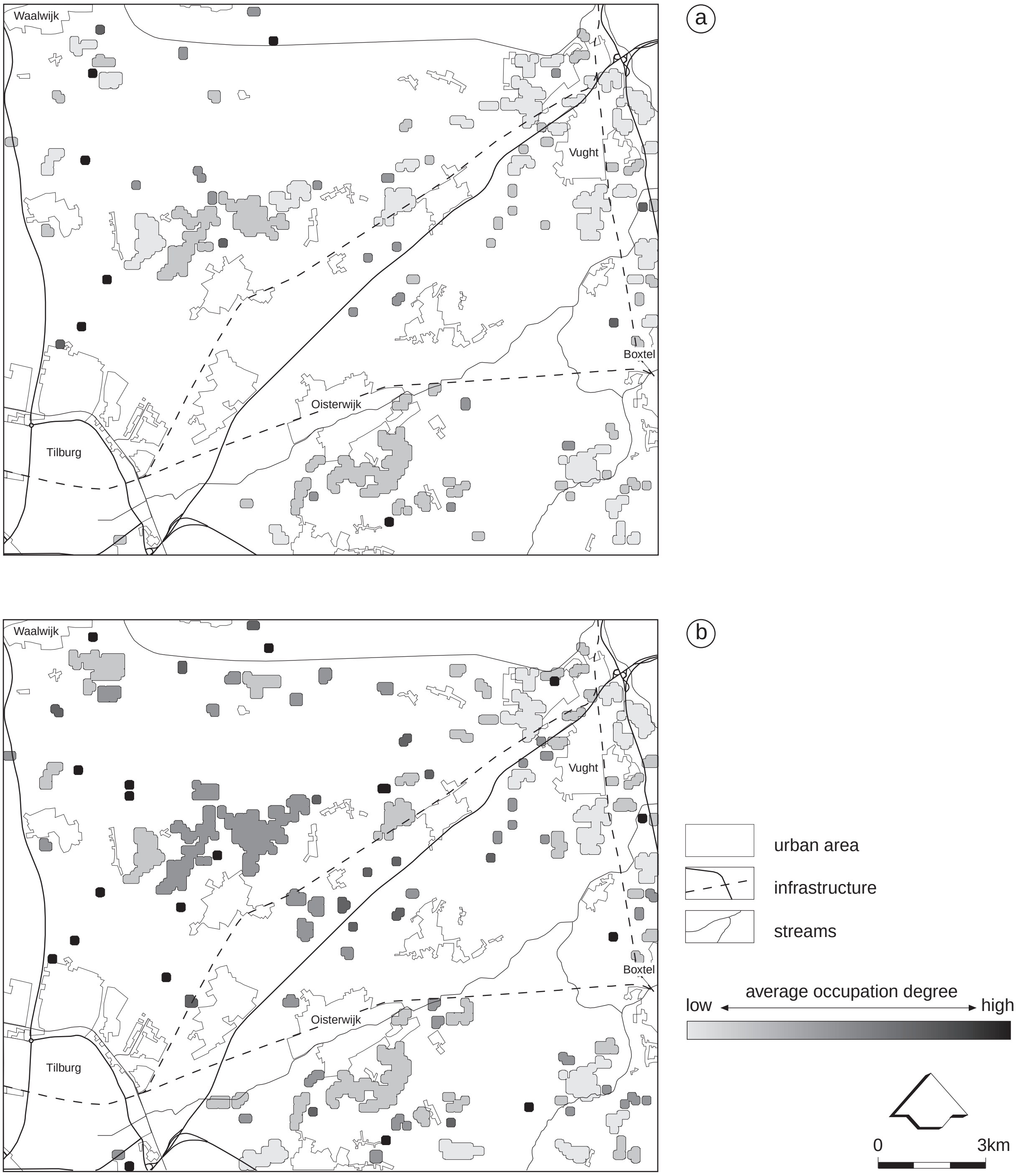

Figure 4. The average occupation degree of patches for the present situation (a) and the modelled situation (b) under the conditions of scenario 1 with the highly intensive type of dairy farming (see text for explanation of these scenarios).

204 ha for scenario 2 (Table 4). This is about 1.5% of the total amount of farmland. Despite of constraint (2), it appears that this percentage is enough to connect the selected source areas. Additional new habitat area (94 ha and 91 ha) will be realized in existing reserves, e.g., by enhancing the habitat quality or transformation

