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Research article

Costs and benefits of protecting linear landscape elements: Applying systematic conservation planning on a case study in the Netherlands

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ABSTRACT

Protecting and increasing linear landscape elements (LLEs) in agricultural lands is regarded as a possible solution for a transition to a more biodiverse agricultural system. However, optimizing the spatial configuration of LLEs protected areas is challenging, especially given the demand for land for food production. *Systematic Conservation Planning* (SCP) can address this challenge, by prioritizing cost-efficient protection areas. We used a SCP approach to look at the LLEs network in the Province of Noord-Brabant in the Netherlands, identifying the possible trade-off between optimizing species conservation, costs and the monetary values of ecosystem services (ES). For this we defined two scenarios. One scenario focuses on achieving species conservation targets at the minimum cost, and the other focuses on achieving targets while maximizing the benefits provided by ES. For each scenario, we further developed two land-management options, namely land-sharing and land-sparing. For each solution, we tested their cost-effectiveness by calculating implementation costs, economic benefits provided by ES, and cost/benefit ratios. First, our scenario analysis indicates that the economic benefits provided by ES always outweigh the implementation costs. Second, it shows that including ES as co-benefits in SCP (*Maximize ES Scenario*) yields more cost-efficient conservation solutions. Third, both land-sharing and land-sparing are possible cost-efficient approaches to achieve conservation targets. Our results are spatially explicit and identify crucial habitat areas for the conservation of the selected species, which represent 12–20% of the current unprotected network of LLEs. Our findings showcase net economic benefit of conserving species and LLEs, thus representing an additional reason for biodiversity conservation.

1. Introduction

Land consolidation and mechanization of agricultural practices of the past decades have led to a consistent modification of European landscapes (Jongman, 2002; Denac and Kmecl, 2021). One of the most visible alterations is the removal of linear landscape elements (LLEs) (*e.g.* hedgerows, wooded banks, field margins) in agricultural areas to make space for large farms and arable crops depending on high input and industrial management practices (Boinot and Alignier, 2022; Niemeijer, 2020). In the Netherlands, this resulted in an estimated loss of 225,000 km of LLEs (Rijsdijk, 2022), with consequent negative impacts on nature, such as biodiversity decline and disruption of Ecosystem Services (ES) (Baudry et al., 2000; Runhaar et al., 2016). These elements, in fact, provide a wide range of ES, crucial in agricultural areas (Phillips et al., 2020; Vanneste et al., 2020), such as pollination, pest control, carbon and nitrogen sequestration, and water and air filtration (Montgomery et al., 2020).

Given current agricultural trends, conflicts arise between the extensive use of land for food production and other services, and the urgent need of conservation requirements (CBS, 2021; Erisman et al., 2016; FAO, 2018; Leclère et al., 2020; Mace et al., 2018). Halting further biodiversity decline has been identified as the main goal of the latest United Nations Biodiversity Conference (COP15), since this is expected to lead to additional loss of ES. Furthermore, there are reasons to believe

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that bending the curve of biodiversity loss and achieve nature positive scenarios can be achieved with synergetic efforts between ambitious nature conservation targets and food system transformations (Leclère et al., 2020).

In this light, conservation and restoration of LLEs in agricultural areas has been identified as a possible solution that contributes to reducing the trades-offs between nature conservation and agricultural production (Blaauw and Isaacs, 2014; Carlier and Moran, 2019; Grass et al., 2016, 2019; Jeanneret et al., 2021). Because the Netherlands is characterized by fragmented multifunctional landscapes, a successful conservation management of LLEs will require a combination of measures, such as land-sharing and land-sparing (Grass et al., 2019, 2021; Immovilli and Kok, 2020; Kremen, 2015; Locke, 2013; Shackelford et al., 2015; Tscharntke et al., 2012; Wilson, 2017). To this end, in line with current EU policies, several Dutch national plans have been proposed to achieve the conservation and restoration of LLEs (e.g. National Strategic Plan; Deltaplan for Biodiversity; Natuur Netwerk Nederland*)* (Ministerie van Landbouw, 2022; Samen voor Biodiversiteit, 2021; Folkert et al., 2020). All of these aim to convert 5%–10% of current arable lands into LLE by 2030 or 2050.

To achieve these targets in time, spatially-explicit conservation and restoration plans are necessary (Armsworth et al., 2017; de Graeff et al., 2021, 2022). However, despite the variety of recommendations and policy agreements, there is little to no translation of such agreements into a spatial operationalisation of these conservation objectives. Also the tools for assessing the financial feasibility of conservation plans are lacking (GLB, 2021, 2022). In fact, optimizing the spatial configuration for the protection of the current network of LLEs is challenging, especially under limited budget and in face of the current trend of increasing demand for land agricultural production. *Systematic Conservation Planning* (SCP) can be used for addressing this combined challenge. It is a spatial-prioritization tool that allows identifying cost-effective solutions for prioritizing areas to achieve clearly stated conservation goals (Margules and Pressey, 2000; Rondinini et al., 2006; Moilanen et al., 2009). It allows the user to identify explicit conservation and/or restoration targets for biodiversity features with associated spatial costs and benefits. Then it selects the available spatial units that allow to achieve all targets while minimizing the costs or maximizing benefits, and staying within the provided constraints.

Traditional SCP analyses focused purely on biodiversity conservation (Cimon-Morin et al., 2013; Diao et al., 2021). However, in the last decade, studies have attempted to include ES into SCP as an additional argument for funding conservation (Fang et al., 2022; Jung et al., 2021; Kukkala and Moilanen, 2017; Remme and Schröter, 2016; Villarreal-Rosas et al., 2020). Most of these studies include demand and supply of ES as a targeted feature to be protected. Monetizing ES could prove to be a powerful incentive for conserving ES and biodiversity, by providing an additional reasons other than ecological and ethical reasons (Cimon-Morin et al., 2013; Egoh et al., 2007; Goldman et al., 2008). In fact, cost-benefit analyses have showed that incorporating ES into SCP as co-benefits or avoided costs could yield a more cost-effective conservation network (Chan et al., 2011), thus constituting an economic justification for biodiversity conservation.

Our overarching aim is to provide tools to gain insights into the balance between costs and benefits associated with the establishment of alternative conservation plans. Our goal is to develop and apply a workflow to identify priority areas to protect species of the Birds and Habitat directive within the current network of LLEs in agricultural areas. To develop cost-efficient conservation plans, we consider financial and opportunity costs, and monetary values of ES (Bhola et al., 2021; Grass et al., 2019; Pennington et al., 2013). We adopt an innovative approach by including into SCP the monetary values of ES as co-benefits (Chan et al., 2011). Following previous work (Karner et al., 2019; Runhaar et al., 2016; Watts et al., 2017), we develop two conservation scenarios. One that aims to achieve species targets while minimizing the costs of the conservation plan ("*Minimize Cost Scenario*") and the other while maximizing the benefits provided by the ES ("*Maximize ES Scenario*"). For each scenario, we discuss two landscape management approaches, land-sharing and land-sparing, which is in line with current European debates on nature conservation in agricultural areas and previous studies (Grass et al., 2019, 2021; Immovilli and Kok, 2020; Kremen, 2015; Mehrabi et al., 2018). Finally, we evaluate if and how the conservation of these elements results in higher economic benefits provided by the ES than the costs associated with the implementation of the conservation plan. The workflow is developed on the current LLEs network in the Dutch province of Noord-Brabant as a case study. It can be used to develop regional conservation plans and obtain financial estimates to inform policymakers on the benefits associated with their implementation. The workflow can be applied in Noord-Brabant as well as other provinces.

