Landscape cohesion and the conservation potential of landscapes for biodiversity: evaluating agri-environment schemes using a spatially explicit agent-based modeling approach

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Abstract

This paper proposes a spatial explicit agent-based model to evaluate the impact of agri-environment schemes on the spatial cohesion of agricultural landscapes in the light of habitat network patterns. Networks of nature reserves are being proposed as a solution when the degree of fragmentation is considered to endanger the long-term persistence of species diversity. Agri-environment schemes are supposed to give a positive contribution to these networks. The model presented in this paper combines the spatial dynamics in land ownership, land use and the importance of agri-environment schemes in conserving biodiversity through capturing the heterogeneity of individual farmers as well as their dynamics in a spatial-explicit landscape. The paper evaluates the effects of two different agri-environment policies on landscape level and proofs that agri-environment schemes with flexible payments based on spatial landscape configuration can be valuable for agri-environment policy development.

Keywords

Agri-environment, agent-based modelling, landscape cohesion, explicit spatial analysis.

1. Introduction

One of the greatest challenges facing the global (human) community is the provision of sufficient food for an expanding population while maintaining the supply of environmental and social services that lie beyond routine commodity production (Hajkowicz et al., 2009 ; Whittingham, 2011). These services might include protecting biodiversity, improving long-term soil productivity, enhancing water quality, sequestering greenhouse gases, and improving landscape scenery. This has led to the emergence of agri-environment schemes (AESs). AESs are designed to secure environmental and social services from farmed landscapes. It typically involves either direct or indirect (e.g. tax breaks) payments to farmers to supply those services (OECD, 2005). In the European Union (EU) AESs are designed, in part at least, to enhance levels of biodiversity on farmland (Whittingham, 2007).

A basic principle of AESs in the EU is that they commit themselves voluntarily for a period of at least five years. Many studies focus on the characteristics of farms and farmers who conclude AESs (e.g., Crabtree et al., 1998; Beedell and Rehman, 2000; Wynn et al., 2001; Vanslembrouck et al., 2002; Wenum, 2002). Van Huylenbroeck et al. (2000), Peerlings and Polman (2004, 2008) and Havlík et al. (2008) developed simulation models to evaluate the impact of AESs on farm production and economic results, in order to better explain contract choice. This paper adds to this literature by including spatial and institutional dynamics in land ownership and intensity of land use on the uptake of AESs. For this purpose we developed an agent-based model (see Parker et al., 2003) to capture heterogeneity between agents (farmers) as well as dynamics through a spatial explicit model, specifically designed for simulations of the effects of agri-environmental policies on agricultural landscape level. Agent-based models (ABMs) within the specific agricultural context were pioneered by Balmann (1997) with the Agricultural Policy Simulator (AgriPoliS). ABMs allow representing economic and social systems as the result of individually acting agents. When applied to agriculture, they can simulate, at the micro-level, the behaviour of individual farmers, without the need of aggregating them in 'representative'

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agents, and then generate the macro (aggregate)-evidence. Furthermore, ABMs can catch the iterations of the heterogeneous farms when competing over common finite resources, such as land (Lobianco and Esposti, 2010).

This paper addresses the contribution of the individual contracts to the spatial cohesion of landscapes in the light of habitat network patterns. The importance of habitat network spatial patterns is widely accepted among ecologists (Opdam et al., 2003) and is also important in the European policy context as shown by the Natura 2000 networks. Where nature conservation is one of the functions competing for space, quantitative tools that relate the spatial conditions in the landscape to conservation goals are needed (Opdam et al., 1995). Because often appropriate data are not available, the planning practice is in need for tools that are independent of actual species distribution data. Therefore it is needed to assess a specific landscape pattern for the potential to conserve biodiversity. So our dilemma is that we must be able to 'read' the landscape pattern for its potential to conserve biodiversity, whereas species differ greatly in the spatial scale at which they respond to landscape features, as well as in the features they are responsive to (Andrén, 1996; Vos et al., 2001; Fahrig, 2001; Kleijn et al., 2006). This implies that there is no simple and direct way to transform landscape features into an index for conservation potential. Existing tools with predictive power either are at the species level, and too complex to apply in multi-species planning, or difficult to generalize and depend on distribution data (empirical regression models). Based on this overview, we introduce a landscape cohesion method based on data that are available: size of the area and spatial configuration. This allows to combine economic governance and planning with ecological objectives. Therefore the following research question can be formulated: What is the contribution of agri-environment schemes to landscape cohesion in habitat network spatial patterns under different economic governance structures?