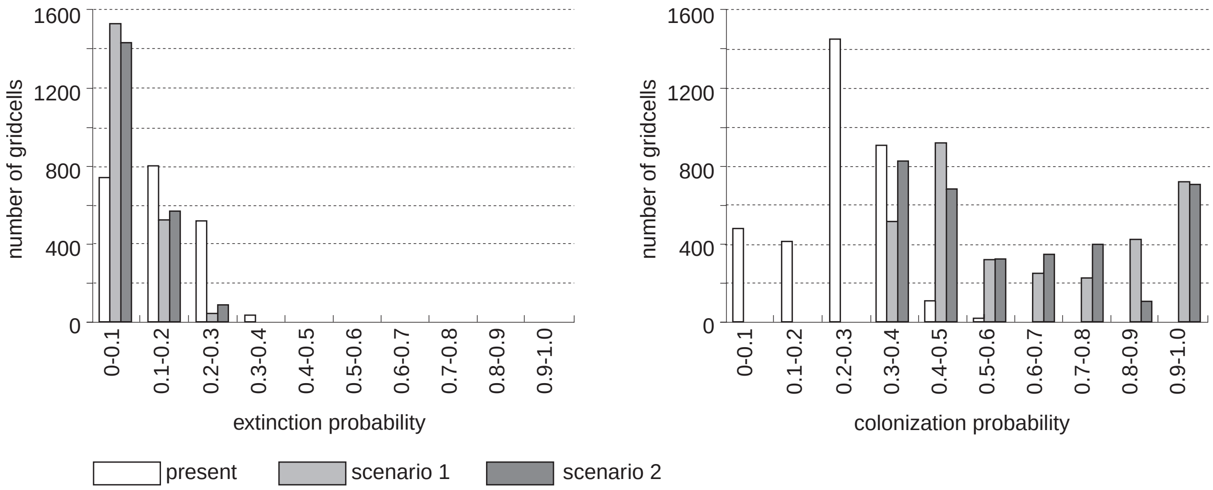

Figure 5. The number of gridcells per class of extinction (a) and colonization (b) probability for the present situation and the modelled situations under the conditions of the two land use scenarios (see text for explanation of these scenarios). The size of a gridcell is 1 ha.

of the forest vegetation from pine trees to oaks. Thus, the total number of future farms appears to be nearly the same. In scenario 1, a minimum of 6 farms can be expected to disappear (from the total of 437 farms). For scenario 2, the reduction will be 3 farms (from the total of 219 farms).

The allocation of future habitat on existing farmland leads to reduced yields. Since the suitability of the land for dairy farming is based on the expected yields for the farmers based on both the bio-physical and spatial conditions (Box 1), we estimated the reduced yields based on the suitability values for agriculture Sa_{ij} of the gridcells that are part of the reserve network. The reduced yields give an indication of the costs for the farmers in scenario 1 related to scenario 2. The area of farmland that is assigned for the reserve network differs slightly between the two scenarios. However, the reduced yields show large differences (Table 4). The hectares with new habitat in scenario 1 with highly intensive use have a higher suitability for the farm type in this scenario than the ones in scenario 2 with a less intensive type. Thus, the expected reduction is lower for the farm type in scenario 2. Allocation of new forests leads to lower costs when the land use in the region is dominated by farm type 2.

Discussion

Our objective was to present an approach that deals with ecological guidelines derived from knowledge about population dynamics of a certain species and with competing land use in the RSSP. We discussed a model for conservation planning in human-dominated landscapes with minimum consequences for agriculture. To make reserve proposals defensible in light of competing land use, we restricted the maximum amount of farmland to be transformed to wildlife habitat. Population dynamics were introduced by the spatial guidelines for minimum sizes of reserves and threshold distances between reserves.

Few examples of model approaches known to us consider population dynamics in the selection of a reserve network (Murphy and Noon 1992; Nevo and Garcia 1996; Hof and Raphael 1997). They also recognize that connectivity between patches is necessary to maintain viable populations when there are no possibilities to plan large reserves. These models give preference to sites in the proximity of others. However, they cannot be used to allocate stepping stones between existing habitat patches. Moreover, they also do not deal with competing land uses.

We acknowledge that our approach is limited to the development of a reserve network that is species-oriented. We focused on a single-species approach since the issues of the size, shape, spacing and quality of reserves can only be addressed as a single-species approach with the available knowledge. Generalization of the spatial requirements of an umbrella species into guidelines for reserve design depends on the spatial scale at which interventions are taken and which species group can be considered to be represented by the umbrella species. The strategy as modelled in MENTOR can also be used for other species. The first

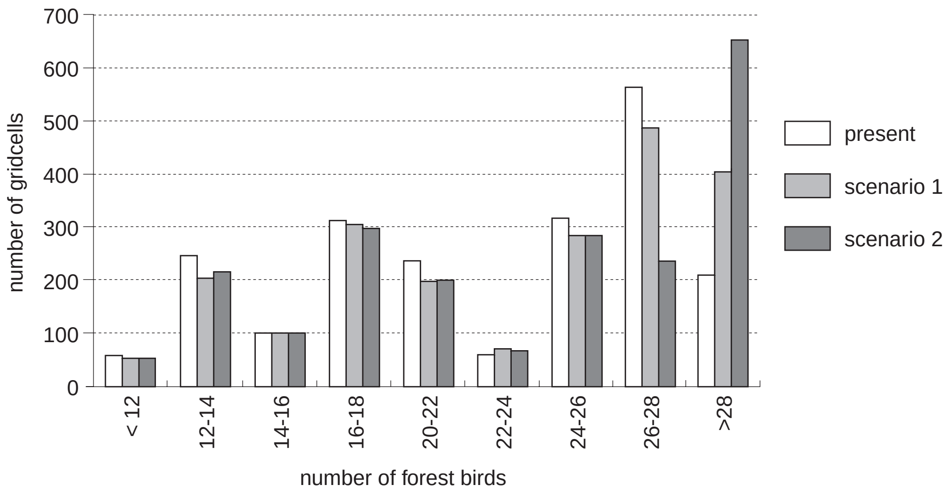

Figure 6. The number of gridcells per class of bird species richness for the present situation and the modelled situations under the conditions of the two land use scenarios (see text for explanation of these scenarios). The size of a gridcell is 1 ha.