2. Material and methods

2.1. Study area

The province of Noord-Brabant is located in the south-east of the Netherlands and covers approximatively a surface of 5082 km^2 (Fig. 1). Noord-Brabant has a total population of about 2.6 million inhabitants (CBS, 2023). The province has an intensively cultivated landscape, with 3,030 km^2 (59.6%) of land dedicated to agriculture, 859 km^2 (16,9%) of build-up areas, and 862 km^2 (16.9%) of nature areas (2017) (CBS, 2023). The total agricultural sector in Noord-Brabant makes a strong contribution in the province economy. It provides 6.3 billion euros in net added value and 76,400 working years of employment. This is 6.5 and 7.1% respectively of the total Brabant economy, and 18.8 and 17.6% of the Dutch agricultural sector (Venema et al., 2019). Due to urbanization and agricultural intensification, most natural ecosystems have been converted, and those that remain are highly fragmented (Jongman, 2002; Lomba et al., 2014). This means that finding the right balance between agriculture and nature is highly important for the province. In fact, Noord-Brabant also hosts some species of national and European importance, such as Hazel dormouse (*Muscardino avellanarious*) and Lesser whitethroat (*Sylvia curruca*) (Sovon, 2023; Verbeylen, 2006). Moreover, the province preserves one of the oldest cultural landscapes in the country, *De Maasheggen,* characterized by 8,000 km of braided hedges (surface of 20 km^2). In 2018 this area has been awarded with the UNESCO Man & Biosphere status *(Maasheggen UNESCO, 2023*) (Fig. 1 A).

2.2. Optimality equation

To develop the workflow for optimizing the protection of LLEs areas, we first translated this problem into a linear programming (LP) decision model, which is frequently used in SCP (Billionnet, 2013; Rodrigues et al., 2000).

In the LP decision model, a conservation activity is assigned to each spatial planning unit (PU). This assignment is as such that multiple conservation targets of multiple features are simultaneously met. Also costs are assigned to each PUs, and an objective function is specified. The conservation activities are assigned in such a way that a solution is found at the minimum costs while still meeting the (multiple) conservation targets.

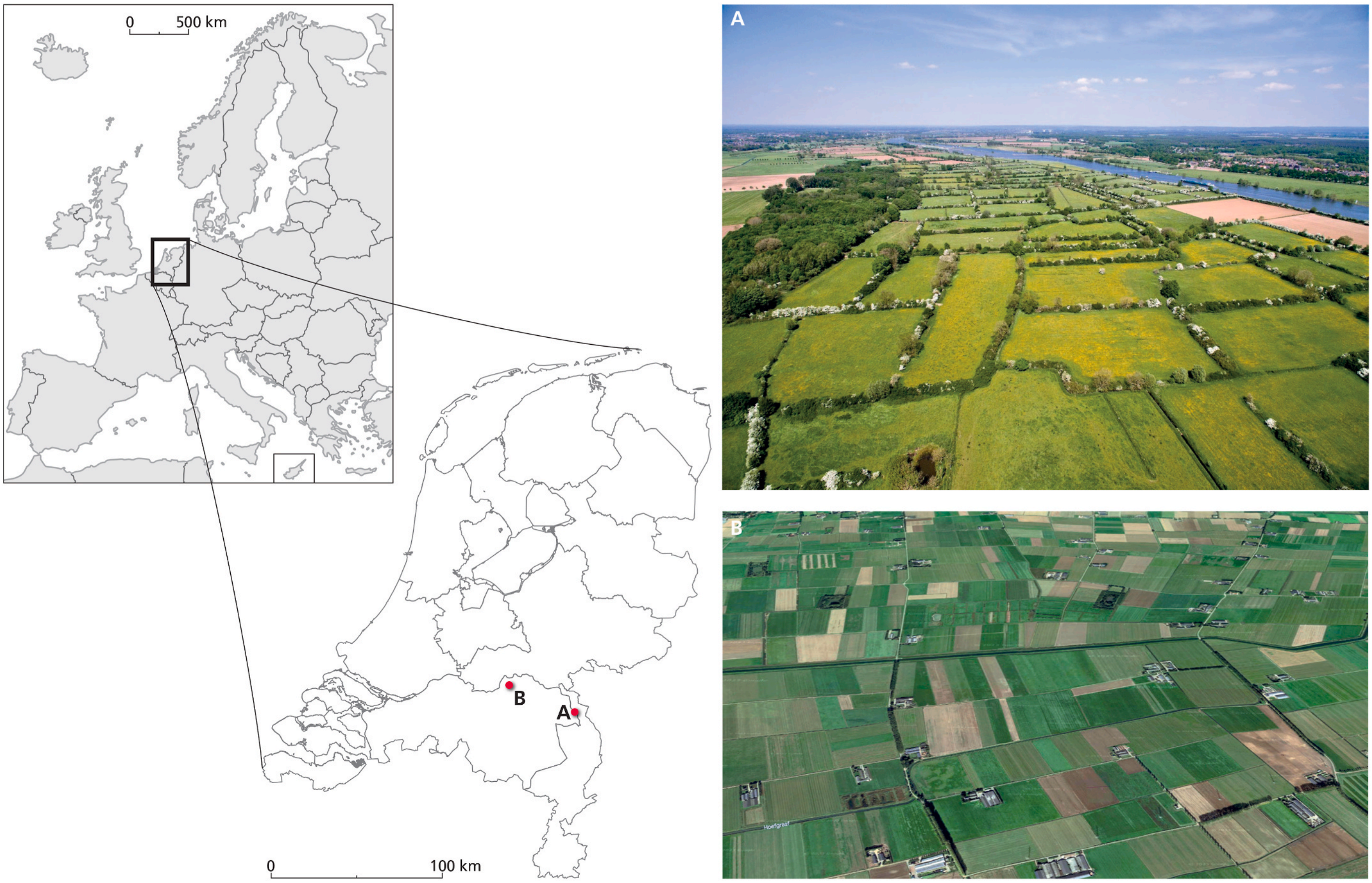

Fig. 1. Left: Map of the Netherland. Right: A) Maasheggen area, UNESCO protected area in Noord-Brabant, resembles how Dutch agricultural landscape used to be. B) Agricultural area representative of modern-day agricultural landscape.

The mathematical expression of this optimization model is:

$$Minimize \sum_{i=1}^{I} x_i c_i \tag{1}$$

subject to:

$$\sum_{i=1}^{I} x_i r_{ij} \geq T_j \forall j \in J \tag{2}$$

Where x_i is the decision variable (e.g., specifying whether planning unit *i* has been selected to be conserved (1) or not (0)), c_i is the cost of planning unit *i*, r_{ij} is the amount of feature *j* in planning unit *i*, and *Tj* is the target for feature *j*. For our case $i = 35.088$ units of 500 × 500 m and $j = 19$ species with specific conservation targets, see further in section 2.3. The first term is the objective function and the second is the set of constraints. In words, our optimization problem finds the set of planning units that meets all the representation targets while minimizing the overall cost (*PrioritizR*, 2023; Rodrigues et al., 2000).

We implemented the LP decision model with the R package *prioritizr* (version 7.1.1.12) (Hanson et al., 2022) and the optimization solver *Gurobi* (2023). The *prioritizr* R package was especially developed to solve spatially-explicit conservation problems (Billionnet, 2013; Hanson et al., 2022).

2.3. Input data

To set up the SCP analysis, three types of input data were used: geographical, biodiversity and cost data (Table 1). The specifics of these data layers are further explained in the subsequent sections (Supplementary Materials, Table 4).

Table 1
Compact list of data.