This paper is organised in four sections. Section 2 describes the methodological approach underlying the proposed spatial explicit agent-based model. After a short introduction of agent-based modelling applied to agricultural landscapes (2.1), the section focuses on two key modelling issues, modelling farmers behaviour (2.2) and making space explicit (2.3), and then describe how the model is structured (2.4). A case-study is then presented in section 3, and results of this application are discussed in section 4 where the model is applied to two alternative scenarios. We conclude in Section 5 with a discussion of the methods applied in this paper.

2. The agent-based model

2.1Conceptual framework

The core of the model discussed in this paper is the understanding and modelling of an agricultural landscape as an agent-based system, thereby taking into account both the farmers' behaviour and the spatial configuration of the landscape. The model focuses on an actual agricultural region, and comprises a large number of individually acting farms that operate in the region, as well as farmers' interactions with each other and with parts of their environment. This model adds to the existing agricultural agent-based models, in that it provides a spatial-explicit landscape in which land ownership and (intensity of) land use is based on empirical data. Empirical data on individual farms and the existing regional landscape spatial structures have been initialized in the model. Also the extension of the model with the application of AESs is new, and to the best of our knowledge has not been previously performed. The software code of this model is written in the object-oriented programming language Java using the open-source agent-based modelling framework *Recursive Porous Agent Simulation Toolkit Symphony* (REPAST, http://repast.sourceforge.net/).

In the following we present a basic overview of the model; those interested in the model code may directly contact the authors.

2.2The farm agent and the auctioneer

The current version of the model contains three types of agents, the *TraderAgent*, the *Auctioneer* and the *Government.* The model contains one such *TraderAgent*, the farmer. Every farmer has a *Valuation*

Strategy that it uses to determine a (private) price for the goods it wishes to trade. Currently, the only tradable goods in the model are farmlands. The strategy used is organized through decision rules which keep track of the total number of parcels in use, the farmers' age, expectations about future land prices, as well as a number of financial indicators and changes as a result of the farm agent's actions. The farm agent keeps track of its nitrogen and feed production through balances at farm level. The most important decision rule of every farm agent is to calculate the parcels contribution to the farm income, given limited rationality of the farm agents. According to Happe et al. (2006) this assumption is reasonable for agricultural enterprises in Western Europe, where farming systems that follow different behavioural objectives such as subsistence farming only play a minor role.

Different implementations can be used in the model for different aspects of the agent's 'daily operations'. The farm agent decisions are exclusively based on their own situation and on the expectations about land prices. When the profit contribution of a specific parcel is known, firstly decisions can be made by the farm agent with respect to trading land. Secondly, farmers who land that is eligible can submit a tender for enrolling in an agri-environment scheme. They base their tender price on opportunity costs.

The second agent currently in the model is the *Auctioneer*. The *Auctioneer* is a mediator between traders and can be representing an actual person or organisation, or - in a more abstract manner - a market. The *Auctioneer* 'requests' traders to make offers to either express their willingness to buy or sell a good. The *Auctioneer* 'uses' a mechanism to match bids and asks to clear the auction. Currently, the model contains a mechanism that uses an heuristic to clear the auction in a number of iterations. It presumes that multiple buyers and sellers are present and parcels are heterogeneous (characterised by multiple attributes).

At the start of each auction the auctioneer informs the traders that the auction is open. Based on the outcome of the farm agent decision-making rules (does the agent want to buy or sell?), traders can respond by expressing interest in the auction. Next, the auctioneer requests all interested agents to provide the parcels they would like to sell with a related reserve price for these parcels. This reserve price is determined by the valuation strategy the agent is applying. Once all asks have been identified, the auctioneer request the interested agents to provide bids for the parcels on offer. A prospective buyer evaluates all available goods and is allowed to create one bid, for the asks that he or she values the most. Again, this is decided by the agent's valuation strategy.

After all bids have been collected, the auction mechanism matches bids and asks based on creation of the largest buyer/seller surplus (difference between bid price and reserve price). The auctioneer will inform the traders involved in an accepted bid, who then complete the transaction and are asked to provide new offers, or can update or retract their open bids and asks in the auction, based on their valuation and decision-making rules.

