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LOCATION-SPECIFIC MODELING FOR OPTIMIZING WILDLIFE MANAGEMENT ON CROP FARMS

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Abstract

In order to guide conservation and restoration of wildlife in agricultural areas research is needed into the trade-off between wildlife and agricultural production and income. This study presents a location specific model for optimizing wildlife management on crop farms using the integer programming technique. Available data and indicators of wildlife production are presented. Furthermore, time and location aspects of wildlife management are discussed. The model is applied to crop farming in the Netherlands. Most important model outcome is a wildlife-cost frontier at the farm level. Model outcomes show that rotating wildlife conservation practices across the farm is economically more attractive than fixed-location practices. Opportunities for use of the insights provided by model results by both policy makers and farmers are analyzed.

Keywords: wildlife management, crop farming, location-specific model, integer programming.

1 Introduction

Agriculture does not only produce food and fiber; it also helps shaping the rural environment. Increasingly, modern society values the environmental benefits which may arise as joint outputs with primary land use, including e.g. semi natural habitats and wildlife. In Western Europe, rapid changes in primary land use have jeopardized the supply of these benefits (Lowe and Whitby, 1997). Specialization by region and within individual farms, as well as intensification, through use of fertilizers and pesticides, have increased. Land amelioration (viz. defragmentation, exchange of land, alterations in accessibility) has also contributed to such. These developments have resulted in a loss of habitat for many wild species, and consequently a rapid decline in numbers and populations. The Common Agricultural Policy has been criticized for supporting these changes and over the last decade European policy makers have begun to respond to such criticism. EU-regulations 1760/87 and 2078/92 mark the acceptance that supporting farmers to conserve wildlife and countryside might help to curb overproduction. These regulations also promote a specific approach: supplementary to a distinct geographical segregation of agricultural and wildlife functions both functions should to a large extent blend within the rural environment. While nature reserves will always be important, there is a shift of attention increasingly to the preservation of biological diversity within the major forms of primary land use (Edwards and Abivardi, 1998). This transformation of agricultural policy being an agri-food policy to more of a countryside and wildlife policy calls for investigation of the mechanisms that would help satisfy the following criteria (Lowe and Whitby, 1997): that payments are targeted to ensure cost-effectiveness; that the level and targeting are responsive to public demands; that the benefit is clearly tangible. The first step towards an effective policy to conserve and restore wildlife in agricultural areas, is investigation into the trade-off between wildlife and agricultural production and income. In this task agricultural economics has an important role to play.

The interactions between agricultural production and wildlife and associated decision making are most pronounced at the farm level. The objective of this study is to present and apply a model that enables the assessment of a wildlife-costs frontier at the farm level: i.e. the definition of best (least cost) management strategies for obtaining different wildlife production levels. Such an optimization model has to account for both time and location specific aspects of agricultural production and wildlife. This particularly applies to crop farming where the production situation differs from year to year due to crop rotation.

Many empirical studies focus on the economics of preventing losses in agricultural yields due to wildlife, for example the body of literature on crop protection and recent work on pre-emptive habitat destruction under the ESA (Lueck and Michael, 1999). In contrast, little work has been done on modeling the production relationship between agricultural practices and wildlife at the farm and field level. Previous ecological and economic studies of wildlife management at the farm level have generally focused on the impact of land use regimes on farm income and biodiversity. For example, the positive effects of refraining from pesticide in northern European agriculture on the abundance of flora and fauna was reported by e.g. Rands (1985), Tew *et al.* (1992), Boatman (1994) and by De Snoo (1997). Economic studies at the whole farm level generally involve a comparison of specific land use regimes by analysis of accounting data and/or farm level modeling (e.g. Van Eck *et al.,* 1987; De Boer, 1995). None of the studies mentioned pays attention to the dynamic and location aspects of the joint production of agricultural outputs and wildlife. Wildlife production, however, not only depends on present management practices but also on management practices in previous year(s). Also, wildlife production depends highly on site specific biophysical conditions and on location aspects such as the distribution of conservation activities like hedgerows and unsprayed field margins in agricultural areas.

The literature on the location aspects of agricultural production and the environment generally focuses on optimal pollution control in relation with water quality of an agricultural watershed: e.g. Braden *et al.* (1989); Braden *et al.* (1991); Moxey and White (1994); Lintner and Weersink (1996). This location dimension, however, is also important in the case of positive externalities of agricultural production, i.e. wildlife. Ecologically, the spatial distribution of species is important for their changes of propagation. Economically, the 'where' question is of importance because of the advantages of selective control, i.e. protecting where it is most effective and least costly. Selective control requires identification of the most effective wildlife management options and also where to apply these. Studies in the field of site selection are virtually all carried out on a regional level and identify the smallest number or cheapest set of sites to realize targeted wildlife criteria; see Csuti *et al*. (1997); Wossink *et al*. (1999). To our knowledge, studies on the location specific aspects of wildlife preservation at the farm level have not been reported in the literature.

The outline of this paper is as follows: section 2 presents an overview of the interactions between agriculture, and more specifically crop farming, and wildlife. Management options for promoting wildlife in agricultural areas are discussed. Section 3 presents a generic model for optimal wildlife management on crop farms. Next section 4 presents the requirements for implementation of the model. An application of the model for Dutch crop farming is presented in section 5. Finally, section 6 discusses opportunities for use of the model results to support decision making by farmers and policy makers.

