Resilience in rural common-pool resource management systems: towards enhancing landscape amenities using a multi-agent approach

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ABSTRACT

Rural areas are continuously subject to changing circumstances, varying from changes in ecosystem conditions to socio-economic changes like food- and financial crises. Within Europe, the Common Agricultural Policy (CAP) reform is driver as well for change of rural common pool resources (CPR). Rural CPRs are defined as rural social-ecological systems which provide landscapes with high agricultural, ecological and cultural-historical values. The conservation of these systems is treated as the enhancement of these values through the protection of rare plant species. Analyzing resilience of rural CPRs offers a framework to emphasize dynamics and interdependencies across time, space and between social, economic and ecological domains. This paper provides insight into the effects of CAP reforms on rural CPRs and its resilience, through the use of a multi-agent simulation approach. The advantage of such a multi-agent approach is that it allows to capture interactions of heterogeneous agents in a landscape that provides space for both agriculture and rare plant species. The simulation model is applied for Winterswijk, which is a rural region in eastern part of the Netherlands. This CPR is characterized by a small scale landscape with high biodiversity. Transferring insights from resilience thinking to rural development strategies would lead to a focus on the factors that build the ability of the rural area to respond to policy changes. The strength of multi-agent models is illustrated and their potential for the analysis of different policy options and implications in rural areas is shown.

Keywords: rural development, multi-agent systems, common-pool resource management, resilience, landscape amenities, policy analysis.

INTRODUCTION

Agricultural activities play a key role in shaping the quality of agricultural landscapes, as in many European countries farmers are responsible for managing more than half of the land area (Turpin et al. 2009). Agricultural landscapes are the visible outcomes from the interaction between agriculture, natural resources and the environment, and encompass amenity, cultural and other societal values (Vanslembrouck and Huylenbroeck 2005, p.41). Agricultural landscape amenities are defined as the scenic value and the environmental qualities of agricultural land (Dillman and Bergstrom, 1991). As with forests resources (see Ostrom 1999), agricultural landscapes are often too large for fencing them or protecting borders from intrusion which makes excluding beneficiaries from access in most cases is very costly. The

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difficulty of exclusion creates the possibility that individuals who benefit from an agricultural landscape will not contribute to long-term sustainability. Further, there is a limitation in use for agricultural production that provides a maximum current output consistent with protection of the resource for future users. The consumption of landscape amenities is rivalrous, meaning that there is the problem of how to encourage investments in enhancing the quality of the landscape in a situation where non-investors (often called free-riders) would enjoy many of the benefits while not bearing the costs for these landscape amenities (Zhang et al. 2007, p.257). The combination of non-exclusion and rivalry in consumption give agricultural landscapes common pool characteristics.

This paper looks at the management of rural common pool resources – focusing on the specific management of landscape amenities. This paper contributes to literature by looking closely at how agents within agricultural landscapes, that bring forth the amenities, adapt to disturbances. In our case, a way to analyze this is to focus on the landscape and its users as a whole: by analyzing the resilience of the resulting social-ecological system (SES). In a SES, this amounts to the capacity of humans to manage resilience. In recent years, resilience has been promoted as a concept to guide the integrative study and management of social-ecological systems. Resilience is – in its most general sense – considered as the capacity of a system to absorb disturbances and re-organize while undergoing change, so as to still remain essentially the same function, structure, identity and feedbacks. The literature on resilient social-ecological systems uses the term adaptability to describe 'the capacity of actors in a system to influence resilience' (Walker et al. 2004). In complex resource management contexts it is often the nature of the interactions between the social and the ecological or resource system that determines the system's capacity to adapt to change. Because human actions dominate in SESs, adaptability of the system is mainly a function of the social component, in our case the rural actors, acting to manage the system. Their actions influence resilience, either intentionally or unintentionally.