If there are still unaccepted asks left after the matching process, a new cycle or iteration of the auction is started, in which all participating agents are again asked to provide a bid for one of the remaining asks. The process continues until there are no asks left, or no more bids are made. The auctioneer will then inform all interested traders that the auction is closed. In order to calculate the transaction prices for all matched bids in the auction, the auctioneer uses a pricing policy in which the surplus is equally shared.

2.3Spatial representation and use of the spatial cohesion Reilly index

The spatial explicit landscape is represented by modeling actual parcels in the studied region. Within this spatial explicit environment, several institutional and bio-physical attributes are associated with each of these parcels: for each parcel the ownership is known, the parcel size, current land use and the possibilities for AESs. Decisions of the government on eligibility of parcels for AES is exogenous for the model. Also the parcel quality for farming is known and provides information about soil quality and crop suitability as well as ground water tables. In the model, we distinguish between three different types of land, namely grass land, maize land and parcels with AESs. For each parcel, the distance to the agent's farmstead is taken into account in the model.

Decision rules for the government agent on accepting parcels are included in the model. The government agent can either accept or reject an offer of a farmer to be contracted. The government can apply different strategies for accepting parcels. It can accept every parcel offered by farmers for AES which is the current policy standard. An alternative decision rule could be based on specific characteristics of parcels or bids of farmers which will be discussed below.

The potential of the parcel to conserve biodiversity, by means of its location and the landscape configuration is taken into account. For each parcel, either conventional, with AESs or possibility for AESs, the spatial cohesion Reilly index is calculated (see the Appendix for method). In this way, information is provided on the (potential) contribution of the parcel to the long term persistence of network populations within habitat networks in the landscape (Opdam et al., 2003). To be able to assess the potential of a specific landscape pattern to conserve biodiversity we introduce a method to calculate the importance of individual plots for landscape cohesion based on spatial data. For this paper, we want to assess the specific AES sites for their potential to conserve biodiversity thereby taking into account their spatial configuration in the surrounding landscape as a way to deal with spatial effectiveness of AES. A number of recent studies have highlighted the importance of the surrounding landscape on the effectiveness of AESs. Whittingham (2011) demonstrates that at landscape scale, the effect of AESs on farmland biodiversity has been shown to be positively related to the extent of nature conservation area and land under AESs in the surrounding landscape.

An AES site located near or in a nature conservation area has a higher spatial cohesion Reilly index score than a site that is located further away. Also larger sites result in a higher spatial cohesion Reilly-index when compared to smaller sites. In section 3, the index is integrated into a spatially explicit agent-based model framework. This model captures both the spatial dynamics in land ownership and land use on the uptake of AESs, but also contributes to the sustainable management of biodiversity in agricultural landscapes by making use of the spatial cohesion Reilly index elaborated on in this section. Finally, it can be the case that there are parcels with a higher spatial cohesion Reilly index than those within a designated area for AES. In those cases other variables not included in the spatial cohesion Reilly index could have been taken into account. As can be seen in section 3, this information can be used for policy evaluation, i.e. to adjust levels of compensatory payments for AESs or in other words the valuation function of the government.

2.4Model flow of one simulation period

Figure 2.1 provides an overview of the dynamics of the model, and the course of events during one simulation period. The model consists of an *initialization module* in which data is conditioned to be used in the model, a *farm module* allowing the calculations of farm income contribution, a *land lease market module* distributing the land among the farmers, and an *output module*. The *initialization module* contains exogenous agricultural census data (reference year 2008). The attributes on farm level are the farm structure, given in age, type of farm, size and number of total owned and rented parcels. At parcel level, attributes are soil quality, crop suitability and land use. At landscape level, attributes are number of farms in the region, spatial land characteristics, size and distance. These attributes do not change during the simulation period. The determination whether conventional farming or an AES is chosen and the derivation of farm organization takes place in the *farm module*. Each farm agent is equipped with a behavioral model that guides decisions and keeps track of the agent's internal state described by attributes such as age, location and size. According to their behavioral model, the individual farm agents evolve subject to their current state of attributes and to changes in their environment.