prerequisite is that these species benefit from habitat networks, i.e., the reserve design principles should be valid for the species concerned at the observed spatial scale. The second is that the spatial requirements of these species can be formulated in terms of threshold distances and minimum area (according to Table 1). The model can be applied to each scale level depending on the species concerned.

Moreover, our approach is not limited to agriculture and wildlife habitat. It can be applied in situations where conservation planning deals with competing land use, e.g., between timber harvesting and wildlife habitat (Li et al. 1993; Lindenmayer and Possingham 1996). Then, questions appear such as 'what part of the wildlife habitat is necessary for stable populations?', and 'what part can be used for growing timber?'. When more species and land use types are involved, the results contribute to solutions for multiple land use. Although the complexity increases, this should be possible since MENTOR is a general model that requires a few input parameters to be specified and a limited amount of data.

For the case study De Leijen region, we could describe effects on the landscape pattern, nuthatch populations, bird species richness and dairy farming as a result of the planning of the reserve network. The scenarios computed by MENTOR resulted in an increase in area for the reserve network. The results show a modest change in the number of patches. We were able to assess the results of the allocation model with METAPHOR. We conclude that the application of MENTOR leads to an effective reserve network in the human-dominated landscape of De Leijen concerning the suitability of the land for dairy farming. The results show a doubling of the average proportion of occupied habitat, an increase in colonization probability of patches, a decrease in extinction probability of local populations, and an increase in bird species richness per patch. Whereas, it results in a relatively small reduction in land currently used by agriculture: about 1.5% of the total amount of farmland. This percentage appears to be sufficient to connect the source areas, although it does not exceed the constraint of 5% of the area currently used for farming.

The scenarios hardly differ in effects on landscape pattern, on the population characteristics or on bird species richness. Stepping stones had to be allocated to connect pairs of source areas regardless of the intensity of the agricultural land use. Both scenarios provide space for the reserve network with relatively small costs for future dairy farms in terms of amount of land. However, the costs in terms of reduced yields differ largely. The planning of a reserve network in scenario 1 leads to higher costs than in scenario 2. This conforms to assumptions that conservation planning meets less objections when the intensity of the existing land use is low. The effects for agriculture were based on data of model farms. In praxis, individual farms may differ in size or management. This may also lead to differences in costs per farm when plans are realized.

The ability to properly map the suitability of the land has decisive effects on the final results. The suitability maps were solely constructed for the illustration of the model MENTOR. For a refinement of these suitability maps, we can add other factors such as acquisition and management costs and political constraints. We found that our approach is sensitive for maps with many gridcells that have the same suitability value. Maps with a skewed frequency of suitability values may influence the importance of these maps in the approach. As is illustrated in Table 2, the weighting coefficients *Wa* and *Wh* may have a large impact on the results. However, this is not clearly shown by the land use scenarios, because a relatively small amount of habitat had to be allocated as stepping stones to actual farmland. Regarding their possible impact on the results, the weighting coefficients *Wa* and *Wh* can be determined using techniques that are replicable and can differentiate between policy priorities (e.g., Saaty 1980). Spatially explicit assignment of the weighting coefficients is also a further refinement in the application of the model since priorities for nature conservation may differ between parts of the study region.

We did not account for environmental impacts of land use, e.g., on the habitat quality of the reserve network due to the intensity of land use. An improvement of MENTOR could be to minimize environmental impacts of land uses on the reserve network. This can be modelled, e.g., with the use of weights for incompatibility between land uses (Martínez-Falero et al. 1995), or by the selection of locations for the sources of the stress (noise, emission, effects on the groundwater level) at certain distances from the reserve network.

Of course, our approach is not a panacea. Though the approach is, like every model, based on assumptions, it can be used as a baseline against which future developments in land use may be evaluated. Spatial optimization models such as MENTOR can be a supporting tool for formulating alternative land use plans. To assess the effects of the allocation results, evaluation tools are needed. The combination of the allocation model MENTOR and the evaluation model METAPHOR may contribute to prospective solutions for the RSSP and the competing land uses. In general, such combinations provide a useful tool for planners and ecologists to explore the relative merits of alternative land use plans and the dynamics of populations in relation to the amount and spatial configuration. For a study region, this may be of practical significance to explore its opportunities for multiple land use.

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