Within this paper, we assess the current resilience of the rural social-ecological system (agricultural landscape) in terms of an identification of the critical thresholds affecting the delivery of landscape amenities in line with sustainable management of the CPR. More specifically we focus on the protection of plant species via agri-environmental schemes, from now on called botanic contracts, to preserve biodiversity within agricultural landscapes and to enhance landscape amenities. Based on the management context of the agricultural landscape amenities, we propose an agent-based modeling approach to explore structural characteristics and identify these critical thresholds that influence the resilience to disturbances of the system. An increase in input price volatility, especially animal feed prices, due to trade liberalization will be taken into account as the particular disturbance. To the best of our knowledge, there are no studies that analyze the effects agri-environmental management on the resilience of common-pool resources such as landscape amenities, using a multi-agent approach.

The remainder of the paper is structured as follows. First, a short description of landscape amenities as a common-pool resource will be given. Second, common-pool resource management will be linked to the resilience of the associated rural social-ecological system. Third, the general structure of the empirical model is described. The model is applied for Winterswijk, which is a rural region in the eastern part of the Netherlands. Fourth, some simulation results are presented, using changes in input prices as a disturbance. Finally, the results of the simulations, the general model structure, and model assumptions are discussed in view of the use of the model and preliminary conclusions are drawn.

RURAL COMMON-POOL RESOURCE MANAGEMENT: LANDSCAPE AMENITIES

Landscape amenities

Management of agricultural landscapes with high cultural-historical and ecological value, the so-called agricultural landscape amenities, is problematic because they can be seen as ‘common pool’ resources. Berkes (1989) has pointed out the principal options for improving management of a common pool resource: it can be privatized, with property rights exercised by an individual or private corporate entity; it can be managed by the government; or it can be managed collectively or cooperatively under a common property regime. Natural conditions and human activities have created many landscape attributes (Vanslembrouck and Huylenbroeck 2005). Over the last three decades, major change has taken place under the combined effect of both technological progress and developments in agricultural policies. In this paper, we focus on government-managed agricultural landscapes, where government ownership is only partial or altogether absent. It is clear that policy is only one factor, and it would be wrong to conclude that this is the only factor influencing the landscape. However, policy is often the easiest one to influence. A chronic problem for government-managed recreational landscapes is overcrowding and resource damage. Especially resource damage by intensive agricultural use is an important problem for scenic agricultural landscapes, and is controlled through regulations for land use, and design controls to protect tourism environments.

Agri-environmental schemes: botanic contracts

The introduction of agri-environmental schemes in the EU-member states aims not only to persuade farmers to contribute positively to the preservation of nature and landscape, but also to avert further degradation (Van Huylenbroeck and Whitby 1999; Vanslembrouck and Huylenbroeck 2005). Agri-environmental schemes encourage farmers and foresters to manage land in such a way as to preserve and enhance the natural space and landscape, protect and improve environmental resources and ensure the sustainable use of forestry resources (EC 2004). Within agri-environmental schemes, farmers can conclude agri-environmental contracts on all or part of their land in which they agree to deliver agri-environmental services in return for a payment (Peerlings and Polman 2008). In this paper, there will be a focus on the Dutch dairy sector. Dairy farming is the most important agricultural sector in The Netherlands. Botanic contracts intended to protect plant species are important agri-environmental contracts in this sector. This paper considers botanic contracts, aiming at developing certain types of grassland with high plant species diversity. Botanic contracts ban the application of nitrogen (N) fertilizers; only N deposited by cattle when grazing is allowed. Kleijn et al. (2004) argued that grassland quality may have an overriding influence on the number of plant species, and thereby on the ecological and cultural-historical value of scenic landscapes: its agricultural landscape amenities.