Data		Description
Geographial data		
	Density map of LLEs in agricultural areas (km/km^2)	Extent of the study area, divided into a set of discrete areas, *planning units* (PUs)
Biodiversity data		
	Species range quantile maps	Set of 19 species of the Birds and Habitat directives highly dependent on LLEs
Cost data		
	Management cost (€/grid/year)	Cutting and trimming LLEs
	Opportunity cost (€/grid/year)	Foregone crop production due to the implementation of the conservation plans
	Carbon sequestration, monetary value (€/grid/year)	Economic value of carbon sequestration as a measure of avoided damage due to CO_2 emissions
	Pollination, monetary values (€/grid/year)	Increased monetary value of crops thanks to the regulating service crop pollination

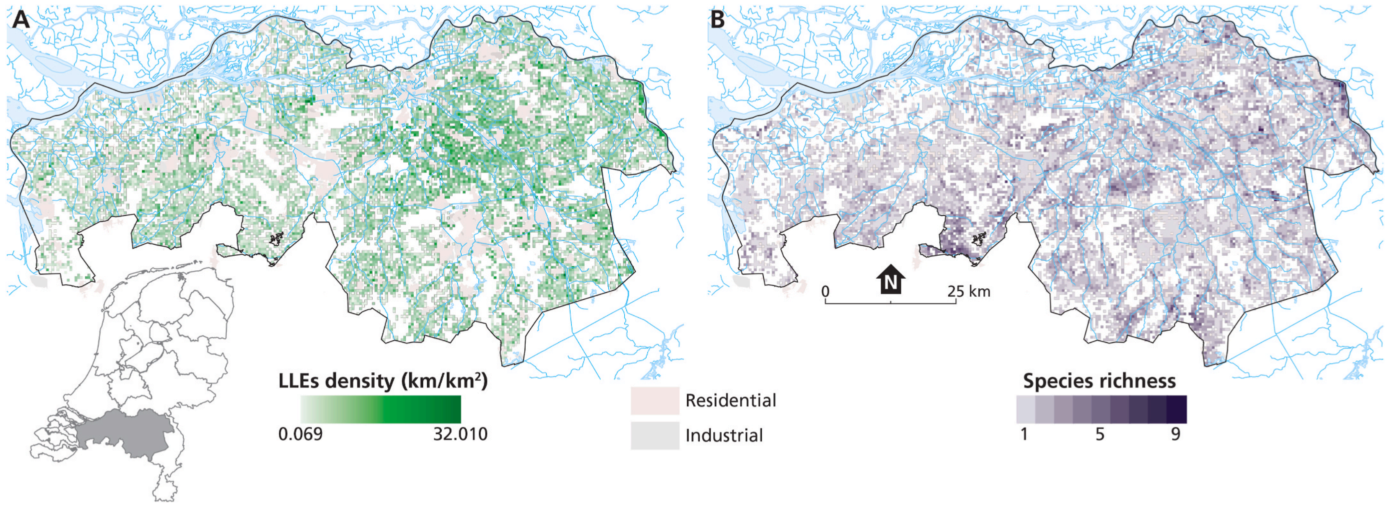

Fig. 2. Density map of LLEs (A) and richness of the 19 selected species (B) in Noord-Brabant, the Netherlands.

2.3.1. LLEs and planning units

We obtained data on the density of LLEs in Noord-Brabant from Statistic Netherlands (van Berkel et al., 2022). LLEs density was calculated by first identifying individual LLEs from the Netherlands' 1:10,000 digital topographic maps. Narrow (<3 m wide) landscape elements are registered as one-dimensional line elements, while wider (>3 m wide) are registered as ordinary tree-covered polygons. A dedicated algorithm was developed to identify those polygons that have an aspect ratio of <10 m wide and >100 m long. The length of both 1D and 2D LLEs was assigned to 500 m grid cells, resulting in a raster map of LLEs density measured in km/km^2.

Among the LLEs there are low and high dense hedgerows, tree lines between fields, as well as higher and open tree lines along roads. The 500 m grid cell resolution is chosen as planning unit (PU) for the entire province. We further selected only PUs that fall within agricultural areas (Fig. 2 A). The location of agricultural areas in Noord-Brabant was compiled from the CBS land-use map (CBS, 2015).

2.3.2. Species and species targets

We prioritized LLEs areas based on conservation targets set for 19 indicator species of the Birds and Habitat directive that depend on LLEs (*BIJ12, 2021*). These are 13 birds, two mammals, three terrestrial amphibians and one insect (Supplementary Materials, Table 5). Among the 13 bird species, nine have an *unfavorable/inadequate* conservation status and three an *unfavorable/bad* status and only one a favourable conservation status. All the other species are reported to be either vulnerable, threatened or endangered.

We retrieved binary species range maps based on the 0.1 and 0.35 quantiles of species probability of occurrence from *Sovon*, the Dutch centre for field ornithology. These maps represent the smallest possible area in which respectively 10% and 35% of the species population is located. The ranges are mapped at 250 m but were resampled at 500 m resolution to match the PUs LLEs density map (Fig. 2 B, and Supplementary Materials Fig. 6).

Species-specific conservation targets for the percentage of each species distribution that should be conserved were set following previous studies (Allan et al., 2022; Rodrigues et al., 2004) and created in two steps. In the first step, we calculated general species-specific targets based on the total species range size (km^2) in the Netherlands. This is done by defining an upper (in our case >10,000 km^2) and lower (in our case <1,000 km^2) bound of the species range area. A 100% conservation target is assigned to species with a distribution smaller than the lower bound (LB), meaning that their entire distribution range should be secured in the conservation plan. A 10% conservation target is assigned to species with a distribution larger that the upper bound (UB). Targets for species with a distribution that falls within the upper and lower bound were set using the logarithmic linear interpolation function of the *prioritizr* package (Hanson et al., 2022; Rodrigues et al., 2004). This yielded logarithmically decreasing targets for species with increasing size of distribution rage. Two amphibian species, *Alytes obstetricians* and *Hyla arborea,* as well as two mammal species, *Myotis emarginatus* and *Muscardinus avellanarious*, one bird species *Corvus frugileus*, and one insect species, *Lucanus cervus,* have a total range smaller than 1,000 km^2 (lower bound). Therefore, a 100% conservation target is assigned to these species. All the other 13 species, which are birds and amphibians, have a range between 1,000 km^2 (lower bound) and 10,000 km^2 (upper bound). Therefore, their conservation targets are log-linearly scaled between the upper and lower bounds, resulting in a value between the 10–100% conservation targets. None of the species has a range bigger than 10,000 km^2, in which case these would have been assigned a conservation target of 10%.

To find final species-specific conservation targets we performed a gap analysis as second step following Allan et al. (2022). In the gap analysis, we adjusted the species targets based on the amount of species range which is already under conservation attention. We calculated the area of each species range that overlapped with the current protected areas network (Natuur Netwerk Nederland – NNN) (Ministerie van Algemene Zaken, 2019) in Noord-Brabant, and expressed this as a percentage of the total species range in the Netherlands. This percentage was subtracted from the species conservation targets obtained by the log-linear interpolation.