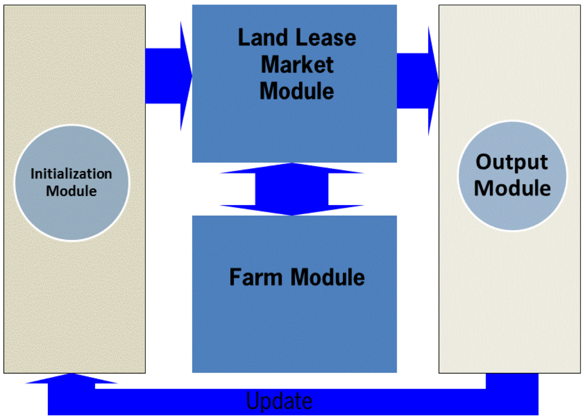

Figure 2.1 Course of events during one simulation period

The results of the farm module for individual farms are merged in the *land lease market module*. A description of the land lease market module was given in the previous section. Finally the function of the *output module* is the conditioning of the model results for the next simulation period. Results on farm level as well as on the regional level are used for update farm attributes and regional attributes in the next period.

3. Empirical data and model initialization

3.1 The study region Winterswijk

We adapted the model to the agricultural region Winterswijk located in the eastern part of the Netherlands. From a landscape perspective, the area represents a cultural-historic landscape where small-scale agriculture and nature areas are closely related providing particular cultural, recreational, ecological and economic value to the region (Provincie Gelderland, 2005). The spatial structure of the landscape attributes are characterized as small fields surrounded by hedges or wooded banks (Mastboom, 1996). Large parts of the region contain important nature conservation areas which belong to the National Ecological Network (NEN) which is part of the European Natura 2000 network. In the 1990s, the Dutch government launched the NEN as a structure of existing nature areas that was to be made more robust and cohesive by enlarging areas, improving environmental quality, and developing new areas and local ecological corridors (Opdam et al., 2008). In this way, the NEN contributes to development of biodiversity in the Netherlands (Lammers and Zadelhoff, 1996).

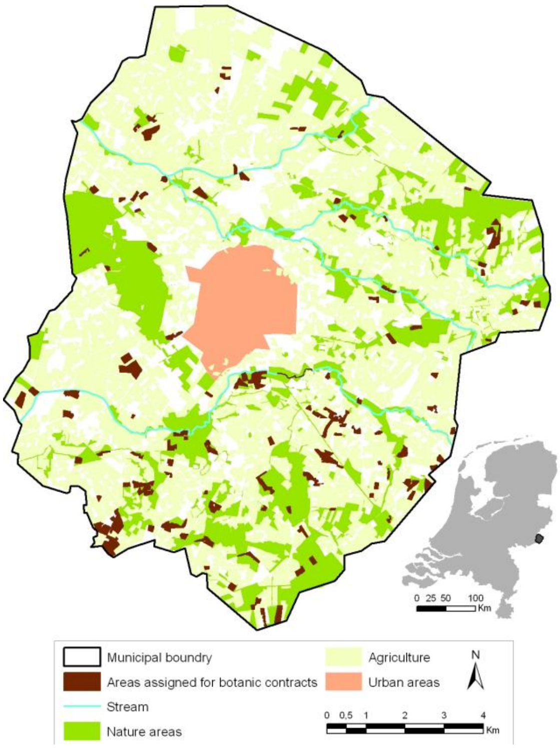

Figure 3.1 The study region Winterswijk

Figure 3.1 gives an overview of the study region. From figure 3.1 follows that nature areas and designated areas for AESs are mainly concentrated in the southern part of the region. Areas not included in the model are white. The main urban area is the city Winterswijk.

3.2 Model initialization

This study concentrates on dairy farms, both specialised dairy farms and mixed dairy/pig fattening farms. For the model initialization, 206 individual farms are distinguished, each of which are taken from the Agricultural Census. For the model initialization, their actual number of dairy cows, age and land use is included. In the model initialization the model uses ownership, size and distance to farmstead for every single parcel. These characteristics are derived from Cadastral GIS-maps. GIS-maps on land use, soil quality, crop suitability and water tables were used to integrate the production characteristics of individual parcels in the model. These dairy farmers are typical for the region (13150 ha; 5846 parcels), and together they cover 60% of the main production area in the region. The size of the nature conservation areas in the region is 3565 ha (289 parcels).