RESILIENCE AND THE RURAL SOCIAL-ECOLOGICAL SYSTEM

Rural social-ecological system

As stated in the introduction, the analysis of common-pool resource management in this paper is taken one step further by focusing on the adaptability of agricultural landscapes to disturbances. Adaptability in this context is the capacity of users of an agricultural landscape to influence resilience. A way to analyze the resilience of the users as well as the corresponding landscape is by focusing on the landscape and its users as a whole: by analyzing the resilience of the resulting social-ecological system (SES). Following Janssen and Anderies (2007), social-ecological systems can be defined as a structure of a common-pool resource, its users and an associated governance system. The SES is subject to a wide variety of disturbances to their governance systems, the resource users themselves, and the underlying ecological system that constitutes the resource. The capacity to manage resilience, intentionally, determines whether they can successfully avoid crossing into an undesirable system regime, or succeed in crossing back into a desirable one. Rural actors can move thresholds away from or closer to the current state of the system, move the current state of the system away from or closer to the threshold, or make the threshold more difficult or easier to reach (Walker et al. 2004). Within this paper, we assess the current resilience of the rural social-ecological system (agricultural landscape) in terms of an identification of the critical thresholds affecting the delivery of landscape amenities.

We propose that resilience thinking offers a framework that could be helpful in the governance of rural disturbances. Transferring insights from resilience thinking to rural development strategies would lead to a focus on the factors that drive the ability of the rural SES to respond to disturbances.

Disturbances resulting from the EU's Common Agricultural Policy reforms

Within this study, the term disturbance is used as the collective noun for all shocks and stresses that can appear within rural systems[c]. The effects of these disturbances on the rural SESs are characterized by episodic surprises, resulting from small events that are magnified through dynamic, nonlinear feedbacks into changing outcomes (Darnhofer 2009). White and Pickett (1985) define a disturbance as 'any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability or the physical environment'. Ecologists tend to focus on natural disturbances, such as fire, floods, hurricanes, insect outbreaks etc., but within social-ecological systems, also economic and social disturbances need to be taken into account.

In this paper we focus on disturbances resulting from the EU's Common Agricultural Policy (CAP) reforms. From the beginning of the 90's, the CAP has been subject to several reforms (EC 2004) focusing mainly on adjusting to a more liberal trade environment. These reforms have led to implications of tariff reductions, the elimination of export subsidies and reduction in subsidies to farmers (Jongeneel et al.

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[c] A shock can be defined as a 'force that is relatively large, infrequent and unpredictable, and produces an immediate disturbance' (Conway 1991). Stress is usually defined as a disturbance that threatens to upset the equilibrium of an organism or system (Deary 1994).

2010). Because of these reforms, an increase in price pikes and price volatility of food prices is predicted. Also price variations for other commodities and inputs to agriculture are already detected over the past few years (Huan-Niemi et al. 2009). This paper focuses on these increased price fluctuations, and assesses the effects of these fluctuations on the maintenance and development of agricultural landscape amenities, by focusing on the resilience of plant species diversity through botanic contracts.

THE AGENT-BASED MODEL

Conceptual framework

To grasp the non-linear, stochastic character of the dynamics within a rural SES, a methodology is needed that allows for experimenting with behavioral processes within different actors and with interactions between actors and the ecosystem. Understanding the dynamics in such complex systems, which is difficult to gain by controlled experiments, may be supported by using simulation models. In other scientific disciplines, such as land use modeling and ecology the use of simulation models have proven to be an adequate method to increase understanding of processes in complex social-ecological systems. Agent-based simulation provides the ability to assess the effects of the actions and interactions of individual and collective entities on the complex system as a whole. This simulation modeling technique offers a perspective on simulating human behavior in complex environments, by combining biophysical and socioeconomic characteristics of a system while taking into account its non-linear dynamics and complex interactions (see, for example Janssen and Ostrom 2006; Matthews 2007).

