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Dairy Farming and Newt Habitat: How Shocks in Milk Prices Influence the Optimal Design of Water Retention Policies

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Abstract: Floods and droughts are expected to occur more frequently due to climate change. Regional water boards in the Netherlands are anticipating water level variations in streams in rural areas. To moderate adverse effects of those variations, they seek for opportunities to enhance retention of rainfall runoff on agricultural land in the stream valleys. This can be done by contracting farmers to apply agri-environmental measures. We focus on this small-scale and flexible (in space and time) rainfall runoff retention by farmers. Farmers can decide to (temporarily) allocate parts of their land to apply agri-environmental measures, depending on shocks of various nature, e.g. shocks due to increased price fluctuation for agricultural products. These patches of land may then serve as water retention areas and can be temporarily habitat to certain species, and the configuration of the habitat patches is highly dynamic. Spatiotemporal habitat dynamics can have strong effects on species' viability. This paper develops an index as a proxy to express the persistence of species in the complex socio-ecological system, depending on crucial – but dynamic – factors landscape history and proximity of habitat. The development of such a "dynamic landscape"-index is scientifically innovative. We aim to support water boards by offering a simulation model to evaluate potential effects of alternative agri-environmental policies and to test the robustness of policies to shocks in the socioeconomic environment. This model contains a spatially explicit agent-based model and a population dynamics model. The agent-based model simulates the allocation of agri-environmental measures by the water board and farmers' land use decisions. To check whether the landscape index indeed promotes species' persistence, the population dynamics of indicator species are simulated in the dynamic landscapes generated by the agent-based model, using the population-dynamic model METAPOP.

***Keywords**:* Spatially explicit agent based model; population-dynamic model; shocks

1 INTRODUCTION

Rural areas are continuously subject to changing circumstances. Ecosystem conditions fluctuate due to climate change, weather extremes, floods and droughts and socioeconomic changes are caused by food and financial crises and price fluctuations for agricultural products, e.g. animal feed prices. At a regional level, these are exogenous shocks: forces that are relatively large, infrequent and unpredictable, and produce an immediate disturbance (Conway 1991).

Regional water boards in the Netherlands are anticipating water level variations in streams in rural areas. To moderate adverse effects of those variations, they seek for opportunities to enhance retention of rainfall runoff on agricultural land. This can be done by contracting farmers to apply agri-environmental measures, taking into account both water retention aspects and habitat development.

Farmers can decide to (temporarily) allocate parts of their land as water retention areas for which they receive subsidies. This might be profitable in times of sudden changes in the socioeconomic environment, e.g. low feed prices, when the profit contribution from subsidies due to the allocation of retention areas would outrage the income after conventional farming. These patches of land, or parts of parcels, that serve as retention areas become swampy and are inundated temporarily due to man-made changes in the surface hydrological system of ditches and sluices. These areas may then be habitat to certain species, e.g. dragonflies, frogs and salamanders.

In many landscapes, (a part of) the nature value is only temporarily present. This is for instance the case when contracts to apply agri-environmental measures are valid for a limited amount of time (e.g. 3 years). When the contract has ended, the parcels can be taken into full production again and nature values disappear. At the same time, other parcels can be allocated for agri-environmental measures. Hence, in some parts of the landscape nature disappears where on other locations, nature remains or is being developed.

Van Teeffelen et al. (in press) show that species are less likely to survive in nature networks where a part of the patches is only temporarily present, compared to networks where all habitat patches are permanently present, even if the net amount of available habitat is equal. This is caused by the local extinction of individuals of species in patches that disappear. Moreover, the colonization of newly developed patches takes time.

We investigate whether sustainable landscapes will develop for Great Crested Newt (*Triturus cristatus*) to survive, when farmers are contracted to allocate parts of their land as water retention areas. Farmers and their allocated land can be contracted by the water board in a spatially random way: first come first served. Alternatively, the relative benefit of parcels as habitat to the species can be taken into account: the ecologically most suitable patch of land - considering the effect of dynamics in the positioning of nature areas on the survival of species - is contracted first, etc. We evaluate potential effects of these alternative agri-environmental policies compare both alternatives with respect to farmers' costs and socioeconomic and ecological benefits. Moreover, we test the robustness of the policies to shocks in the socioeconomic environment.

We adapted the model to the agricultural region Winterswijk (about 22.000 ha) located in the eastern part of the Netherlands. The landscape is characterized by small fields surrounded by hedgerows (Mastboom, 1996). Large parts of the region contain important nature conservation areas which belong to the National Ecological Network which is part of the European Natura 2000 network. Additionally, agri-environmental schemes contribute to conservation and improvement of biodiversity. The Great Crested Newt has been encountered regularly in the study area over the last decade.