The farms are assumed to operate with production techniques that are considered to be typical for the region. The required coefficients regarding production, calculations of marginal values and income contributions are derived from FADN data. Regarding AESs on grassland, the potential uptake is 128 ha for the farms in the sample and consists of 63 parcels. Data on this matter was distributed by the Dutch Ministry of Economic Affairs, Agriculture and Innovation by means of GIS-maps with potential contract area for the year 2008. Whenever there is an uptake of AESs, the farmer obliges itself for a period of six years.

3.2 Policy scenarios

As stated in section 2.3, the potential of a parcel to conserve biodiversity, by means of its location and the landscape configuration is inherited in the model by means of the spatial cohesion Reilly index. It is assumed that the maximum budget available for AESs on 128 ha in the study region amounts approximately 130,000 euros. This amount is calculated by the sum of the assigned parcels for AESs times the compensatory payment per hectare. At this moment, the compensatory payment is a fixed amount per hectare, independent of location, parcel quality or spatial configuration in the landscape.

For this paper, we calculate the spatial cohesion Reilly index for each individual parcel with AESs or possibility for AESs. The total number of spatial cohesion Reilly points, assigned to the parcels is equal to about 62,000. From the perspective of landscape cohesion and the contribution to spatial cohesion of individual parcels, it is beneficial to link payments to the spatial cohesion Reilly index. We calculate the compensatory payment per individual Reilly point by dividing the total budget by the total number of assigned Reilly points. For this paper, we define two policy scenarios on which model simulations are ran:

- *Base scenario: fixed AES compensatory payments;*
  For the *base run scenario* we assume a fixed annual AES compensatory payment per hectare, independent of location and spatial configuration in the landscape. This scenario is in line with current European AES programmes. The government agent decision rule is to accept every parcel offered.
- *Spatial differentiated scenario: flexible compensatory payments based on contracted Reilly points;*
  For this *alternative scenario*, we assume a flexible compensatory payment per hectare, based on the contracted Reilly points for the particular parcel. In this way, information is added with respect to the contribution of the parcel to the long term persistence of populations within habitat networks in the case study region. This contract type allows for higher payments for plots that contribute more to the habitat networks. It is assumed that every eligible farm agent tenders for a contract. The spatial differentiated government decision rule is to select those bids maximizing Reilly points.

We simulate different levels of fixed compensatory payment per hectare by running the model for different budget sizes. For different budget sizes we analyze the contribution to landscape cohesion and habitat networks by showing the average number of contracted Reilly points on the contracted parcels in the simulation period for both scenarios.

4. Simulation results

The result of the simulations are shown in Table 4.1 and 4.2. Table 4.1 reports both the base run scenario and the alternative scenario for the percentage contracted AES area. We calibrated the model on the current contracted area in the region, namely 60% of the designated AES area.

Table 4.1 Percentage of AES-eligible area contracted for base run with fixed AES payment and alternative with spatial differentiated payments under the current budget and a budget increase and decrease

Scenario	Current budget*	Budget plus 50%	Budget minus 50%
Sc 1 Base: fixed AES payment	60%	81%	28%
Sc 2 Spatial differentiated payment	25%	38%	14%

*Calibrated on current contracted area

Table 4.1 shows that the base run scenario results in a higher contracted AES area. When the expenditures are simulated, it can be concluded that the base scenario results in small change in the area contracted whereas the area increases almost by 50% in the spatial differentiated areas. If the budget is half of the current budget the area contracted drops with more than 50% in the base run and a bit less than 50% in the spatial differentiated scenario. Table 4.2 gives an overview of the percentage of total contracted Reilly points that is contracted in the two scenarios.

Table 4.2 Percentage of Reilly points contracted for base run with fixed AES payment and alternative with spatial differentiated payments under the current budget and a budget increase and decrease

Scenario	Current budget*	Budget plus 50%	Budget minus 50%
Sc 1 Base: fixed AES payment	65%	85%	55%
Sc 2 Spatial differentiated payment	71%	84%	61%

*Calibrated on current contracted area

Table 4.2 shows that the alternative scenario, based on the spatially differentiated payment per hectare results in a higher percentage of Reilly points contracted. It can be concluded that the alternative scenario results in a higher contribution to landscape cohesion. If the budget increases/decreases by 50% the effects are relatively larger with respect to the amount of Reilly points contracted in the base scenario compared to the spatial differentiated payments.