2 Crop farming and wildlife

The interactions between agricultural practices and the presence and abundance of wildlife are complex. Two major developments in agricultural practice have caused a reduction in the state of wildlife the last three decades. The use of chemical inputs, in terms of pesticides and nutrients, and monocultures of crops have left little opportunities for wildlife survival. Emissions of chemical inputs to non-agricultural habitats have also contributed to such. Furthermore the number of non-agricultural habitats on the farm is reduced through field enlargement, merging of farms etc., decreasing the chances of survival for wildlife.

Research into ways of enhancing wildlife in arable farming has predominantly focused on unsprayed and/or out of crop field margins and on alternative management of fallow land (Boatman and Sotherton, 1988; De Snoo, 1997). Especially field margins receive much attention. Yields in margins, especially on headlands are often lower due to a higher pest and weed pressure, soil compaction or shady conditions (De Snoo, 1995). At the same time, wildlife abundance is higher in margins, owing to the unfavorable growing conditions for agricultural crops and the location often next to non-agricultural biotopes such as ditches or woodland. From an agricultural point of view, enhancing wildlife in field margins may cause yield reductions in the center of the field due to weed invasion and wildlife damage. On the other hand positive impacts of unsprayed field margins are reported through biological control of pests in the fields (Boatman and Sotherton, 1988; De Snoo, 1997). However, no information is available on whether these positive effects outweigh negative agronomic effects. Fallow land offers special opportunities for wildlife as in general no chemical inputs are used. Furthermore financial compensation may be obtained through the EU-set aside scheme. However, when set aside is applied in margins a minimum width of 20 m is necessary for obtaining financial compensation (MINLNV, 2000).

Apart from alternative management of field margins and fallow land other opportunities for enhancing wildlife in crop farming are available. Winter cover crops are used in agriculture to save nutrients and for maintaining organic matter content in the soil. For wildlife these crops may provide cover and food during the winter period. Furthermore, non-agricultural habitats on the farms may receive alternative management aimed at enhancing wildlife. Ditch banks offer special opportunities for vegetation development by creating a poor nutrient situation. Rough vegetation may be created on these banks providing cover and nesting opportunities for mammals and birds.

Various wildlife-enhancing activities are thus available at the farm level, each with specific cost and wildlife features, depending on the location on the farm, crops grown, and crop rotation. Incorporating wildlife in farm modeling therefore is rather complicated. The next section presents a theoretical economic model to optimize wildlife management at the farm level taking into account the various optional activities, and the spatial and dynamic interactions.

3 Generic model

The theoretical model meets two criteria (Braden *et al.*, 1989): (1) it accounts for the effects of management restrictions on wildlife production at the farm level; and (2) it identifies the pattern of management activities on the farm that maximizes farm income over a predefined time horizon. Index $t=1, ..., T$ denotes time periods and index $j=1, ..., J$ denotes the number of management units recognized on the farm (e.g. field margins, field centers, ditches etc.). Let f denote the production relationship between agricultural inputs and outputs, and let g denote the relationship between agricultural inputs and wildlife outputs (See also Van Wenum *et al.*, 2001).

$$Max\ Z = \sum_{t=1}^{T} \sum_{j=1}^{J} q' y_{jt} - C(y_{jt}, r_t, x_{jt}; l_j) \quad [1a]$$

s. t.

$$f_{jt}(y_{jt}, x_{jt}; l_j) \leq 0 \quad \forall\ j,t \quad [1b]$$

$$g_{jt}(x_{jt}, u_{jt}; l_j) \leq 0 \quad \forall\ j,t \quad [1c]$$

$$\sum_{t=1}^{T} \sum_{j=1}^{J} u_{j,t} \geq N \quad [1d]$$

and

$$x_{jt} \in X_{jt} \quad \forall\ j,t \quad [1e]$$

Z = farm profit
C = cost function
q = vector of prices of agricultural outputs
y = vector of marketed outputs
r = vector of prices of agricultural inputs
x = vector of farm specific management activities
u = vector of wildlife production scores
X = set of all management activities
l = vector of bio-physical and other location specific characteristics (production environment)
N = wildlife production level at the farm level

The production relationship, *f(.)*, between agricultural inputs and outputs [1b] is location (j) and time (t) specific. Yields among locations, even within the farm and within fields vary and for multi-year cropping variants both inputs and outputs between the years as well as associated gross margins may differ. The production relationship, *(g)*, between agricultural inputs and wildlife outputs [1c] again is location and time specific. Wildlife varies across locations and across time. The latter specifically counts for multi-year fallow where wildlife may develop or change over time.

Solving the equation set yields x^*, the vector of agricultural management activities including management restrictions that satisfies the requirement for wildlife conservation as expressed by N. Varying N gives a wildlife conservation costs frontier $Z(N)$ for the total farm studied, that is the change (decrease) in farm profit, Z, associated with producing specific levels of N.