2.3.3. Implementation costs

In this study management costs are directly dependent on the LLEs density since the maintenance of these elements has an average cost per meter. Assuming an average width of 2.5 m, we estimated the cost of management (cutting or trimming hedges) to be € 232.79 per 100 m per year (*BIJ12, 2021*). Opportunity costs are costs of forgone opportunities and/or revenues due to the implementation of the conservation plan (Adams et al., 2010). For agricultural areas this equals to the value of lost crop production, derived from matching data on crop type and prices (D'andrimont et al., 2021; van Everdingen and Wisman, 2018). The final implementation cost map is represented by the sum of management and opportunity costs (Supplementary Materials, Fig. 7).

$$\mathit{Implementation\ Cost} = \mathit{Management\ cost} + \mathit{Opportunity\ cost} \tag{3}$$

2.3.4. Monetary values of ES, carbon sequestration and pollination

We obtained spatially explicit data on monetary values of ES Carbon Sequestration and Pollination from CBS (Horlings, 2020; van Berkel et al., 2022) (Supplementary Materials, Fig. 8). These are maps at 500 m resolution that give information of the monetary value of ES per grid cell per year (€/ha/year). The economic value of carbon sequestration represents a measure for avoided damage due to CO_2 emissions. This is calculated based on the price at which the necessary cumulative reduction in CO_2 emissions is achieved at the lowest costs (Aalbers et al., 2016). Called the efficient price of CO_2. The economic value of pollination is defined as the avoided crop production loss, expressed in euro/ha, thanks to the regulating service of crop pollination by wild pollinators (Klein et al., 2007). Maps for the pollination service were based on a spatial analysis of both supply (spatial location of ecosystems that are suitable for pollinators) and demand (spatial location of crops that require pollination) of the service (Remme et al., 2018; van Berkel et al., 2022).

In this study, we used spatial data of monetary values of ES as benefit layer. This represents the potential economic gain provided by the ES due to the conservation of LLEs. In order to create the ES benefit map, we inverted the monetary values maps by subtracting the value in each grid cell from the maximum value of the map. The final cost layer is described by the following formula.

$$Benefits = mv\ Carbon\ sequestration + mv\ Pollination \tag{4}$$

where *mv* is monetary value.

2.4. Scenarios

Table 2 shows the analysis framework. We developed two conservation scenarios, and for each scenario we created two solutions. One scenario aims to achieve species targets while minimizing the costs of the solution (*Minimize Costs Scenario*) (Table 2 A-B); the other scenario while maximizing the monetary values of ES (*Maximize ES Scenario*) (Table 2 C-D). The main difference between scenarios is the cost layer employed. We used management and opportunity costs in *Minimize Cost Scenario*, and monetary values of ES in *Maximize ES Scenario*. In the latter, the monetary values of ES are employed as benefits (Chan et al., 2011).

For each scenario we further evaluated two land management approaches (solutions), land-sharing and land-sparing, that exhibit different levels of spatial compactness. To develop these solutions, we applied spatial constraints (boundary penalties) to the objective function. The higher the boundary penalty, the more it favours solutions that spatially clump planning units together based on the overall boundary length (perimeter) (Hanson et al., 2022). This creates outcomes with grid cells that are spatially scattered at low values of the boundary penalty which become progressively spatially more clumped for higher values of the boundary penalty.

After the SCP analysis, we conducted a post-hoc analysis to gain insight into the cost-effectiveness of our solutions. Here, we calculated implementation costs, return in economic benefits provided by ES and the cost/benefit ratio: economic advantages in terms of benefit provided by the ES per costs (€ spent) for the implementation of the conservation plan. In addition, we calculated the proportion of LLEs network secured in each solution.

2.5. Sensitivity analysis

The design of our SCP workflow is affected by multiple methodological decisions, which are summarized in Table 6 (Supplementary Materials). To explore how this may affect our outcomes, we carried out a sensitivity analysis by performing multiple SCP runs, using different combinations of parameter values. We executed a total of 2,352 runs considering variations in (1) lower and (2) upper bound of target setting, and (3) costs (Supplementary Materials, Table 7, Plot 1). Regarding the lower bound used for defining species targets, we create a sequence of 14 values, ranging from 100 km^2 to 6,000 km^2, following a logarithmic increase (Supplementary Materials, Table 7). The logarithmic increase gives more values for lower numbers (where small changes have a large effect), and less for higher numbers (where small changes have a small effect). This choice was made because the maximum range area of the selected species is 5,320 km^2, therefore variations in the outcome are expected for values lower than that. Contrarily no variations are expected for values higher than 5,320 km^2 because all species would have the same conservation target across runs. For the upper bound, a sequence of 14 numbers ranging from 7,000 km^2 to 20,000 km^2 was created (Supplementary Materials, Table 7). For the costs, we used 3 possible combinations per scenario: either one of the two cost layers or both layers together (Supplementary Materials, Table 7 and Plot 1). By using these values, 588 iterations (14 lower bound times 14 upper bound times 3 combinations) per land management type (land-sharing & land-sparing) and cost type were set up, obtaining 1,176 different solutions per scenario. Generalized Additive Models were fitted on the outcomes of the sensitivity analysis to evaluate which variables explained most of the results. We then evaluated the effect of each predictor variable on the implementation costs, the economic benefits of ES, and the cost/benefit ratio.

3. Results

3.1. Species targets and range overlap with NNN areas

Target setting for the species range to be protected consisted of two steps: log-linear interpolation and gap analysis. The gap analysis produced final species-specific targets by correcting the species conservation targets for the proportion of species ranges already located in conservation areas at the scale of Noord-Brabant, which are shown in Fig. 3. On average only 25.3% of the species ranges (birds 24.5%; amphibians 25.5%; mammals 24.5%; and insects 10.2%) overlaps with the NNN areas in Noord-Brabant. The least unrepresented species are three bird species *Falco tinnunculus*, *Sturnus vulgaris*, *Turdus viscivorus* and one amphibian species *Alytes obstetrician* (<10% range overlap with NNN areas) (Fig. 3, light blue bars). For two-thirds of the species (eight birds, two amphibians, two mammals and one insect), the proportion of species range that requires conservation attention is bigger than what is currently protected by NNN areas in the province. Only in few cases, five birds (*Athene noctua, Emberiza cintrinella, Triturus cristatus, Linaria cannabina and Columba palumbus)* and one amphibian (*Phoenicurus phoenicurus*), the species are already well represented in NNN areas. Thus, their

Table 2
SceanrioFramework

		Land Sharing		Land Sparing
Minimize Cost Scenario	**A**	Costs = Management + Opportunity Objective: Minimize Costs	**B**	Costs = Management + Opportunity Objective: Minimize Costs
Maximize ES Scenario	**C**	Benefits = *mv* Pollination + *mv* Carbon Sequestration Objective: Maximize *mv* ES	**D**	Benefits = *mv* Pollination + *mv* Carbon Sequestration Objective: Maximize *mv* ES

**mv - monetary values*

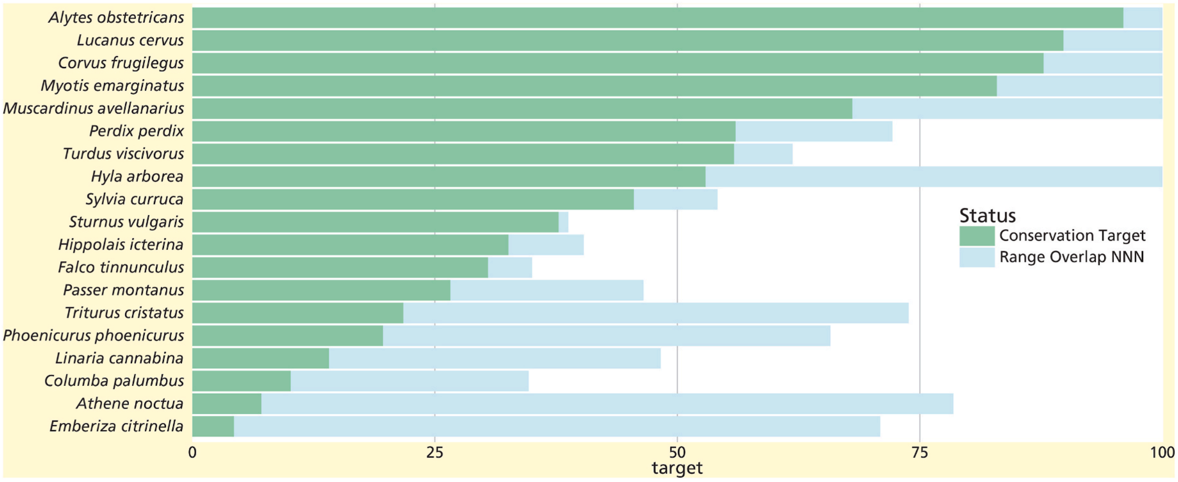

Fig. 3. Stacked bar plot showing species conservation targets, given as a percentage of the total species range in the Netherlands. The total bar length (green and light blue bars) shows the overall species conservation target calculated with the log-linear interpolation function. The green bars show final species-specific conservation targets, calculated by subtracting the percentage overlap of the species range with protected natural areas (NNN) (light blue bars) from overall species conservation targets (total bar length). The light blue bars show the current overlap of species-specific ranges in Noord-Brabant with NNN areas in the province. See Supplementary Materials, Table 8 for specific targets values.

final conservation target is smaller than the proportion of their currently protected range.