The results showed that assuming a flexible compensatory payment rate based on spatial configuration and size can result in higher gains for habitat networks in agricultural landscapes, and thereby is assumed to contribute to the development of biodiversity in the studied region.

5. Conclusion and discussion

This paper shows how the use of spatial explicit agent-based models can contribute to the evaluation and development of policies with regard to AESs. The model provides better understanding of the social-ecological system dynamics, and the role of individual decision making for landscape management. The model can assist in the identification, design and evaluation of policy interventions and can inform the governance processes focusing on AESs. The results indicate that whenever policy makers are targeted at achieving the highest amount of AES area, independent of spatial configuration, the current fixed compensatory payments are preferable. Whenever policy makers want to achieve the highest contribution to the spatial habitat network through their AES policy, they could consider spatially differentiated payments.

The model presented in this paper aims to map the individual decision behaviour of farmers as well as their spatial configuration in the surrounding landscape. Nevertheless, some caveats of the model exist with regard to the farm agents behaviour and the spatial configuration of AES area in the model. A caveat is that potential public and private transaction costs of schemes (see Mettepenningen et al., 2009) are not taken into account. Further, it is assumed that all farmers with parcels that are eligible will tender for their opportunity cost. The model could be extended by including auction mechanisms dependent on Reilly points (see for auction mechanism for instance Glebe, 2008). With regard to the farm agents behaviour, their behaviour is limitedly rational, meaning that the decision making process of the farm agent is path dependent, and not globally optimizing. Another caveat is that investment activities as well as off-farm labour activities are not included in the model.

With respect to the spatial configuration of AESs in the model, it would be a valuable model extension to let loose the assigned locations of parcels for AESs. It would be interesting to see what the behaviour of farm agents will be whenever all parcels in the case study area could be contracted. Another interesting model extension considers the spatial cohesion Reilly index. Now, the spatial cohesion Reilly index is calculated once for each parcel. It would be interesting to see what happens if we re-calculate the Reilly index after each simulation period, thereby taking into account the dynamics of other AES-parcels and their location with regard to nature conservation areas within each run. We also should mention that the landscape cohesion method used in this paper is pretty rough and should not be used when there is a lot of detail required on i.e. the role of habitat quality of particular species. By using the proposed method, much detail is exchanged for simplicity and generality. However, for most regional planning and governance this could be sufficient. Finally, thorough calibration and sensitivity analysis are part of the future work.