4 Implementation of the generic model

4.1 Agricultural production function

Implementation of the generic model requires information on the production relationship between agricultural inputs and outputs, $f(.)$, see equation [1b]. The production level of agricultural outputs, in terms of marketed product(s) per hectare, y, is determined by the production environment, l, and by production techniques and methods applied as expressed by the activity set, X. The activity set is predominantly determined by the farming strategy applied, i.e. organic, integrated or conventional farming and by farm specific constraints such as the availability of labor and machine equipment. Given a farm specific activity set and known production environment, different input/output relationships for various crops can be estimated. Data to such may be obtained from farm accountancy data networks and/or experimental stations.

4.2 Wildlife production function

Implementation of the generic model further requires information on the relationship, $g(.)$, between agricultural inputs x_{jt}, and wildlife results u_{jt}, see equation [1c]. The production environment, l, at a specific site represents the setting for wildlife production and is characterized by (bio)physical factors that include climate and aspects of the soil (groundwater table, type of soil). Furthermore wildlife production is determined by site specific factors not controllable by management: (a) weather during the growing season (solar radiation, rainfall, temperature), (b) factors due to management in the past such as the level of eutrophication and desiccation of the soil, presence of vegetation remnants and extent of the flora seed bank. The biophysical factors together with the non-controllable factors (production environment) thus determine the 'potential wildlife yield' on a farm. The extent to which this potential level is achieved in practice depends on growth factors that are controllable by management, *x*. These include crops selected (including fallow), rotation, size and spatial pattern of field and field margins as well as nutrient management, water management and pest control. Together with the production environment these factors determine 'actual wildlife yield' (Turner *et al.*, 2000). Whereas agricultural outputs are easy to quantify and measure in terms of marketable yield y_{jt}, wildlife results**,** that is u_{jt} in equation [1c], are much more difficult to assess. A direct measurement of the presence and abundance of all wildlife on a farm is not feasible; therefore indicators of wildlife production have to be used.

Within the OECD work on agriculture and the environment, *p*ressure, *s*tate and *r*esponse indicators are recognized (PSR-framework, see OECD, 1994). Recently this framework has been applied to agriculture and biodiversity. Pressure indicators are measurements of agricultural activities that cause changes in the state of biodiversity such as the use of pesticides and fertilizer. State indicators are direct measurements of the state of biodiversity arising from these pressures, in terms of species, habitats or environmental parameters. Finally response indicators refer to responses by farmers, government or society to changes in the state of biodiversity, such as the use of financial incentives to farmers to enhance biodiversity.

Obviously for solving the normative generic model and implementation of the wildlife production function, indicators of the state of biodiversity, are needed. Main requirement for equation [1c] of the generic model to be implemented is an indicator applicable at the farm level to provide a complete picture of the state of wildlife. Furthermore the relationship of the indicator outcomes with farm management practices has to be clear.

Many attempts have been made to indicate wildlife and biodiversity. The term biodiversity in the sense of the Biodiversity Convention of the UN Conference on Environment and Development in Rio de Janeiro (1992) encompasses the whole range of the genetic diversity within species, the diversity of species and higher taxa, up to ecosystem diversity, and even the diversity of ecological interactions. Clearly the Rio convention focuses on the more complex qualitative aspects of biodiversity. Quite obviously, such broad diversity of life cannot be measured in a comprehensive manner (Duelli, 1997).

The traditional scientific quantitative concept of biological diversity is based on species diversity. Indexes considering the quantitative aspects of biodiversity are often constructed as a function of species counts and the relative abundance of species (Magurran, 1988). Others have looked at evenness: biodiversity measures as a function of genetic distances among members of a species set (Weitzman, 1992; Solow, Polasky and Broadus, 1993). Species richness is the simplest form of these measures neglecting differences in abundance or genetic distance. Species richness provides an extremely useful measure of diversity if the study area can be successfully delimited in space and time and the constituent species enumerated and identified.

In this study two indicators for wildlife production are used, considering vascular plants only. The species richness indicator (in terms of species density) is compared with an extensive species based indicator specifically developed for agriculture: the wildlife yardstick (see Buys, 1995; Van Wenum *et al*., 1998). Whereas species richness considers the density of species, this yardstick provides information on the ecological or protection value of species. Another reason for using this indicator is its application in proposed future measures on agricultural wildlife conservation in the Netherlands. The use of two indicators also enables analysis of the impacts of indicator choice on the selection of optimal management strategies (Eiswert and Haney, 2001).

The wildlife yardstick for vascular plants consists of a representative set of species. This representative set was put together for simplicity reasons. However to gain a more complete picture this study considers all plant species. To each plant species now, a rating V (0-100 points) has been assigned based on its protection need as determined by rarity, population tendency and international importance (all three at the national level).

A wildlife score per area measure (*U*) now is calculated as the sum of ratings of all plant species *r* found for the respective area measure regardless of the number of plants per species (Van Wenum *et al*., 2001):

$$U = \sum_{r=1}^{R} V_r \qquad [2]$$

When species richness is considered, a wildlife score per area measure, *U,* simply is the number of species found.

To implement the indicators into the generic model, data are needed on the presence of plant species for all management activities X given site characteristics l. Research into the relation between agricultural management and wildlife however, usually takes into account a limited number of management options. Also assessments for consecutive years are scarce. Furthermore research is carried out on different locations, with inconsistent location specific conditions hampering a comprehensive analysis. Van Wenum *et al*. (2001) however, presented a functional form and estimation technique for a wildlife production function at the farm level. A random effects model was developed to capture the relationship between wildlife output, management practices, regional conditions and non-observed farm specific factors. The study used species richness and the wildlife yardstick (both considering vascular plants) in estimating wildlife production functions.