3.2. *Conservation plans based on four scenarios*

The scenario analysis produced four cost-effective conservation plans that identify optimal areas within the network of LLEs to reach species conservation targets. Two conservation plans for land-sharing, where spatial constraints (boundary penalties) were not applied; and two for land-sparing, in which penalties were applied (Fig. 4, A-B-D-E).

In all four conservation plans, the economic benefits provided by the ES are nearly twice as large as the implementation costs (Table 3). Across scenario and land management type, pollination is the main contributor to the total economic benefit, with values ranging between €11.1 and €13.9 million (Table 3). Instead, carbon sequestration represents a smaller source of economic benefit provided by the conservation plans, with values ranging from €3.0 to €3.5 million (Table 3). Paired sharing and sparing solutions differ little across scenarios and exhibit similar spatial patters and cost/benefit outcomes. However, land-management type solutions considerably differ within each scenario (Fig. 4C–F). Land-sharing solutions require a smaller economic investment than land-sparing (€4.9 million and €6.9 versus €7.9 and

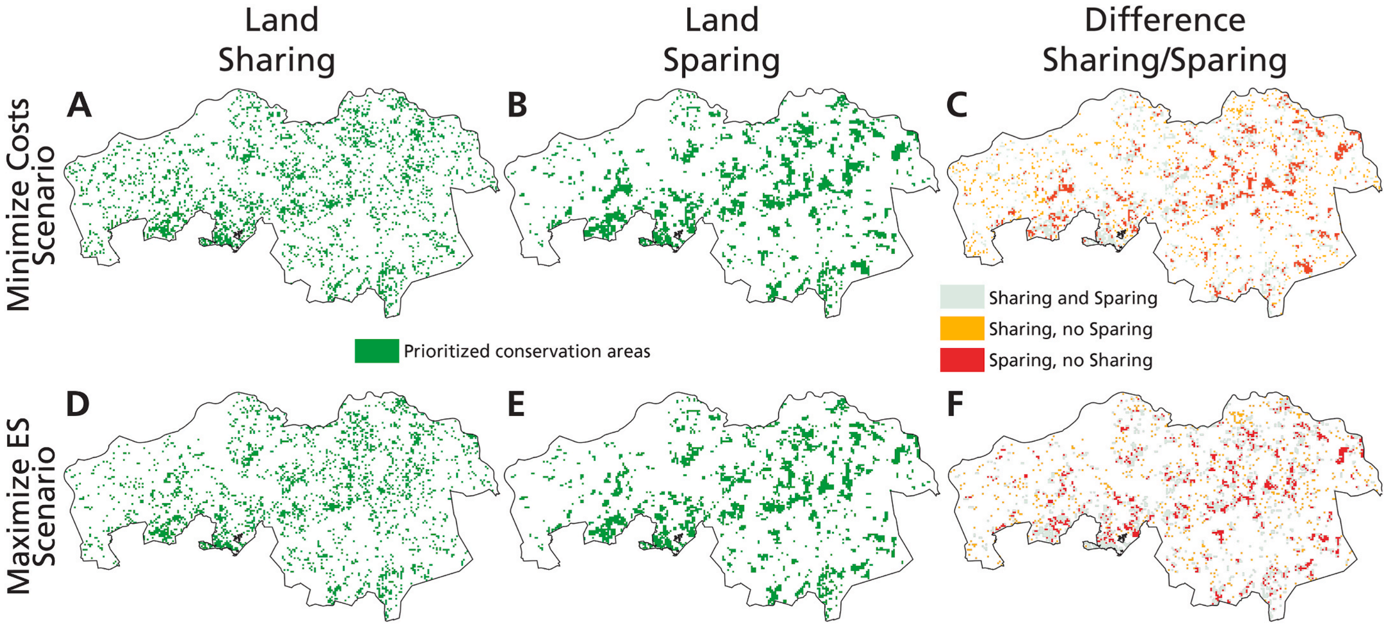

Fig. 4. The figure shows the four conservation solutions, two for each scenario. The upper row shows solutions for *Minimize Costs Scenario* (A, B). The lower row shows solutions for *Maximize ES Scenario,* (D, E). The columns show solutions for each conservation management approach: Land-Sharing in the first column (A, D); Land-Sparing in the second column (B, E). The third column (C, F) shows the difference between the two land management approaches within the same scenario.

Table 3
The table shows the proportion (%) of LLEs network secured in the solutions (A-D), the area (km^2) of LLEs, the ratio between monetary values of ES saved per each euro spent, implementation costs and monetary values of ES secured in the solutions, in total (ES saved) and per ES.

		Land Sharing		Land Sparing
Minimize Cost Scenario	**A**	12.2% LLEs network conserved 5.1 km^2 LLEs €2.90 ES saved for €1 spent Costs € 4.9 M ES saved € 14.5 M Pollination € 11.4 M C.Sequestration € 3.5 M	**B**	19.0% LLEs network conserved 8 km^2 LLEs €1.80 ES saved for €1 spent Costs € 7.9 M ES saved € 14.2 M Pollination € 11.1 M C.Sequestration € 3.1 M
Maximize ES Scenario	**C**	16.9% LLEs network conserved 7.1 km^2 LLEs €2.43 ES saved for €1 spent Costs € 6.9 M ES saved € 16.9 M Pollination € 13.5 M C.Sequestration € 3.3 M	**D**	20.4% LLEs network conserved 8.5 km^2 LLEs €1.66 ES saved for €1 spent Expenses € 8.3 M ES saved € 14.0 M Pollination € 13.9 M C.Sequestration € 3.0 M

€8.4, see Table 3 and Fig. 4), and have a higher cost/benefit ratio, respectively €2.90 and €2.43 in *Minimize Costs Scenario* and *Maximize ES Scenario*. While this is €1.80 and €1.66 in land-sparing solutions.

To achieve the conservation of the 19 selected indicator species, 12–20% of the LLEs network needs to be added to current conservation areas (NNN). This has an operating cost that ranges from €5 to €8.5 million with associated economic benefits provided by the ES pollination and carbon sequestration of about €14–17 million (Table 3).

3.3. *LLEs in land-sharing and land-sparing solutions*

The area of LLEs network prioritized for the conservation of the selected indicator species differs across land-management type solutions (Fig. 4C–F). Land-sharing solutions require a smaller area for achieving species targets at minimum cost or for the maximum return in ES benefits. This is 12.2% (5.1 km^2, 2,721 grid cells) and 16.9% (7.1 km^2, 2,427 grid cells) of the total LLEs network in Noord-Brabant (currently 41.9 km^2), for the *Minimize Costs Scenario* and *Maximize ES Scenario* respectively. Land-sparing solutions require a larger area, which amount to 19.0% (8 km^2, 2,911 grid cells) and 20.4% (8.5 km^2, 2,778 grid cells) (Table 3, Fig. 4). The larger area required for achieving species targets is due to the boundary penalties applied to land-sparing solutions. No considerable differences in spatial patterns between same land-management solution across scenario were found.