2. METHODS

2.1 Theoretical Framework

The interdisciplinary research reported in this paper builds on results from ecology and the social sciences. The ecosystem and the social system are located in an agricultural area, with mainly grasslands, criss-crossed with streams and interlarded with patches of wood.

The social system under study consists in the population of land owners, which are mostly farmers, and the water board. The water board anticipates larger variations in water supply due to climate change and aims to contract farmers to dispose of land in stream valleys for water retention. The contracts are fixed-term. The water board's second objective is to optimize the area's ecological quality. The ecological goal can be expressed as some set of over-all indicators for the entire region, e.g. survival of particular species. However, the potential contribution of individual plots of land offered for water retention cannot be measured directly. Some proxy indicator must be defined for selection of plots to be contracted (see section 2.3). The model presented in this paper serves to evaluate the proxy's effectiveness.

The social system is simulated by a spatially explicit agent-based model, built upon actual data about farm structure, geographical structure, soil attributes, land use, and land ownership in the region. Farmer agents are designed to decide on farm management, retirement, land market, and offering land for water retention. The farmer agents use actual and expected prices of inputs and outputs for their decisions. Different scenarios of price development and price shocks can be fed into the simulation. Water retention contracts are awarded according to the scores of offers on the proxy indicator. The agent-based simulation of the social system results in a sequence of maps representing land use (e.g. water retention areas that serve as habitat) at some (typically annual) frequency over the simulation period.

The ecological system is simulated by a spatio-temporally explicit metapopulation model. The dynamics of the habitats generated by the agent-based model, that become clear from the above described sequence of maps and represents the effects of price scenarios and shocks, are input to computation of the actual ecological indicators, such as number of individuals of particular species. Thus the coupled model can be used to evaluate the effectiveness of proxy indicator under various price development and shock and no-shock scenarios.

Figure 1 depicts the relations between the model's components. Sections 2.2 and 2.4 describe the agent-based model and the metapopulation model in more detail.

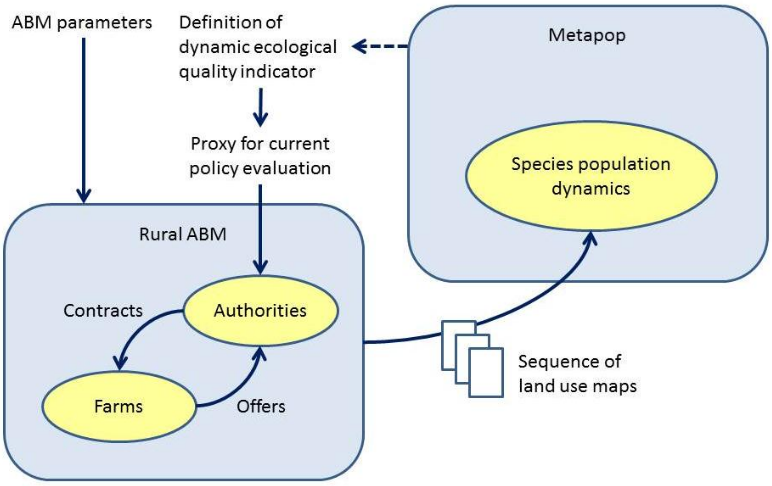

Figure 1. Coupled simulation models used.

2.2 The Rural Agent-Based Model

The core of the ABM 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 as relevant for salamanders. The model is an extension of the model by Schouten et al. (2011) by introducing the possibility to farmers to allocate (parts of) their land as water retention areas. Farmers receive subsidies as these patches of land may then be habitat to certain species, e.g. dragonflies, frogs and salamanders. 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 (see Schouten et al., 2011). Empirical data on individual farms and the existing spatial landscape structures have been initialized in the model. The model includes the application of agri-environmental schemes (AESs).

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. Within the simulation phase, each farm agent is equipped with a behavioural model that guides decisions and keeps track of the agent's internal state described by attributes, such as age, location and size (Schouten et al. 2012). 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 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/).

2.3 The Dynamic Landscape Index

Not all parcels are equally beneficial to function as habitat to species. To estimate and compare the ecological contribution of parcels under agri-environmental measures, the number of 'ecopoints' per parcel can be calculated.

In recent literature, the concept of ‘ecopoints’ is used to express the ecological value of a patch of land, and to compare these patches (see e.g. Johst et al. 2011). There are various ways to express the number of ecopoints. A parcel with a high nature value on its own can get more ecopoints than a parcel with a low nature value. Moreover, the position of a parcel in the vicinity of other nature can be taken into consideration. A patch of nature that is well positioned within a network of nature patches generally contributes more to metapopulation processes that an isolated patch of nature. Current methods to calculate the number of ecopoints include both the local and the regional nature value (e.g. Hartig & Drechsler 2009; Schouten et al 2011).