4.3 Optimization procedure

A schematic representation of the optimization procedure is presented in Scheme 1. In order to model and optimize wildlife management, the farm is divided in spatial units ($j=1, \ldots, J$). In a conventional farming situation, different crop fields and non-productive biotopes such as woodland and ditches can be observed. Management on crop fields or within a non-productive biotope type will normally be uniform. Incorporating wildlife management options may result into more activities per field and thus an increase in the number of spatial units to be recognized. Each recognized spatial unit is assumed to have uniform conditions and management. Therefore it is necessary to formulate the model in an integer context. Management activities now are integers forcing the model to select only one management activity per spatial unit j per year t.

Solving the equation set from section 3 may require a model of considerable size due to the integer context of the problem. Also other factors may affect model size: (1) the length of the planning period, (2) the number of management units (sites) recognized, (3) the number of management alternatives to each unit and (4) the combinatorial complexity of the problem. We discuss these aspects in more detail.

Ad (1): Decisions regarding incorporating wildlife management are made on the tactical and strategic level. For the present study a planning horizon of one rotation (usually lasting 4 years) is considered appropriate. Impacts of past activities influencing wildlife and or agricultural production in following years can therefore be incorporated in the model.

Ad (2): Without specific attention being paid to wildlife management, an individual field (including margins, headlands and center) will generally be treated uniformly. However with the introduction of wildlife management alternatives, management on field margins may be different from the field center. Moreover distinction between headlands and longitudinal sides should be made for their differing agronomic and economic features. Besides non-agricultural habitats need separate consideration.

Ad (3): When all available activities may be applied on each site the selection problem is huge. Therefore it looks appropriate to define an optimal baseline situation, considering crops and whole fields only. After this baseline run, for each site the standard crop activity is known and wildlife management alternatives may be defined for new optimizations to be carried out.

Ad (4): Combinatorial aspects have to do with the influence of past on present activities on sites, and with activities on certain sites influencing the wildlife or agronomic situation on other sites. Furthermore farm level constraints on top of site constraints add to the combinatorial character of the model.

4.4 Model output

The most important outcome of the model is a wildlife-cost frontier at the farm level. For each wildlife production level N, the associated set of management activities that maximizes farm income is defined. Due to the nature of the applied LP-model, this frontier is a piecewise linear function where each step corresponds to a particular basic solution to the income-maximizing problem. This means that the objective function is not continuously differentiable. So rather than $\partial Z/\partial N$ (see section 3), $\Delta Z/\Delta N$ needs consideration, where ΔN is a discrete change in wildlife production.

5 Application of the model

5.1 Representative farm

A representative crop farm type was chosen for a first application of the model as presented in Scheme 1. The crop farm is representative for the central clay area in the Netherlands. Parcellation of farms in this area is relatively simple and the number of crops grown on these farms is limited. Therefore this area is ideal for a first application of the model. The cropping plan of the farm is presented in Table 1.

The representative farm has a cropping plan based on a 3-year rotation with one-third of the acreage planted with potatoes. The farm consists of two blocks of 30 ha, typically for the considered region. The blocks are subdivided into 4 fields (2 of 20 ha and 2 of 10 ha respectively). A graphical representation of the farm is presented in Scheme 2. For the initial situation crops were assigned to the fields for 4 years for the representative farm. Each field was subdivided into 13 spatial units enabling the introduction of 3 m, 6 m and 20 meter wide margins on each side of the field. A decomposed field is presented in Scheme 3.

5.2 Model input

For each spatial unit in the model next to the baseline cropping activity, alternative wildlife management activities were offered in the optimization procedure. Application of unsprayed cereals was restricted to 3 and 6 meter margins whereas fallow alternatives may also be applied in 20-meter margins and on whole fields. Furthermore fallow alternatives may be applied for 1 year or for 2, 3 or 4 years consecutively on the same field or margin. No other permanent cropping variants were offered as most crops require rotation to prevent yield losses from soil born diseases. Table 2 gives an overview of all considered alternatives.
Table 3 presents gross margins for all available crop and wildlife management activities for both margins and field center. Gross margins for the field center were obtained from PAV (1997). For field margins lower yields were assumed and gross margins were calculated accordingly. Yield reductions were obtained from De Snoo (1995), Schoorlemmer (1998) and Van Bemmelenhoeve Research Farm. For fallow variants, Table 3 presents gross margins for the first year. With the exception for

natural vegetation gross margins for the 2nd to 4th year are higher as seed costs are only applicable in the first year.