The core of the model discussed in this paper is the understanding and modeling of a rural social-ecological system as an agent-based system for the purpose of resilience assessment while simulating the effects of disturbances. The model shows how the CPR agricultural landscape and its corresponding landscape amenities, behaves as a result of disturbances in output prices. The agricultural landscape amenities are represented in the model by the area of botanic contracts. The model establishes a virtual world of a rural region and comprises a large number of individually acting farms that operate in a region, as well as farms interactions with each other and with parts of their environment. In contrast to Happe, Kellermann and Balmann (2006) it is assumed that all farmers have equal capabilities and all agents have perfect information. The modeler can fully control the rules of the model. The model is an abstract region, and provides interfaces to initialize the model with empirical data on individual farms and existing regional agricultural spatial structures. A time horizon of twenty-five years is chosen that allows farmers to take investment decisions in land, and model calculations are limited to path-dependencies. In the following, we present a description of the single entities of the model, and describe their relationships. The software code of this model is written in the object-orientated programming language Java using the open-source agent based modeling framework *Recursive Porous Agent Simulation Toolkit Symphony*[d].

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[d] http://repast.sourceforge.net/

Landscape

The spatial explicit landscape is represented by modeling actual parcels in the studied area. Within this spatial explicit environment, several 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 botanic contracts. In the model, we distinguish between three different types of land, namely grass land, maize land and parcels with botanic contracts. For each parcel, the distance to the agent's farmstead is taken into account in the model.

The farm agent

The main element of a farm agent is its behavioral model. This behavioral model is organized through decision rules which keep track of 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. The most important decision rule of the farm agent is to calculate the parcels contribution to farm income, given limited rationality of the farm agents. According to Happe, Kellermann and Balmann (2006) this assumption is reasonable for agricultural enterprises in Western Europe, where farming systems that follow different behavioral objectives such as subsistence farming play only a minor role.

For each parcel owned and made available to the land market, the farm agent calculates the farm income contribution of the respective parcel. This is done for conventional grassland parcels, parcels with botanic contracts, parcels with possibilities for botanic contracts and maize land parcels. The farm income contribution of the parcel is a function of the revenue from dairy production and compensatory payments, and the costs for transport to the parcel, bought feed, disposed nitrogen, fertilizer costs and other costs. Whenever there is a feed surplus produced on the farm, the farm agent is able to gain revenue from selling feed. Whenever there is a shortage of nitrogen on the farm, the farm agent is able to gain revenue from applying extra nitrogen to the parcel.

The farm agent decision unit is exclusively based on their own situation and on expectations about land- and output prices; expectations about the behavior and actions of other agents are not included. We make use of an expectation price $(P_{\exp_t})$ for land (per hectare), which is equal to the moving average of the expectation price in previous period ($P_{\exp_{t-1}}$) plus the actual price in the current period (P_t), and a decay in expectation prices from the previous period (2) (α=0.5).

$$P_{\exp_t} = \alpha P_t + (1-\alpha) P_{\exp_{t-1}}$$

When the profit contribution of the respective parcel is known, decisions can be made by the farm agent. Table 1 illustrates the trade-offs of the farm agent.

Table 1. Farm agent parcel tradeoffs

Income conventional parcel		*Income parcel botanic contract*	*Expectation price*				*Decision*
Parcel is conventional and possibility for botanic contract, or contract expires next period							
If πY_i	<	πY_{i_b}	And πY_{i_b}	<	$p_{\exp}$	Then	Offer parcel to market
If πY_i	<	πY_{i_b}	And πY_{i_b}	>	$p_{\exp}$	Then	Botanic contract
If πY_i	>	πY_{i_b}	And πY_i	<	$p_{\exp}$	Then	Offer parcel to market
If πY_i	>	πY_{i_b}	And πY_i	≥	$p_{\exp}$	Then	Conventional
Parcel has no possibility for botanic contract							
If πY_i	<				$p_{\exp}$	Then	Offer parcel to market
If πY_i	>				$p_{\exp}$	Then	Conventional
Parcel has botanic contract							
		If πY_{i_b}		<	$p_{\exp}$	Then	Offer parcel to market
		If πY_{i_b}		>	$p_{\exp}$	Then	Botanic contract

In each period farmer agents calculate the income contribution of the parcel of their conventional grass (πY_i), parcels with botanic contract (πY_{i_b}) and maize parcels (πY_{i_m}). Also for the new parcels offered by the land market to the farmers, which can be conventional grassland, conservation grassland and maize land parcels, the income contribution is calculated. The same method is used as for the parcels that are already in use. In case of a parcel with botanic contracts: whenever the contract expires, the farm again has the opportunity to choose whether conventional or conservation farming is applied to the parcel. There is also a possibility to offer the parcel to the land market. The farm agent will offer the parcel against a reserve price which is conform the individual valuation price, which is set at 70% of the transaction price of the past two periods. Whenever a contract is signed, the farmer cannot choose anymore to explore conventional farming on the parcel, so only selling or continuing is possible. In the model the latter also applies to maize land (πY_{i_m}).