In many landscapes however, a part of the natural or ecological value is only temporarily valid, e.g. when farmers are only temporarily contracted to apply agri-environmental measures. Van Teeffelen et al. (in press) show that the survival of species is lower in landscapes where a part of the habitat patches is only temporarily present, compared to landscapes where all habitat patches are always present, even if the total available area of habitat is equal.

Considering this effect of dynamics in availability of habitat on species survival, we take these dynamics into account in calculating the amount of ecopoints:

$$E_i = (1-m)\cdot L_i + m\cdot C_i(r) \quad (1)$$

where Ei is the number of ecopoints assigned to gridcell i. The parameter m ($m \in [0,1]$) defines the importance of the local component in relation to the regional component. The local gridcell quality is defined by:

$$L_i = \frac{a_i}{a_{\max}} \quad (2)$$

where ai is the number of years a gridcell is already habitat, with a maximum of amax. The calculation of the connectivity C is derived from Hartig & Drechsler (2009), who define connectivity as the fraction of all gridcells within a radius r around cell i, that is also habitat. Additionally, we take the age of all habitat cells into consideration:

$$C_i(r) = \left(\sum_{d_{ij}<r} \frac{\sigma_j a_j}{a_{\max}} \right) \cdot \left(\sum\nolimits_{d_{ij}<r} 1 \right)^{-1} \quad (3)$$

Hence, considering the number of ecopoints as a proxy for ecological effectiveness, this calculation stimulates habitat development in the surroundings of older habitat. Since older habitat has a bigger chance to be occupied by species, the colonization chance of new patches of habitat in the surroundings is larger. We expect this proxy indicator to result in more sustainable populations of species.

2.4 The METAPOP Model

We used the metapopulation model METAPOP (e.g. Schippers et al. 2009) to simulate the dynamics of the Great Crested Newt (*Triturus cristatus*) in the Winterswijk area. The Great Crested Newt is a vulnerable species in the

Netherlands that can profit from additional temporal habitat as created from agri-environmental measures (retention areas). The model calculates the effects of changes in the configuration of habitat patches induced by the adoption of agri-environmental schemes by farmers on the Newts in a deterministic manner. The model is spatially explicit, simulating the Great Crested Newt populations (divided into 3 age classes and 2 sexes) in space and time. Life history events are reproduction, survival/aging and dispersal. The life history events occur sequentially during each time step, i.e. a year (details and parameters are available on request by the authors):

1. Reproduction: each pair of adult females/males (a male or female can only be assigned to one pair simultaneously) produces a number of 1-year old recruits according to a Poisson distribution.
2. Survival/aging: Juveniles (<3 years old) have an age-class specific probability to survive and reach the next age class. Adults survive with a given probability and stay in the same age class.
3. Dispersal: We do not explicitly model dispersal of individuals between winter habitat and breeding habitat, because the distance between breeding habitat and winter habitat in the study region is always <400 meter. Instead, we model dispersal by juveniles in search for breeding habitat before they reach adulthood. Juveniles disperse away from the natal patch with a given probability. We use a pie-slice model without shadow effects to calculate the probability of an individual to arrive to another patch, which is determined by inter-patch distance and target patch area.

2.5 Simulations

The simulation period taken into account in the ABM is 24 years (reference year 2008), and a milk price disturbance regime change like the price swings experienced in the period 2007-2009 (see Jongeneel et al., 2010) is imposed to the farm agents active in the rural landscape. Consecutive extremely high price peaks and falls will be experienced as a surprise by the farm agents in that period. Then, these swings followed a relatively long period of steady milk prices. For the remaining of the simulation period, farmers experience a stable average annual milk price (calibrated on an average annual milk price; 0.25 euro/kg). For these two milk price disturbance regimes we compare two different policy mechanisms: (1) a policy mechanism with fixed compensatory payments for suitable land; and (2) a policy mechanism with payments based on ‘ecopoints’ (see Section 2.3).

For the policy mechanism with fixed compensatory payments, we assume a fixed base annual compensatory payment per hectare, independent of location and spatial configuration in the landscape. This mechanism is in line with current mechanisms used in current Dutch AES programs. We run the model for two different levels of contract duration with comparable corresponding budget sizes. For these different contract duration periods we analyze the contribution to habitat networks by showing the average number of contracted ecopoints on the contracted parcels in the simulation period.