Wildlife scores, *U,* for each activity were obtained from Van Wenum et al. (2001): Species richness and wildlife yardstick values of vascular plants were estimated using a random effects procedure. The following model was estimated:

$$U_{it} = M_i + \sum_{k=1}^{8} \alpha_k A_{ikt} + \sum_{i=1}^{2} \beta_k S_{ik} + \gamma_1 D_{it} + \gamma_2 D_{it}^2 + \lambda \log P_{it} \qquad [3]$$

where U_{it} is wildlife, measured either as species richness or as yardstick value. M_i is an unobservable farm specific management variable for the ith farm, A_{ikt} denotes a dummy variable for agricultural management activities of the ith farm at time t with k=1 (grass-clover), 2 (nature mix fallow), 3 (natural vegetation), 4 (unsprayed winter cereals), 5 (unsprayed spring cereals), 6 (potatoes), 7 (sugar beet) and 8 (phacelia fallow). The dummy variables A_{ikt} take the value 1 if activity k is present at time t at farm i and 0 otherwise. S_{ik} are regional dummy variables with k=1 (northern clay area) and 2 (central clay area) that take the value 1 if the j-th region applies and zero otherwise. The northern sand area is the reference area in this regression, i.e. S_{ik} is zero for all i,k in the northern sand area. D_{it} represents the distance in meters from the sampling spot to the edge of the field. The quadratic specification allows for both increasing and decreasing marginal effect of distance on wildlife production.

For this study wildlife scores (both species richness based and yardstick based) were calculated for each activity. Equation 3 was used to this end with the following input parameters: central clay region, plot size of 100 m^2 and distance to the field edge of 1,5 m for the 3 meter margins, 4,5 meter for the 3-6m margin units and 6 meter for the central units of the field. Table 4 presents the wildlife scores for the different activities. An average farm specific factor *M* was assumed (value 0). No distinction was made between multi-year and one year fallow variants because wildlife data for more permanent activities were lacking. Therefore, wildlife scores were assumed to be constant over years.

5.3 Model results

The baseline situation was calculated using the cropping plans of Table 1. Total Gross margins (per year) for the baseline situation of the representative farm is NLG 313998. In the baseline situation the species richness indicator valued -262 per year and the wildlife yardstick valued 3288 per year. A stepwise increase of wildlife scores was imposed and Total Gross Margins were obtained through optimizing the model. Wildlife cost frontiers for the farm using species richness indicator and yardstick values are presented in Fig. 1 and Fig. 2 respectively. No big leaps in the frontier, characteristic for integer optimizations, are observed. The considered four-year period and the large number of spatial units recognized, give the model a large number of opportunities to keep the step width limited.

When a stepwise increase of species richness indicator or yardstick values is imposed Total Gross Margin for the representative farm is dropping. When small increases are imposed conventional cereal margins are replaced by unsprayed cereal margins. Table 5 and 6 show results of optimizations when larger increases are imposed. Optimization 1 in both tables results into a similar cost level and the same accounts for optimization 2. This therefore enables both indicators to be compared on their resulting management strategies for the farm. Furthermore it helps understanding the species richness and yardstick score levels by showing the activities that are replaced and by comparing the indicator values of the replaced and the new activity. From Table 5 it is clear that optimization 1, using the species richness indicator, predominantly leads to replacing wheat fields and margins by unsprayed margins and natural vegetation. When the yardstick is used, for a comparable cost level, also margins of other crops such as ware potatoes were replaced (Table 6, optimization 1). This indicator therefore results in a larger network of field margins at a similar cost level. This pattern was also visible for other optimizations at slightly higher and lower cost levels.

A further increase in indicator values up to the levels of optimization 2 in Table 5 and 6 reduces the differences in results between both specifications. Both optimizations show outcomes where wheat fields are replaced by natural vegetation and margins are altered to unsprayed variants. An interesting result of the optimizations is that no multi-year fallow alternatives are used. It can therefore be concluded that rotating wildlife activities across the farm is more attractive than permanent activities.

Furthermore at high wildlife levels crops with low gross margins, especially the cereals, are replaced and the more intensively grown crops are not affected. Intensive cropping plans with low proportion of cereals will therefore result into higher costs for enhancing wildlife levels. Crops like potatoes and sugar beet that have higher gross margins and a higher use of inputs (fertilizer and crop protection agents) than cereals will then have to be replaced by wildlife activities resulting in higher costs to obtain similar wildlife levels.

6 Discussion

The model presented gives farmers more insight and a better understanding in selecting best management practices to obtain different wildlife production levels. Furthermore the model outcome gives policy makers information on costs associated with different wildlife production levels. Incentive development and cross compliance instruments may therefore benefit from the model outcome. However before using the outcomes for policy design a study on the acceptance of the proposed wildlife activities is necessary as perceptions and preferences among farmers towards wildlife conservation may vary.

Model results indicate that rotating of wildlife activities across the farm, mainly following the cereal crops is most attractive: wildlife scores are thus obtained at lowest cost. The model however assumed uniform conditions across the farm, whereas in practice conditions between fields and also within fields may significantly differ opening opportunities for permanent coverage with wildlife activities. Furthermore wildlife scores for permanent fallow activities were held constant. With a positive wildlife development over time, multi-year fallow also becomes more attractive. However, multi-year fallow implies that also crops with high gross margins will be replaced and that this type of wildlife activities therefore will be costly. Connectivity of wildlife activities was not considered in this study. However by forcing the model to leave field centers in tact and allowing only margins to change to wildlife activities, the spread across the farm, and the chances for connectivity, would be better with increasing wildlife levels.