After a farm agent has reached a certain age, a generational change takes place. From agricultural census data is known whether a farm agent has a potential successor. Whenever the farm agent does not have a potential successor, the farm agent will stop farming and will offer its land to the land market against the same reserve price as discussed above.

Land lease market

Near all work done so far in the field of ABMs in rural areas made use of a land auction system in which the farm agents proactively chooses a particular parcel to bid on (Happe 2003; Happe, Kellermann and Balmann 2006; Freeman, Nolan, and Schoney 2009; Balmann 1997). Also in this model direct interactions between agents are organized using an iterative auction for grassland, maize land and grassland parcels with botanic contracts which is fully endogenous in the model. Farm agents do not interact on a product, capital, or labor market; these are treaded exogenous in the model.

In the model, farm agents extend their area exclusively via renting land. Regarding land ownership, all land is either owned or rented by farm agents. When the model is run, land available on the market stems from two sources: one is farms that are retired and do not have a potential successor, the other is land offered to the market due to high opportunity costs.

The land market is organized as an iterative single auction that allocates free parcels to all farms present in the region. In brief, the land allocation process works as follows. To allocate free land to farms, the model implements an iterative auction during which an auctioneer, a market agent, allocates free plots to all farm agents that intend to rent additional parcels of land. First, each farm agent produces a bid for a particular parcel, given the land-use of the parcel (grass, maize, botanic contract, possibility for botanic contract). The bid depends on the farm income contribution of the respective parcel. Second, the auctioneer allocates a free parcel to the farm agent with the highest bid. This procedure is repeated until all free land is allocated or no more bids are made that satisfy the reserve prices of offered land. The status of the allocated parcels can be defined as a lease contract with infinite contract duration.

Model flow

Figure 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*, 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) that influences the rural social-ecological system in the study region. One of the most important attributes on farm level are the farm structure, given in age, type of farm, size and number of total owned and rented parcels. At regional level, the important attributes are number of farms in the region, spatial land characteristics, size and distance. The determination whether conventional farming or botanic contracts are 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 actual state and to changes in their environment.

