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Modelling social and economic influences on the decision making of farmers in the Odra region

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The context of the model: Land reclamation in the Odra river region

The CAVES (Complexity, Agents, Volatility, Evidence, and Scale)[1] project aims at describing the emergence, the characteristics and long-term behaviour of social networks of people who use natural resources such as land or water. It includes case studies in Great Britain, Poland, and South Africa to acquire data on real world evidence of social networks.

The Polish case study (with input provided by Wroclaw University[2] and the Wroclaw University of Technology[3]) is concerned with issues of land use in the Odra river region. More specifically, it focuses on those parts of the region that are prone to regular flooding due to a lack of maintenance of an old land reclamation system (LRS). Maintaining or re-establishing this land reclamation system which consists mainly of channels and ditches used for drainage and irrigation purposes requires social mobilisation of the farmers concerned. Thus it is important that the acquaintance and/or friendship links that exist amongst them are utilised appropriately. Moreover, it is suspected that land reclamation possesses the structure of a social dilemma, and that it therefore represents a collective action (Olson, 1965; Ostrom, 1990). If so, existing theoretical insights can be used to investigate this issue further.

The overall simulation model that is currently being developed and which is to reproduce to some extent the phenomena found in the Odra region consists of two main components: a biophysical model of the environmental conditions and an agent-based model of the decision making and activities of the actors in the area. The biophysical model developed by the Wroclaw Institute of Technology provides a first basic insight into the costs and benefits of farming and land reclamation under certain climatic and water regime conditions. Complementing this, the agent-based model called SoNARe (Social Networks of Agents' Reclamation of land), that is the focus of this paper, seeks to capture key aspects of the reasoning of the actors involved and their interactions with their biophysical and social environment. SoNARe is based on an explicit representation of social influence on the one hand and the individual agents' perceptions of economic success on the other hand. The agents exert and perceive social influence in social networks while at the same time deriving their perception of economic success from feedback of the coupled biophysical model. These two central dimensions – the social and the economic - drive and determine the agents' decision making as regards farming and LRS maintenance as well as social behaviour.

The following sections provide a description of the SoNARe model including some details of the case study, the abstract structure of the situation found there, the technical realisation of the model, and how it interfaces with the biophysical model. Subsequently, some results of initial simulation runs for three basic scenarios are presented and discussed. Finally, an outlook is given on how the model is to be further enhanced in the future.

The SoNARe Model

The SoNARe agent-based model is part and parcel of the attempt to provide a useful and plausible abstraction of key features of the CAVES Odra case study for the purpose of simulation. First and foremost, these features are:

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[1] see http://cfpm.org/caves/. The authors wish to thank the European Commission for funding under the FP 6 NEST programme.

[2] The authors are much indebted to Karolina Królikowska for conducting and evaluating interviews with regional stakeholders and for her invaluable collaboration regarding the compilation of abstracted decision rules.

[3] The biophysical model referred to in this paper – *S*imple *H*ydro-*A*gricultural *M*odel (version 0.2.3) – was implemented by Grzegorz Holdys. The authors greatly appreciate his contribution creating a lean yet sophisticated environmental model.

- *Environmental shocks/extreme weather conditions.* Flooding or drought leads to a substantial loss of crop yield.
- *Water stress: Local coping strategies.* The farmers in the Odra region have two means at their disposal for coping with water deficiency and water excess stress, namely maintaining their local section of the land reclamation system (LRS) and/or operating the sluice gates in the ditches. The LRS consists of channels and ditches, which drain the soil directly, or through a drainage pipes system and thus protects a field against flooding. The LRS maintenance process mainly involves the periodic cleaning of channels and ditches, e.g. by removing vegetation and sediments from the channels' and ditches' beds. In addition, an LRS may be equipped with sluice gates to facilitate irrigation in dry years. However, this passive irrigation can only be used for pastures and meadows. As this papers focuses on arable land with a (hypothetical) crop, we only consider LRS maintenance and excess water stress. Therefore, farmers can decide either to
  - participate in the LRS, i.e. maintain the LRS locally on their respective land parcel and thus increase the level of protection against environmental shocks, or
  - neglect the LRS, leading to degradation and subsequently to a decreased level of protection against environmental shocks.