A bottleneck of the model presented is the availability of data on the relationship between agricultural practices and wildlife indicators. More data from ecological research under various conditions will increase the reliability of the model outcome. The model is further restricted by including a fixed spatial arrangement of fields and non-agricultural elements on the farm, limiting the number of wildlife options to be considered. Another drawback of the model is its limitation to wildlife as the sole externality of farming. If other environmental externalities had been included, such as pesticide use, the focus would probably shift from cereal replacement to replacing potatoes and sugar beet (margins) being crops with higher pesticide use.

A linear relationship was assumed between indicator values and acreage: two hectares of a certain activity with a certain wildlife indicator score (either species richness based or yardstick based) had twice the score of one hectare of the same activity. Within farms this linear relationship may hold, however on the regional level the wildlife value of yet another hectare of the same activity may have a lower value to wildlife. Further research in this field is advised. The same counts for the development of wildlife over time, especially for multi-year activities as data in this field are scarce.

Many of the private initiatives currently taken to enhance wildlife in agricultural areas depart from co-operation of farmers on a regional level. When considering an analysis on a regional scale spatial connections e.g. linking of important ecological objects (ecological networks) needs special attention (Lintner en Weersink, 1996; Wossink *et al*., 1997). An optimization to be carried out on a regional scale may well lead to different contribution efforts by farmers to meet the regional determined wildlife objectives. Equity among participants therefore also needs special attention (Önal *et al*., 1998). The model presented here does not account for these two aspects. However, the farm specific outcomes of the model may well serve as a basic input for aiding decision making on a regional scale. In this respect Walpole and Sinden (1997), offer an interesting approach using farm level benefit-cost ratios and GIS predictive modeling, to aid land degradation management on a regional scale. Such an approach would also offer great potential for supporting regional wildlife management decision making.

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Table 1 Cropping plan of representative farm

Crop	Acreage (ha)
ware potatoes	20
winter wheat	20
sugar beet	12
Onion	6
Fallow black	2
TOTAL	60

Table 2 Overview of cropping and wildlife activities and sites applicable

Activity	Field margin			Field center	Whole field
	3m	6m	20m		
ware potatoes				x	x
Winter wheat				x	x
Sugar beat				x	x
onion				x	x
Seedgrass				x	x
Phacelia fallow	x	x	x	x	x
grass-clover	x	x	x	x	x
nature mix fallow	x	x	x	x	x
Natural vegetation	x	x	x	x	x
Unsprayed winter cereals	x	x			
Unsprayed spring cereals	x	x			

Table 3 Gross Margins (NLG/ha) of cropping variants and wildlife activities for spatial field units

Activity	Spatial field unit					
	0-3m		3-6m		6-20m	center
	head land	length side	Head land	length side		
ware potatoes	4596	5626	5626	6141	6656	6656
winter wheat	2203	2585	2585	2776	2967	2967
Sugar beat	3838	5084	5084	5707	6330	6330
onion	2178	4250	4250	5286	6322	6322
Seedgrass	1292	1640	1640	1814	1987	1987
Phacelia fallow*	-175	-175	-175	-175	-175	-175
grass-clover*	-140	-140	-140	-140	-140	-140
nature mix fallow*	-205	-205	-205	-205	-205	-205
Natural vegetation*	-8	-8	-8	-8	-8	-8
Unsprayed winter cereals	2008	2302	2302	2449	2596	2596
Unsprayed spring cereals	1303	1577	1577	1714	1851	1851

*) Gross margin in first year, excluding EU-MacSharry premium for set aside land. Premium is only applicable for set aside fields or set aside field margins with a minimum width of 20m.

Table 4 Wildlife scores of cropping variants and wildlife activities for spatial field units (management factor = 0)

Activity	Species richness			Yardstick value		
	0-3m	3-6m	6-20 m/ field center	0-3m	3-6m	6-20 m/ field center
Ware potatoes	-0.7	-1.3	-3.1	66.5	67.1	47.4
Winter wheat	-2.7	-3.2	-5.0	71.2	71.7	52.1
Sugar beat	-4.6	-5.2	-7.0	75.9	76.4	56.7
Onion	-2.7	-3.2	-5.0	71.2	71.7	52.1
Seedgrass	-2.7	-3.2	-5.0	71.2	71.7	52.1
Phacelia fallow	5.9	5.3	3.5	63.7	64.3	44.6
Grass-clover	6.4	5.8	4.0	109.5	110.0	90.3
Nature mix fallow	12.9	12.3	10.5	103.3	103.9	84.1
Natural vegetation	11.8	11.2	9.4	111.6	112.2	92.5
Unsprayed winter cereals	9.9	9.3	7.6	132.4	132.9	113.2
Unsprayed spring cereals	11.7	11.1	9.3	137.1	137.6	117.9