3.4. *Sensitivity analysis*

The marginal effect plots (Fig. 5) show the cost/benefit ratio sensitivity to variations of lower (LB) and upper (UB) bound for defining species targets (see methods 2.3.2), as well as its dependence on cost layers. The cost/benefit ratio remains positive in all the iterations of the sensitivity analysis, meaning that the economic benefits of ES always outweigh the costs, independent to the parametrizations of the conservation areas for the species. In land-sparing solutions of *Minimize Cost*

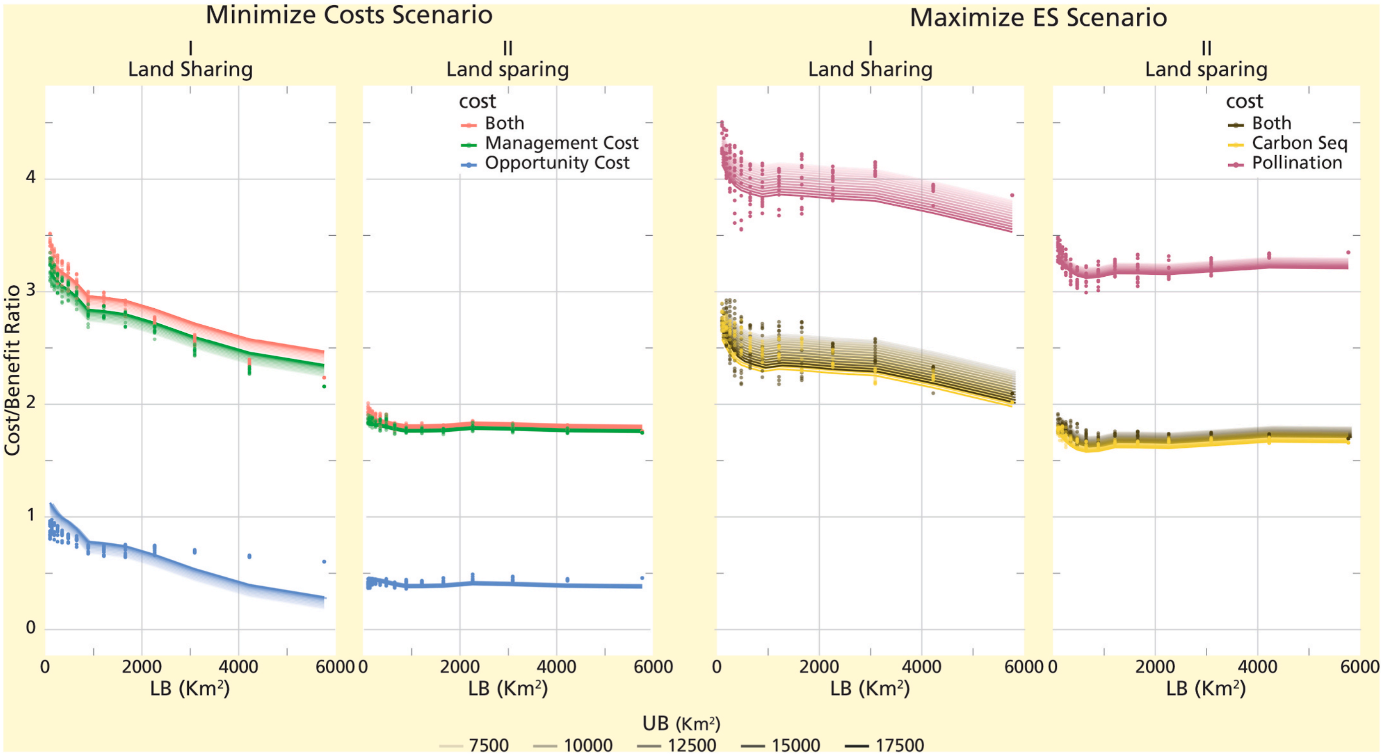

Fig. 5. Marginal Effect Plots of the sensitivity analysis. For each scenario the plots show variations in the cost/benefit ratio (y-axis) relative to changes in (1) LB -Lower Bound in x-axis, (2) UB - Upper Bound shown by line shades (see also legend at the bottom), and (3) Costs, shown by colors.

Scenario and *Maximize ES Scenario*, the cost/benefit ratio is less influenced by variation in LB and UB. This is because the penalties applied to fragmented solutions have a stronger influence than the target setting parameters. Overall, the marginal effect plots on the cost/benefit ratio indicate that the internal parametrization - variations in LB, UB and cost layers – is less influential across scenarios than the external land-sharing/land-sparing narratives.

In addition, both implementation costs and return in ES benefits are sensitive to the variables used. Across scenario and land-management types, LB has a strong positive effect on the amount of ES secured in the solution and the costs, while UB has a small positive effect. Regarding the effect of cost layers, the marginal effect plots show that in *Maximize ES Scenario*, Pollination has a positive effect on the cost/benefit ratio, while Carbon Sequestration has a strong negative effect. In *Minimize Costs Scenario*, the cost layer Management Cost has a strong positive effect on the cost/benefit ratio, while Opportunity Cost has a negative effect.

4. Discussion

4.1. Conserving nature is economically convenient

With this Systematic Conservation Planning (SCP) analysis we identified four different conservation plans to optimize the protection of Linear Landscape Elements (LLEs) and achieve species conservation goals. The results show that even though substantial investments are necessary for achieving the conservation of threatened species belonging to the Birds and Habitats Directives and LLEs in Noord-Brabant, the financial benefits greatly exceed the costs. In fact, by adding 12–20% of the current LLEs network in agricultural lands to conservation areas (NNN), the economic benefits provided by carbon sequestration and pollination can offset the implementation costs by two times (Table 3), which is in line with similar global studies (Claes et al., 2020; Waldron et al., 2020), other regional cost-benefit analyses (Naidoo and Ricketts, 2006; Remme and Schröter, 2016), and field studies (Morandin et al., 2016).

SCP attempts to achieve conservation targets for the lowest cost, and therefore the selection of the cost layers is crucial to inform the prioritization process and describe the expenditure of each planning unit. Moreover, previous studies have demonstrated how integrating cost data into SCP problems can achieve larger biological gains than when the costs are ignored (Ando et al., 1998; Ferraro, 2003; Naidoo et al., 2006; Stewart and Possingham, 2005). In standard SCP analysis, different types of implementation costs are usually considered, such as acquisition, management, transaction, opportunity and damage costs (Naidoo et al., 2006). In addition, traditional conservation planning analyses solely aim at biodiversity. However, more recent studies have showed that combining Ecosystem Services (ES) and biodiversity is more effective for conserving both, than when these features are treated separately (Cimon-Morin et al., 2013). Several studies have already demonstrated the importance of including supply and demand of the ES for effective conservation (Cimon-Morin et al., 2014; Cimon-Morin and Poulin, 2018; Villarreal-Rosas et al., 2020), and to preserve more features of ecological importance then when planning conservation only based on biodiversity (Remme and Schröter, 2016). However, because of the complexity of social, ecological and economic attributes of ES, a common approach for handling this type of data in SCP is still missing, and most studies include ES as a targeted feature to be protected (Cimon-Morin and Poulin, 2018; Fang et al., 2022; Jung et al., 2021; Mu et al., 2022; Villarreal-Rosas et al., 2020).