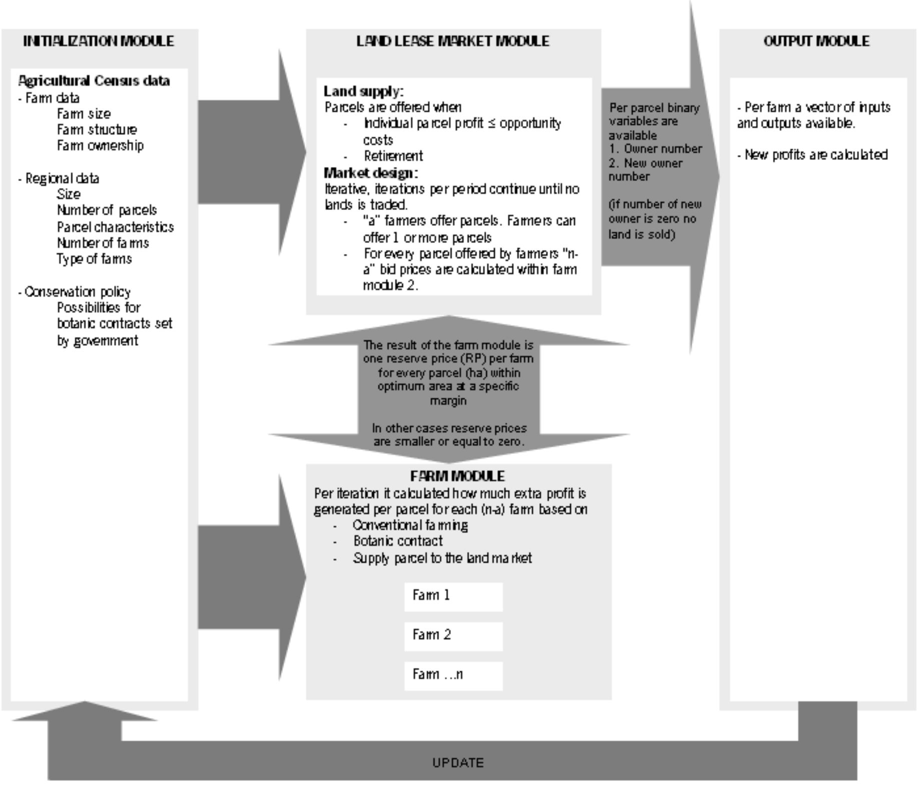

Figure 1. Rural social-ecological system dynamics and course of events

The results of the farm module 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 and the analysis of the model results. Results on the farm level as well as on the regional level are used for update in the next period.

CASE STUDY: WINTERSWIJK

As stated in the introduction, the proposed model is illustrated with a case study in the rural region Winterswijk where processes of diversification of farm practices and farm expansion are reshaping the landscape structure, and its landscape amenities. The study area is located in the eastern part of the Netherlands and covers an area of approximately 60.650 ha. By 2005, there were around 2300 agricultural holdings; about 66% of them were dairy livestock farms (Agricultural Census data). Part of this area represents a cultural-historic landscape where small-scale agriculture and nature areas are closely related providing a particular cultural, recreational, tourist, ecological and economic value to the region (Provincie Gelderland 2005a). Important characteristics of the area are small fields surrounded by hedges or wooded banks. The spatial structure of the landscape has been the result of the interaction between biophysical (e.g. soil characteristics and water availability) and socio-economic factors and processes (e.g. land tenure, accessibility and labor demand)(Mastboom 1996).

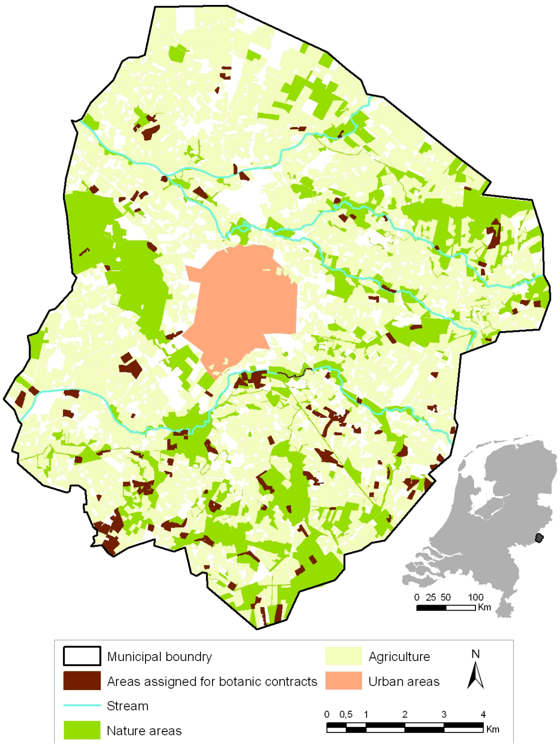

Figure 2. The study area Winterswijk

In the last decades, social changes such as the increasing environmental awareness and the growing demand for recreation and tourist areas, together with legislative changes such as the establishment of milk quotas, restrictions on manure applications, and compensatory payments for nature and landscape conservation have influenced the rural dynamics in the study area tremendously (Provincie Gelderland 2005b).