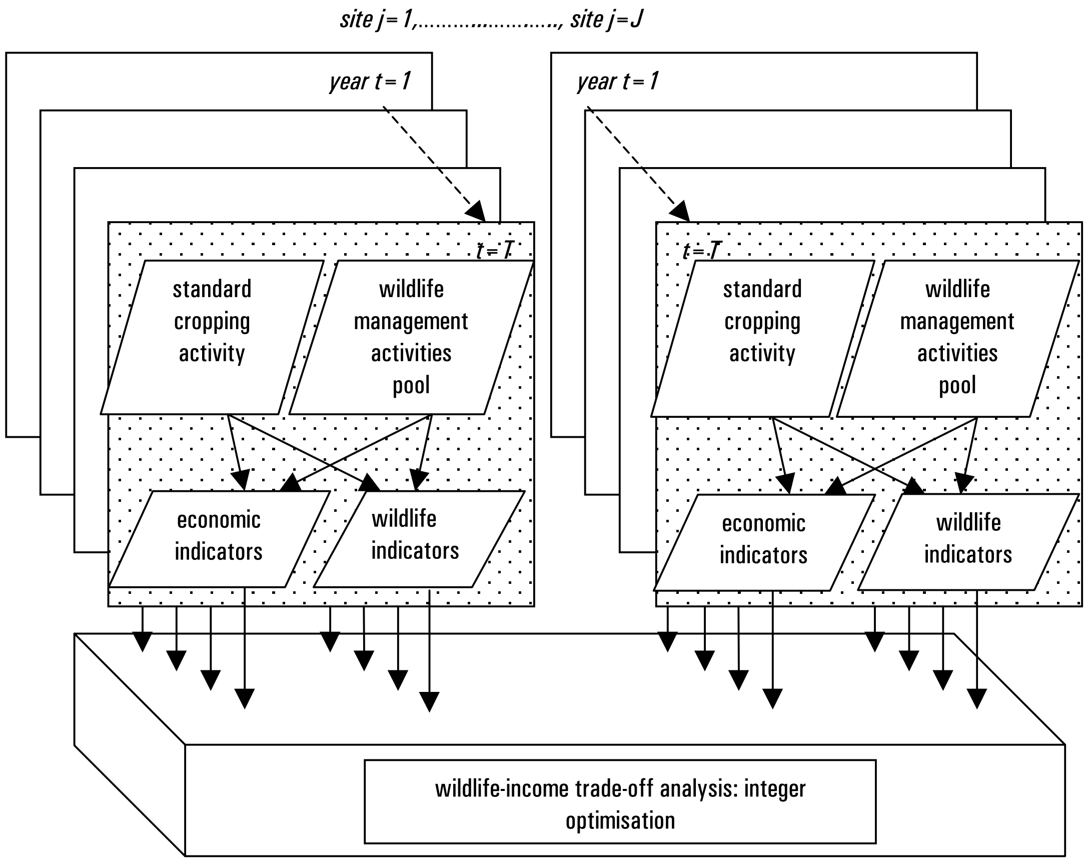
Table 5 Results of 2 optimizations with imposed species richness scores (replaced crops in parentheses)

Year	Optimization 1 Imposed species richness score: -175/year Costs: NLG 10090/year	Optimization 2 Imposed species richness score: -113/year Costs: NLG 18850/year
Year 1	+ 0.54 ha 6m margins wheat unsprayed (wheat) +1.80 ha 20m nature mix fallow (wheat, fallow black)	+20 ha natural vegetation (wheat)
Year 2	+1.50 ha 6m margins wheat unsprayed (wheat) +0.80 ha 20m nature mix fallow (fallow black)	+20 ha natural vegetation (wheat)
Year 3	+20 ha natural vegetation (wheat)	+ 0.50 ha 6m margins wheat unsprayed (wheat) + 0.30 ha 3m margins wheat unsprayed (wheat)
Year 4	+ 1.08 ha 6m margins wheat unsprayed (wheat)	+ 0.24 ha 6m margins wheat unsprayed (wheat) + 0.40 ha 3m margins wheat unsprayed (wheat)

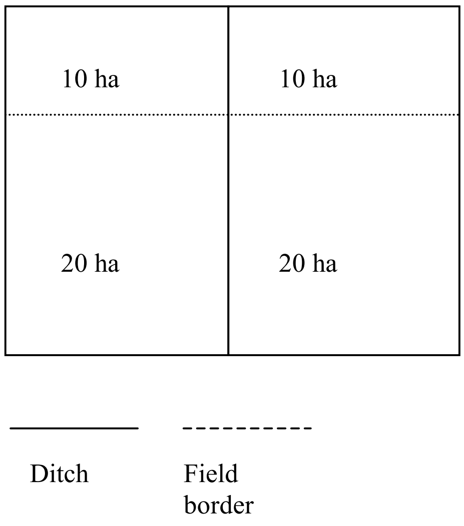
Table 6 Results of 2 optimizations with imposed yardstick scores (replaced crops in parentheses)

Year	Optimization 1 Imposed yardstick score: 14300/year Costs: NLG 11110/year	Optimization 2 Imposed yardstick score: 14900/year Costs: NLG 18950/year
Year 1	+0.60 ha 3m margins barley unsprayed (sugar beet, onion, ware potatoes) +20 ha natural vegetation (wheat)	+1.08 ha 6m margins wheat unsprayed (wheat)
Year 2	+ 1.5 ha 6m margins wheat unsprayed (wheat) +0.24 ha 3m margins barley unsprayed (ware potatoes)	+1.02 ha 6m margins wheat unsprayed (wheat) +0.56 ha 3m margins wheat unsprayed (wheat)
Year 3	+1.08 ha 6m margins wheat unsprayed (wheat) +0.24 ha 3m margins barley unsprayed (ware potatoes)	+20 ha natural vegetation (wheat)
Year 4	+1.08 ha 6m margins wheat unsprayed (wheat) +0.60 ha 3m margins barley unsprayed (sugar beet, onion, ware potatoes)	+20 ha natural vegetation (wheat)