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References
Andrén, H., 1996. Population responses to habitat fragmentation: statistical power and the random sample hypothesis. Oikos 76, 235-242.
Balmann, A., 1997. Farm-based modelling of regional structural change: A cellular automata approach. European Review of Agricultural Economics 24, 85-108.
Beedell, J., Rehman, T., 2000. Using Social-psychology Models to Understand Farmers' Conservation Behaviour. Journal of Rural Studies 16, 117-127.
Cotteleer, G., 2008. Valuation of Land Use in the Netherlands and British Columbia; a Spatial Hedonic GIS-based Approach, Wageningen University, Wageningen.
Crabtree, B., Chalmers, N., Barron, N., 1998. Information for Policy Design: Modelling Participation in a Farm Woodland Incentive Contract. Journal of Agricultural Economics 49, 306-320.
Fahrig, L., 2001. How much habitat is enough. Biologial Conservation 100, 65-74.
Gelderland, P.S.v., 2005. Streekplan Gelderland 2005: kansen voor de regio's.
Hajkowicz, S., Collins, K., Cattaneo, A., 2009. Review of Agri-Environment Indexes and Stewardship Payments. Environmental Management 43, 221-236.
Happe, K., Kellermann, K., Balmann, A., 2006. Agent-based analysis of agricultural policies: An illustration of the agriculutural policy simulator AgriPolis, its adaptation and behavior. Ecology and Society 11.
Havlík, P., Enjolras, G., Boisson, J., Jacquet, F., Lherm, M., Veysset, P., 2008. Environmental good production in the optimum activities portfolio of a risk averse-farmer. Review of Agricultural and Environmental Studies 86, 9-33.
Kleijn, D., Baquero, R.A., Clough, Y., Díaz, M., De Esteban, J., Fernández, F., Gabriel, G., Herzog, F., Holzschuh, A., Jöhl, R., Knop, E., Kruess, A., Marshall, E.J.P., Steffan-Dewenter, I., Tscharntke, T., Verhulst, J., West, T.M., Yela, J.L., 2006. Mixed biodiversity benefits of agri-environment schemes in five European countries. Ecology Letters 9, 243-254.
Lammers, G.W., Zadelhoff, F.J., 1996. The Dutch national ecological network, in: Nowicki, P., Bennet, G., Middleton, D., Rientjes, S., Wolters, R. (Eds.), Perspectives on ecological networks. ECNC Publications Series on Man and Nature, Volume 1. European Centre for Nature Conservation, Tilburg, The Netherlands.
Lobianco, A., Esposti, R., 2010. The Regional Multi-Agent Simulator (RegMAS): An open-source spatially explicit model to assess the impact of agricultural policies. Computers and Electronics in Agriculture 72, 14-26.
Mastboom, J.M.J., 1996. Protoindustrialization and agriculture in the eastern Netherlands. Social Science History 20, 235-258.
Mettepenningen, E. A. Verspecht & G. Van Huylenbroeck , 2009. Measuring private transaction costs of European agri-environmental schemes, Journal of Environmental Planning and Management, 52:5, 649-667
OECD, 2005. Evaluating agri-environmental policies: design, practice and results., Organisation for Economic Co-Operation and Development, Paris.
Opdam, P., Foppen, R.F.B., Reijnen, R., Schotman, A., 1995. The landscape ecological approach in bird conservation, integrating the metapopulation concept into spatial planning. Ibis 137, 139-146.
Opdam, P., Pouwels, R., van Rooij, S., SteingroÌˆver, E., Vos, C.C., 2008. Setting biodiversity targets in participatory regional planning: Introducing ecoprofiles. Ecology and Society 13.
Opdam, P., Verboom, J., Pouwels, R., 2003. Landscape cohesion: An index for the conservation potential of landscapes for biodiversity. Landscape Ecology 18, 113-126.
Parker, D.C., Manson, S.M., Janssen, M.A., Hoffmann, M.J., Deadman, P., 2003. Multi-agent systems for the simulation of land-use and land-cover change: A review. Annals of the Association of American Geographers 93, 314-337.

Peerlings, J., Polman, N., 2004. Wildlife and landscape services production in Dutch dairy farming; jointness and transaction costs. European Review of Agricultural Economics 31, 427-449.
Peerlings, J., Polman, N., 2008. Agri-environmental contracting of Dutch dairy farms: The role of manure policies and the occurrence of lock-in. European Review of Agricultural Economics 35, 167-191.
Reilly, W.J., 1931. The Law of Retail Gravitation. W.J. Reilly, Inc., New York.
Van Huylenbroeck, G., Jacobs, G., Vanrolleghem, P., 2000. A simulation model to evaluate the impact of environmental programmes on dairy farms. International Transactions in Operational Research 7, 171-183.
Vanslembrouck, I., Van Huylenbroeck, G., Verbeke, W., 2002. Determinants of the willingness of Belgian farmers to participate in agri-environmental measures. Journal of Agricultural Economics 51, 489-511.
Vos, C.C., Verboom, J., Opdam, P., Ter Braak, C.J.F., 2001. Toward Ecologically Scaled Landscape Indices. The American Naturalist 157, 24-41.
Wenum, J.v., 2002. Economics Analysis of Wildlife and Conservation in Crop Farming, Wageningen University, Wageningen.
Whittingham, M.J., 2007. Will agri-environment schemes deliver substantial biodiversity gain, and if not why not? . Journal of Applied Ecology 44, 1-5.
Whittingham, M.J., 2011. The future of agri-environmental schemes: biodiversity gains and ecosystem service delivery? Journal of Applied Ecology 48, 509-513.
Wynn, G., Crabtree, B., Potts, J., 2001. Modelling farmer entry into the environmentally sensitive area schemes in Scotland. Journal of Agricultural Economics 52, 65-82.