On the farm level, 206 individual specialized dairy farmers are distinguished, each of which are taken from the Agricultural Census. As stated before, these dairy farmers are typical for the region, and they cover 60% of the main production area in the region. The farms operate with selected 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 standard farm management data samples provided by the Agricultural Economics Research Institute. The following section presents a selection of preliminary results of the model.

SIMULATIONS: INPUTPRICE DISTURBANCES

Due to further EU CAP agricultural and trade liberalization, it is expected that an increase of price pikes and price volatility of food prices, as well as other commodities such as inputs to agriculture will occur. This paper focuses on price disturbances as a consequence of price volatility increase. We therefore simulate sudden disturbances in input prices, especially animal feed prices and simulate the effects on the maintenance and development of landscape amenities within the Winterswijk region. Particularly, there is a focus on the adaptability of farmers within the region, with respect to the number of parcels with botanic contracts, in reaction to the disturbances.

Within the area, farmers receive an annual compensatory payment of 1018 euro/ha whenever they sign a botanic contract for a period of six years. Implementing such a contract will lower feed production on the farm. Feed shortages can be bought externally. Whenever there is a feed surplus produced on the farm, the farm agent is able to gain revenue from selling feed.

Several disturbances are simulated. A disturbance is imposed at t=10 in terms of a sudden increase in animal feed prices. This disturbance lasts for one year. After this disturbance, the animal feed prices return to their initial value.

Literature on infrequent disturbances in ecosystems (e.g. Paine, Tegner, and Johnson 1998; Turner et al. 1998; Turner and Dale 1998) assumes that there is always a set of species and functional groups available for ecosystem reorganization. They assume that reserves that can be defined as an overcapacity in diversity, have to be of substantial size, and with substantial ecological memory that ensures rapid reorganization. However, as reserves become smaller, they become insufficient for rapid reorganization after disturbances, and they become more and more dependent on the surrounding landscape. This represents a reduced resilience which increases with probability that disturbances may occur implying a dynamic minimum area depending on the probability of disturbances.

The concept of minimum dynamic areas can also be applied to rural social-ecological systems. As a first step in this direction, we simulate a threshold level for the minimum area under agri-environmental schemes that represent enough diversity to secure buffering capacity and resilience of the landscape. Taking into account the input price disturbances discussed in the previous section, it is assumed that whenever 80% of the assigned parcels in the area Winterswijk is covered with botanic contracts, it is assumed that the respective size of the area is large enough to withstand disturbances, and to secure buffering capacity and resilience of the landscape. Simulations are run for the scenarios in which animal feed prices decrease and increase and farmers receive the prescribed compensatory payment of 1018 euro/ha.

SIMULATION RESULTS

Taking into account the price and production expectations of the farmers, it can be seen that the number of hectares with botanic contracts reduces significantly when a sudden increase in animal feed prices occurs. A second disturbance which is simulated is a sudden decrease in animal feed prices. It is shown that a sudden drop in animal feed prices results in a temporary higher number of botanic contract area. Further, it is shown that agricultural landscape amenities through botanic contracts are only resilient on temporary basis. The animal feed price disturbance is an incentive for farmers to attract more or less botanic contracts. In figure 3, the effects of a policy intervention are shown, under a scenario of sudden animal feed price increases. The figure shows the simulation results of an increase of compensatory payment up to 1500 euro/ha.

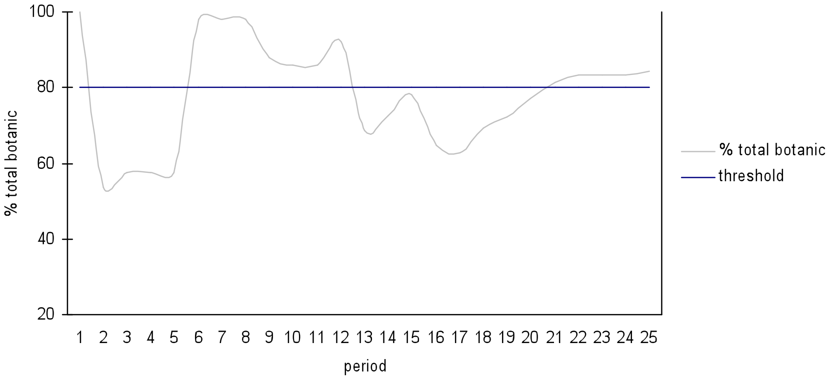

Figure 3. Percentage area with botanic contracts with threshold under sudden increase animal feed prices, increased compensatory payment (1500 euro/ha)