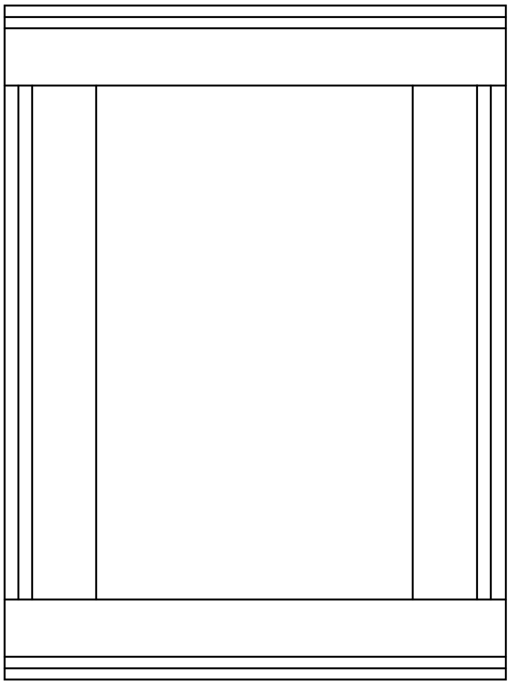
Scheme 1 Optimization procedure



Scheme 2 Spatial layout of the representative farm



Scheme 3 Decomposed field



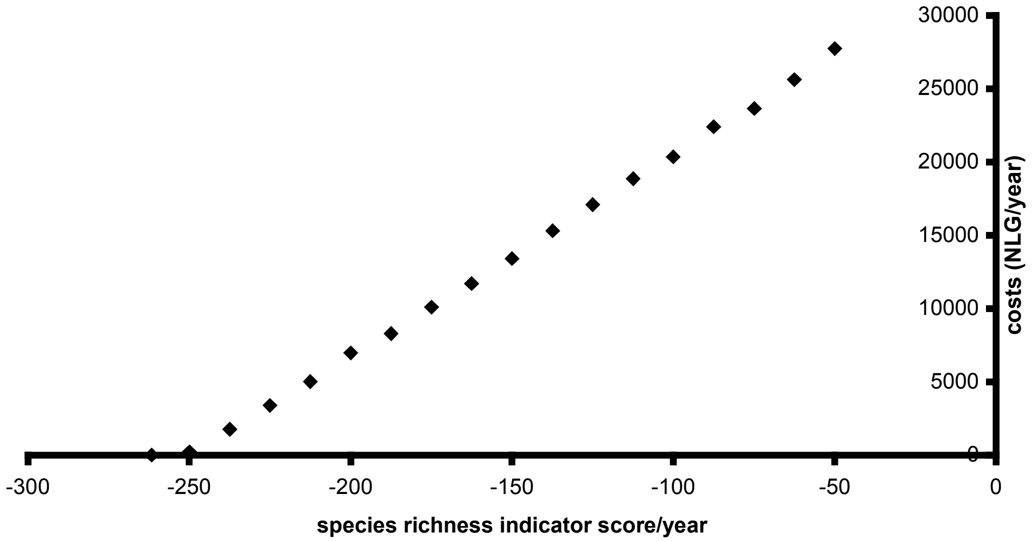


Fig. 1 Wildlife-cost frontier (species richness indicator based) for the representative farm

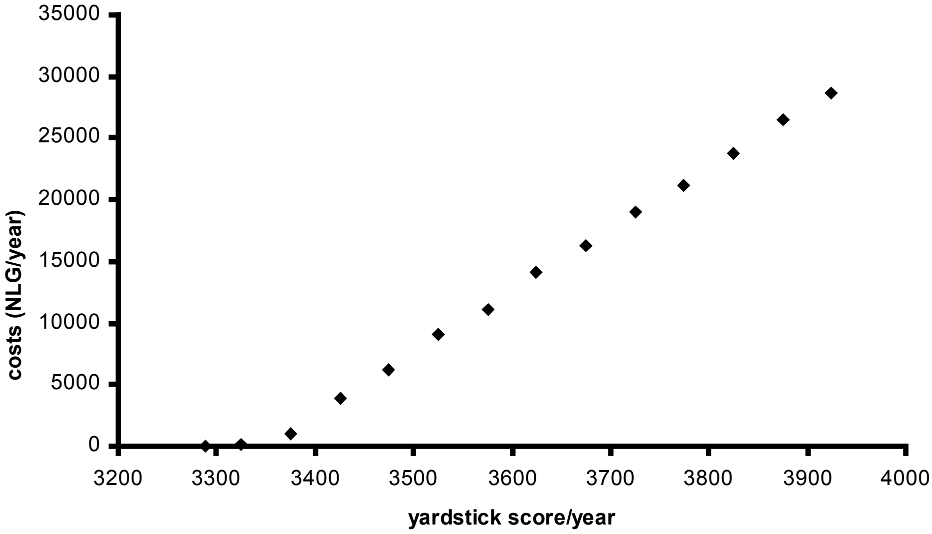


Fig 2. Wildlife-cost frontier (yardstick score based) for the representative farm