Appendix

The Reilly index derives from Newton's law of gravitation, where gravity is stronger for larger 'bodies' and gravitational strength is inversely related to the distance between 'bodies'. It was originally applied to the study of retail markets (Reilly, 1931), to reflect the attractiveness of different retail areas (cities) in terms of the trade-off between consumers' travel costs and the size of alternative retail areas. We modify the Reilly index to calculate the impact of surrounding nature conservation areas on the potential for biodiversity conservation by sites with AESs. We employ distance to nature conservation areas. Rather than population, we use the size of the nature conservation areas (measured in square meters). Equation (1) gives the formula for the calculation of the spatial cohesion Reilly-index. The calculation of the spatial cohesion Reilly-index starts at the point where the site (measured in square meters) is located. After that, the size of the nature conservation areas (abbreviation NCA) within a certain radius (i.e. 5 km) is determined, as well as the size of the AES site. Based on the sum of all the distances of the site to the nature conservation areas located within the chosen radius, and on the size of the nature conservation areas and AES sites, the spatial cohesion Reilly-index can be calculated (Equation 1). Distance is measured in meters, size in squared meters.

(1) Spatial cohesion landscape Reilly-index for AES site $_i$ =

$$\sum_{j=1}^{J} \frac{\text{Size of NCA } j\,(\text{within radius}) + \text{size AES site i}}{(\text{distance of site i to NCA})_{ij}^{2}} .$$

The index captures, in one number, the size of the nature conservation area in proximity to the AES site, and the distance from the site to certain nature conservation areas (Cotteleer, 2008). Strong points of the spatial cohesion Reilly index are the combination of distance with size, and the fact that nature conservation areas located further away or which are smaller in size are weighted less. As such, the spatial cohesion Reilly index is a measure for the share of land used for a certain land-use function in the surroundings of a specific location.

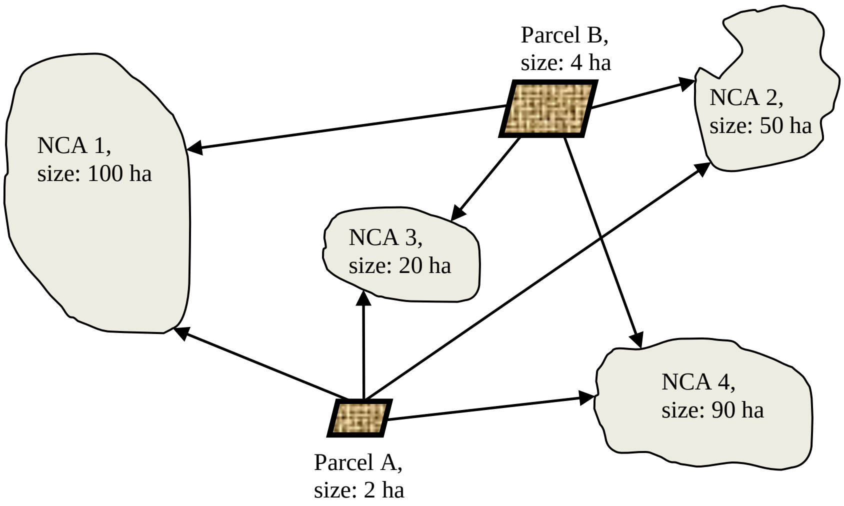

Figure 1 Graphically presentation of the spatial cohesion Reilly-index

We illustrate the calculation of the spatial cohesion Reilly-index in Table 1 and Figure 1 for the location of two AES-sites: A and B. The two sites (A and B) are heterogeneous in size and are situated in the proximity of four different nature conservation areas. The size of the four nature conservation areas is also given. Figure 1 shows the two sites, and their location in relation to the four nature conservation areas. The arrows in Figure 1 give the distance to the four nature conservation areas. The size and distance correspond with Table 1.

Table 1 Spatial cohesion Reilly-index for two AES sites given the size of sites and NCA and the distance to the NCA

NCA	NCA size (m^2)	Size site A (m^2)	Distance to site A (m)	Size / $(Distance)^2$	Size of site B (m^2)	Distance to site B (m)	Size / $(Distance)^2$
1	1,000,000	20,000	1,000	1.02	40,000	1,400	0.53061
2	500,000		2,100	0.11791		400	3.375
3	200,000		600	0.61111		700	0.4898
4	900,000		1,200	0.63888		900	1.16049
Spatial cohesion Reilly-index			**2.38791**			**5.5559**	

Source: Adapted from Cotteleer (2008, p.101) and adjusted.

From Table 1 and Figure 1, it is apparent that for site B, the spatial cohesion Reilly index is much larger than for site A, because site B is located closer to one of the nature conservation areas. Although location 2 of the nature conservation area is not the largest area, the shorter distance from site B to this area is largely responsible for the larger Reilly score for this site.