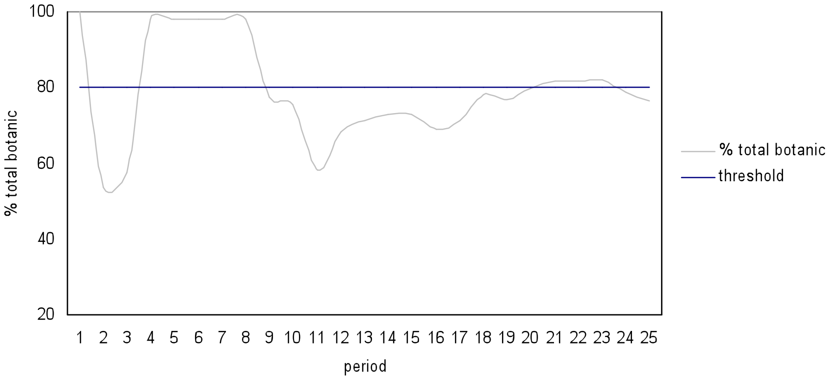

Figure 4. Percentage area botanic contracts with threshold under sudden decrease animal feed prices, increased compensatory payment (1500 euro/ha)

Figure 3 shows that during the disturbance, the increased animal feed prices result in a smaller botanic contract area, because of the increased incentive to produce animal feed on conventional parcels. Figure 4 shows the effects of a compensatory payment under a scenario of sudden decreases in animal feed prices. It is shown that the botanic contract area increased over a longer time span. Whenever the compensatory payment is increased to 2000 euro/ha, the simulation results show that almost all assigned botanic contract parcels are in use (on average 97%) under a botanic contract. From both figures it can be concluded that the resilience to disturbances in feed prices of landscape amenities is enhanced due to the increased compensatory payments.

DISCUSSION AND CONCLUSION

The model presented here is developed to systematically analyze rural social-ecological system dynamics in response to disturbances in economic circumstances. The first results show that taking into account interaction between farm agents in form of changing land ownership is important to gain insight in spatial consequences of rural polices within the European Union. The area of Winterswijk with its aging farmer’s population shows relevant dynamics in land ownership and effects on plant species protection contracting. Contracting depends on farmers’ characteristics and quality of parcels (distance to farm and size).

This paper shows the need to study the dynamics of coupled social-ecological systems, especially their capacity to cope with disturbances, as a theoretical basis for ecosystem and resource management. Better understanding of system dynamics and the source and role of change in enhancing system resilience, will assist identification, design and evaluation of policy interventions and can inform a management process focused on resilience enhancement. In an agricultural landscape, which is created and managed historically throughout the centuries, it is difficult to imagine how disturbances impact the system, and how policies can react upon this, and ultimately how their resilience develops throughout time. This paper demonstrates that the model has potential for analysis of different policy options and their implications.

A caveat of the model is that the farm agent's behavior can be referred to as limited-rational because the decision making process of the farm agent is path dependent and not globally optimizing: it only takes the expected income change of a single transaction opportunity into account. Another caveat is that investment activities are not taken into account in the model. It is assumed that only on-farm family labor is used, hired labor is not included in the model. Also a financial module, in which a farm can balance short- and long-term liquidity shortages and credits as well as investments in liquid capital and machinery, is not taken into account. Another valuable model extension is the explicit inclusion of cognitive, institutional and social processes. For example the inclusion of cooperation among farmers in social networks can be a valuable extension of the model. This paper covers only a small selection of the results from the model. More results, a thorough calibration and sensitivity analysis and model extensions are part of the future work.

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