In our study, we have combined these information and considered two types of costs: management and opportunity, as in standard SCP analyses, and monetary values of ES, (carbon sequestration and pollination) (Biffi et al., 2022), which are rarely used in SCP (Chan et al., 2011). We included monetary values of ES as avoided costs for estimating the economic benefits provided by the conservation of LLEs. We found that this approach yields higher economic benefits than when traditional costs are employed (Table 3, Fig. 4), which is in line with results of Chan et al. (2011), that shows that including monetary values of ES as co-benefits or costs yields more cost-effective conservation plans than when ES are included as targeted features.

Including ES in our SCP analysis allowed us to gain insight into the balance between costs and benefits of conservation scenarios. Because features of socio-ecological importance such as ES have been identified as an incentive for conserving nature, our results could further justify the utilization of monetary values of ES in SCP for funding conservation (Cimon-Morin et al., 2013; B. Egoh et al., 2007; Goldman et al., 2008; Knight et al., 2006).

It is however important to highlight that assigning an economic value to ecosystems rises the ethical concern of seeing nature as a commodity to be used by humans, distracting from its intrinsic value, which should not be forgotten (Horlings, 2020; van Berkel et al., 2022). The economic considerations here described in no way should compete with the ethical arguments for conservation, because maintaining diversity of life on Earth is essential in its own right.

4.2. The need of an expanded basket of ecosystem services

Whether ES are included or not in the SCP analysis, we identified that in the four conservation plans the economic benefits provided by ES are always greater than the cost, which is in line with previous studies (Balmford et al., 2002; Cimon-Morin et al., 2013). Nonetheless, these economic benefits are underestimated. The reason is that the ES accounting maps reflect only about 30% of the LLEs density. This is because they are based on models that only include 2-dimensional LLEs (wider than 3 m) but exclude the 1-dimensional LLEs (up until 3 m wide), which represent about 70% of the total LLEs density in the Netherlands. This produces an error in ES accounting which is three times higher than the estimated benefits. This error is smaller for carbon sequestration, because this ES is more dependent on the LLEs areas rather than the length. Whereas, for pollination the error is higher, because the length of LLEs has a stronger influence on the service rather than the area. Despite our analysis show that the economic benefits of the proposed conservation scenarios outweigh the implementation costs, this result is anyway an underestimation of the true benefits.

In addition, up to now our study only includes two ES, even though previous analyses have shown that considering multiple ES increases the cost/benefit ratio of conservation (Naidoo and Ricketts, 2006; Polasky et al., 2012). Here, other ES provided by LLEs, such as natural pest control, water and air filtration, habitat connectivity and cultural services (de Groot, 2006; Hölting et al., 2020; López-Felices et al., 2022; Van Den Berge, 2021) were not taken into consideration because these are public services lacking explicit payments, because of unavailability of such data, or because the link with LLEs was not feasible to include. Moreover, in line with other studies, our sensitivity analysis showed that costs and benefits associated with the conservation plan are sensitive, among other things, to the number and type of layers used (Allan et al., 2022; Kujala et al., 2018). For these reasons, the inclusion of additional ES in our study would alter the spatial solutions to meet species conservation targets (Allan et al., 2022), and increase the benefits associated with the conservation plan itself, representing an additional source of fundings and further contribute to conservation (Claes et al., 2020).

To obtain a realistic estimate of conservation benefits, it is needed to expand the basket of spatially-explicit ecosystem services. However, these are still missing due to unavailability of data, and lack of standardize methodologies and resources (Hein et al., 2020; Schröter et al., 2015). Further SCP analyses that include a wider range of ES and improved estimates of the pollination ecosystem service - depending also on the width of 1-dimetional elements (Bishop et al., 2023) - will help identify realistic costs and benefits of conservation actions. This can represent an additional incentive and justification for planning biodiversity conservation and help identify the real conservation beneficiaries (Balmford and Whitten, 2003; Cimon-Morin et al., 2013).

Because our results show that the economic benefits of the ES outweigh the costs of implementation, this may provide the option to adequately compensate farmers for providing these services. Compensation mechanisms are currently part of policy debates. In the new European Common Agricultural Policy (CAP) 2023–2027, there is more attention for compensation schemes to promote ES provisioning. These use point based system which determines the height of financial compensation that individual farmers receive to compensate them for forgone benefits or investments when adopting conservation measures and delivery of ES (European Commission, 2023). However, it is still up to the farmers to participate in this system. The willingness to participate will undoubtedly depend on the cost-effectiveness of the compensation. Therefore, although our model does not directly address mechanisms to compensate farmers, the model results provide useful information for estimating realistic costs and benefits, which can subsequently be used to establish appropriate levels of compensation.

4.3. Land-sharing or land-sparing?

Land-sharing and land-sparing alternatives were developed for each scenario to align our results with current European debates regarding nature conservation and agricultural lands, to gain insight into which scenario is the most convenient in terms of conservation of biodiversity, costs and economic benefits, and to provide examples of multiple real-optimal solutions for decision-approaches. We found that both LLEs management type allow to achieve conservation targets for all the indicator species. This outcome is promising, since recent discussions about the type of conservation in agricultural areas in Europe suggests that, because of the high spatial fragmentation of European landscapes, a successful management of these areas will require a combination of land-sharing and land-sparing measures to halt the decline of farmland biodiversity under increasing agricultural demand (Grass et al., 2019, 2021; Immovilli and Kok, 2020; Kremen, 2015; Locke, 2013; Shackelford et al., 2015; Tscharntke et al., 2012; Wilson, 2017).

Despite the positive cost/benefit ratio of both land management types, our results show that land-sharing is a more cost-efficient approach, securing ES worth more than double the amount of the implementation costs. In addition, the sensitivity analyses have indicated that the external land-sharing/land-sparing narrative is more influential across scenarios than the internal parametrization - variations in lower bound (LB), upper bound (UB) and cost layers. Nonetheless, independent to the external parameterization we have used in the sensitivity analyses, we found that the cost/benefit ratio is always positive, meaning that the economic benefit of ES always outweighs the costs.

In land-sharing solutions of *Minimize Cost Scenario* and *Maximize ES Scenario*, the cost/benefit ratio is sensitive to LB; while in land-sparing solutions, the ratio is not influenced by variation in LB and UB. The lower sensitivity in land-sparing solutions to LB is due to the presence of boundary penalties that are applied to scattered solutions, which in turn create more expensive solutions with a lower cost/benefit ratio. In fact, when any value of boundary penalty (even a low value) is applied, fragmented solutions are penalized. As a results, grid cells that are the most cost-efficient are selected at first, and subsequently neighbouring cells are selected even if they do not exhibit a convenient cost/benefit ratio. Therefore, scenarios in which increasing levels of boundary penalty are applied result per definition in more expensive solutions. This is in line with a previous study (Lentini et al., 2013) that demonstrates that including connectivity parameters (*e.g.* boundary penalty) in SCP results in more expensive conservation solutions. However, our sensitivity analysis also shows that for high values of LB (~5,000 km^2) the difference in cost/benefit ratio between land-sharing and land-sparing diminishes (Fig. 5). As 18 out of 19 species have a total distribution range smaller than 5,000 km^2 (only *Columba palumbus* has a distribution range of 5,320 km^2), for high values of LB, conservation targets close to 100% are applied to all species in land-sharing and land-sparing, and therefore an equivalent large area is prioritized for conservation in both land management type solutions. Thus, resulting in a similar cost/benefit ratio.