For the second policy mechanism alternative, we assume a flexible compensatory payment per hectare in addition to a fixed base payment for the particular parcel. The flexible payment is based on the number of ecopoints as a proxy for the ecological value of the land to be contracted. In this way, information is added with respect to the contribution of the parcel to the long term persistence of the population of salamanders within habitat networks in the case study region. This contract type allows for higher payments for plots that contribute more for to the habitat networks for a longer period. The contract offers an incentive to elongate because the payment level takes into account duration of management. It is assumed that every eligible farm agent tenders for a contract. The role of the government is to select those bids maximizing the number of ecopoints.

To distil a map with permanent and temporal habitat to the Great Crested Newt in the Winterswijk area (25x25m), we assigned all fresh water bodies and bog areas in the Winterswijk area as permanent habitat and all stream valley polygons from a geomorphological map as potentially suitable habitatMetapopulation models assume species to live in homogeneous populations which are connected to one another via dispersing individuals. In theory it is also possible to model on a grid basis, assuming each grid cell contains a population, but this has consequences for computation time (due to the large amount of grids). We therefore clustered permanent habitat grid cells to patches if they are 'direct' neighbours (i.e. each cell has four direct neighbouring cells). The configuration and distance to neighbouring patches is approximated via circular shaped patches. There are of course more ways to cluster habitat cells (e.g. using additional cell characteristics such as soil or vegetation), but we decided to keep it simple. We ran the METAPOP model for a landscape that consists of only permanent habitat and agricultural parcels that are unsuitable for the species (base run), and for the landscapes resulting from the two policy mechanisms, both under two milk price regimes.

3 PRELIMINARY RESULTS AND DISCUSSION

In Table 1 we compare indices at the end of the simulation periods for area contracted, ecopoints, total costs and the increase in the number of species compared to the base run with permanent habitat only, following from METAPOP. In the no-shock scenario the area of habitat patches increases by about 150 ha for a fixed payment of 4000 euro/ha compared to a situation without the policy. Comparing to a no shock situation it shows that the area under contract, number of ecopoints, change in number of species (following from METAPOP) and cost depend on the policy mechanism implemented.

Table 1. Indices for both policy mechanisms under both a no-shock and shock scenario.

Policy mechanism	Area under contract (ha)	Ecopoints (-)	Change in number of species (%)	Cost (€/ha)
No price shock scenario				
1. Fixed per ha	100	100	8%	100
2. Spatial and time differentiated	77	91	2%	77
Price shock scenario				
1. Fixed per ha	88	102	19%	89
2. Spatial and time differentiated	230	134	44%	237

Table 1 illustrates that, when imposing milk price disturbances to the system, both mechanisms behave in a different way. The area under contract for spatial and time differentiated payments shows to be more sensitive to fluctuations in the milk price in the simulation period. When milk prices fluctuate, farmers probably prefer to keep the contract based on ecopoints because of the guarantee for a high revenue that is gained in case of contract renewal, especially for parcels with a large contribution to the spatial cohesion of the habitat network. Furthermore, Table 1 shows that our dynamic landscape index – the number of ecopoints – resembles the change in number of species ($R^2 = 0.96$).

4 CONCLUSION

Although it might be difficult to assess the occurrence of milk price shocks beforehand, the results indicate that whenever policies are targeted at achieving the highest amount of area for water retention and milk price shocks do not occur, the current fixed compensatory payments are preferable. Whenever water boards want to achieve a contribution to both water retention and enhancing spatial habitat networks through their agri-environmental scheme policy and possible milk price shocks do occur, they could consider to add spatially and time differentiated payments. In this case, an increase in habitat area and species numbers will imply that the species will be better buffered against disturbances, also in the natural system, such as weather extremes (e.g. droughts; Oliver et al. 2010, Verboom et al. 2010).

In this paper, it is assumed that all farmers with parcels that are eligible will tender for their opportunity cost. The model could be extended by including farmer attitudes to contract characteristics (see e.g. Polman and Slangen, 2008). Another caveat is that investment activities as well as off-farm labour activities are not included in the model. These activities will have consequences for the type of contracts included in this paper.

With respect to the spatial configuration and time component of the schemes in the model for both water retention aspects as species habitat, it would be a valuable model extension integrate the ABM and METAPOP further. Scheme design could be developed by including more indicators and feedback between ecological indicators and farm management. This could potentially also result in higher public and private transaction costs for schemes. The method for modelling water retention and species habitat used in this paper remains pretty rough and should be developed further by focussing on the improving the incentives it gives to farmers including their reaction to different social and ecological shocks. Finally, thorough calibration and sensitivity analysis are currently worked on. Schippers et al. (2009) already investigated that METAPOP is especially sensitive to adult mortality and recruitment. The ABM seems to be sensitive to the settings of parameters with respect to the budget for compensatory payments and on-farm feed production.

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