In reality, land-sharing can be expected to yield a higher level of the ES pollination because of the proximity of LLEs to pollination dependent crops. In fact, LLEs that are more evenly distributed across the agricultural landscape, are expected to generate a higher pollination service in pollination-dependent crops. Contrarily, in land-sparing a smaller degree of the service is generated because of the reduced proximity of LLEs to crops.

The fact that land-sparing solutions are less cost-efficient, however, does not indicate that they should be disregarded when choosing a conservation plan to be implemented. In fact, larger contiguous conservation areas could better sustain viable population of a greater variety of species (*e.g.,* species with a larger home ranges) (Haddad et al., 2015; Lawrence et al., 2021). On the other hand, a fragmented conservation area could represent a more efficient option for connecting the existing network of protected areas and could be preferred not merely for its economic benefits but also for its increased connectivity potential, boosting biodiversity and species abundance in agricultural areas (Alison et al., 2021; Santini et al., 2016; Saura et al., 2018).

4.4. Conservation strategy for Noord-Brabant

Our workflow aims to develop scenarios for spatially operationalizing biodiversity, LLEs, and ES conservation within agricultural areas. The solutions here proposed give a spatial indication of new conservation areas that should be established in addition to the current network of protected areas in Noord-Brabant. By expanding current protected areas with 12–20% of the existing network of LLEs, the province can achieve the conservation of key indicator species that belong to the Birds and Habitat Directives while also increasing the conservation of the LLEs network and its ES, which represent an important step towards achieving the goals of the National Strategic Plan and *Deltaplan for Biodiversity*. Nonetheless, the priority areas that we identified represent only a small fraction of what it is needed to achieve the conversion of 10% of agricultural lands into LLEs (GLB, 2022). In fact, the province of Noord-Brabant (5.082 km^2 surface), which currently contains about 42 km^2 of LLEs, is expected to restore its LLEs network in agricultural areas up to a total of 160 km^2 for achieving the 10% target by 2050. A similar approach to this study can be used to identify optimal locations for restoration strategies of LLEs. This would require an enhanced spatial analysis on the convolution of habitats that provide ES and species, such as the spatial convolution of new LLEs habitats and locations of pollination dependent crops.

4.5. Replicability and validation

To our knowledge other studies that use SCP for introducing extensive land use for biodiversity conservation by prioritizing the conservation of LLEs do not exist. However, there is extensive scientific literature on studies employing SCP for protecting biodiversity (Bousarie et al., 2023; Cimon-Morin and Poulin, 2018; De Zwaan et al., 2022; Diao et al., 2021; Jung et al., 2021; Remme and Schröter, 2016), as well as one study that employs ES in SCP for prioritizing conservation areas (Chan et al., 2011), as we discussed in section 4.1. Other studies have measured the provision of ES by LLEs (Montgomery et al., 2020; Phillips et al., 2020; Vanneste et al., 2020) and other field methodologies have been used to estimate the economic benefits of ES provided by LLEs (Morandin et al., 2016). In particular, this field study shows that the conservation of LLEs in agricultural areas is always economically profitable, as indicated by our results.

In addition, our analysis allows to alter the type and amount of conservation features, ecosystem services and costs, and set different conservation targets. Because all the input data layers used were available for the extent of the Netherlands, our analysis can easily be reproduced for all Dutch provinces and for the entire country. The analysis can also be used for other countries and scales, however attention should be given to quality and resolution of the input data. Our code is well documented and available at our GitHub repository (see Code Availability section).

4.6. Limitations to conservation scenarios

Similar to other studies our analysis is sensitive to the data and methods applied (Jung et al., 2021). Especially, the analysis is sensitive to a set of methodological decisions (Supplementary Materials, Table 6) which are core to SCP, for instance, the selection of species and species conservation targets (Levin et al., 2015; Vimal et al., 2011), and type of cost data (Allan et al., 2022; Rondinini et al., 2006; Wilson et al., 2006).

In this study, we did not aim to comprehensively conserve all species diversity in Noord-Brabant, instead only few target species were selected as indicator species to be conserved in agricultural areas. In addition, target setting remains a major challenge for effectively conserve species. Because targets for biodiversity features were not available from the province, we defined a protocol based on range size, which is built around few arbitrary decisions, such as the selection of the lower (LB) and upper bound (UB). By using different combinations of LB and UB, we tested how sensitive our results are to variations in species targets. We found that this has a direct effect on the total area of the conservation solutions, which is also shown by another study (Egoh et al., 2010), and costs and benefits associated with the conservation plan. Nonetheless, we found minimal variation in the cost/benefit ratio across run of the sensitivity analysis.

We are aware that other approaches for setting species targets are also available, for example based on the minimum amount of species habitat required for the species to be qualified as “Least Concern” in the IUCN Red List status (IUCN, 2012; Mogg et al., 2019) or based on Favourable Reference Values (FRVs) (Bijlsma et al., 2019). In addition, species targets based on the range size might not guarantee the persistence of all species and it is not correlated with reducing extinction risk (Jung et al., 2021). However, the aim of our analysis is to provide ecologically credible area-based conservation targets, and the implementation of quantile species range maps for calculating the targets makes the calculation more conservative. Additionally, the approach followed here is the only one which is widely used (Allan et al., 2022; Rodrigues et al., 2004).

Furthermore, we tested how sensitive our solutions are to the type of cost data used. Because of unavailability of additional ES data, we only tested for different combinations of cost layers. We found that the costs and benefits, as well as the cost/benefit ratio of the conservation plans here proposed are sensitive to the cost layers employed for the analysis. Especially, the cost/benefit ratio is sensitive to management costs and monetary value of carbon sequestration, respectively in *Minimize Cost Scenario* and *Maximize ES Scenario.*

Finally, our analysis does not consider changes in cost and benefits of the conservation plan overtime and future economic trends which might influence the demand of the ecosystem services, as well as future land-use change and future projection of species distribution and/or ES supply.

5. Conclusions

Our analysis has shown that conserving LLEs in agricultural areas is economically convenient, with economic gains provided by the ES off-setting the implementation costs by two times on average. In addition, by including the monetary values of ES as a cost layer (*Maximize ES Scenario*), we found that this approach yields higher benefits - therefore conserves more ES - than when ES are not included in the prioritization analysis. This result further proves the advantage of including ES as co-benefits in SCP for planning more cost-efficient solutions. The proposed spatially explicit conservation plans show that by adding 12–20% of the existing network of LLEs to currently protected areas, the province of Noord-Brabant can secure the conservation of important species of the Birds and Habitats Directive (*e.g., Strepopelia turtur*, *Passer montanus*, *Perdix perdix* and *Hyla arboreas*), and at the same time benefit from the ES provided by the LLEs. In addition, our scenario analysis shown that both land-sharing and land-sparing are possible conservation solutions, achieving biodiversity targets while maintaining a positive cost/benefit ratio.

This study represents a workflow for planning conservation of species, habitats, and ES in Noord-Brabant, but can also be applied in other Dutch provinces. Its advantage is that it allows to alter the type and amount of conservation features, ES and costs, to achieve different conservation targets. For this reason, we believe it is a good decision support tool to develop realistic conservation scenarios to help guiding policymakers and provide useful information to adequately compensate farmers for the provision of ES. Its implementation has the potential to make a significant contribution to nature, as long as it is also accompanied with parallel efforts of restoring LLEs.

Authors contributions

F.A. conceptualized and led the study, performed the modelling and analysis, coordinated the writing of the original draft, and performed the writing of the final draft, including review and editing. E.v.L, was involved in the conceptualization, study design, modelling, result analysis and article writing. S.C.D. and D.P.v.V. contributed to the study design, result analysis and article writing. K.F.R. was involved in the conceptualization of the study. P.W.B. contributed to writing the article and data support.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.119262.

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