  In principle, if viewed independently from other channel sections, the maintenance of the local section of the land reclamation system (LRS) serves to mitigate or even eliminate the negative effects of extreme weather conditions, especially excess water stress in the case of flooding, whereas neglecting it will only increase these effects.
- *Water stress: Global asymmetrical dependency.* LRS maintenance must, however, be regarded as a collective task that requires social mobilisation of the participants, i.e. the farmers whose land parcels are located along a ditch or a communicating ditch system. This is because the difficulties concerning land and water use in the Odra case study region result mainly from the fact that the conditions encountered on individual land parcels depend highly on the amount of LRS maintenance (and/or the sluice gate operations) performed on other (adjacent) land parcels. In wet periods, for example, LRS neglect leads to a loss of yield on neighbouring land parcels upstream since the runoff of excess water is blocked, whereas LRS maintenance has the opposite, beneficial effect since the runoff is facilitated. The latter effect arises even if the upstream neighbours do not themselves maintain their section of the LRS (free riding). Downstream effects can be observed mainly in dry periods, if the LRS on a particular land parcel is not maintained (or the sluice gate on that parcel is closed). This causes a decrease in the amount of water flowing down to adjacent parcels resulting in a loss of yield on those parcels. For the reasons stated above, sluice gate operation will not be considered in the presented version of the model.

Maintenance of the land reclamation system thus enables to overcome flooding and drought with reduced or even without loss of harvest, but it requires a collective effort. Moreover, the asymmetrical dependency entails a social dilemma structure, in turn providing incentives for such problematic types of behaviour as free riding. It is expected that it is this social dilemma structure that hinders and in some cases prohibits the installation of a functioning LRS.

Against the background of these problem features it is the particular purpose of SoNARe to reflect the reasoning of the actors involved on an adequate level of abstraction and to seamlessly interface with an underlying biophysical model from which agents perceive the state of the environment and which they act upon. In order to do so, the implementation is based on results of interviews with actual farmers and other stakeholders in the Odra region. More importantly, however, a set of abstract decision rules for different types of actors was compiled which forms the basis for the implementation of the agent decision rules in SoNARe.

Technically, the SoNARe model uses production rules implemented in JESS (the Java Expert System Shell; http://herzberg.ca.sandia.gov/jess/), and JESS's reasoning engine to simulate the cognitive control structure and decision making of farmers and other relevant actors, while the actors themselves and their interaction with the social and natural environment is treated in a straightforward way in Repast (Recursive Porous Agent Simulation Toolkit, cf North et al 2006). This is consistent with a long-standing rule-based representation of problem solving and cognition (e.g. Anderson, 1983). It opens the possibility to provide Repast agents with full cognitively plausible capabilities. Since JESS is written entirely in Java and allows for calling Java methods from rules, it integrates well with any Java software. JESS consists of a rule interpreter which can apply both forward and backward chaining, using an improved version of the fast but memory-intensive RETE algorithm (Forgy, 1982) to match facts from the fact base to rules in the rule base. Declaring facts and rules is done via a script language with a LISP-like syntax. Actions are buffered and later executed by the Repast part of the model. The details of the model will be described next, followed by some scenario results and their discussion.

Model setup

Environment (the biophysical model)

The biophysical model simulates the effects of different weather conditions, LRS maintenance and LRS neglect as well as sluice gate operations on the water levels and thus on the crop yield of individual land parcels along a channel. It offers a number of parameters to be varied across simulation runs, most importantly for our purposes:

- *Weather sequence.* This is a repeated sequence of normal, wet and/or dry years, which differ in the mean water levels in the channel per month.
- *Land parcels.* The number of land parcels per channel and the type of land use of each land parcel can be set. Currently, the biophysical model allows for two types of land use, namely arable and fish-pond, of which only the former is used in the simulation runs described in the next section. Moreover, the initial condition of the LRS section on each individual parcel can be specified.

The model is run at monthly steps with crops for arable land parcels being planted in month 5 and harvested in month 10. The condition of the local LRS slowly degrades when it is not maintained and (at present) it fully recovers within a month of an agent first maintaining it. By instantiating the biophysical model multiple times it is possible to simulate any number of channels in parallel without any interrelations among them.

Agents

As a first step of agent modelling, generalised farmer types were determined based on elicited knowledge, i.e. the storylines derived from the transcripts of the interviews. These farmer types differ along dimensions like land ownership, activity related to LRS maintenance, social network integration or agricultural knowledge. The current version of the model considers two of those actor types: the farmer, i.e. a general prototypical farmer type, and the water partnership initiator (WPI). Farmer agents are embedded in a dependency network according to the location of their land parcel along their respective channel and in an overall acquaintance network which is randomly superimposed on the dependency networks thus spanning all channels. The acquaintance network not only includes all farmer agents, but also a WPI agent, which is linked to all farmer agents in a star-like manner. Water partnerships are formal institutions with the aim of maintaining the common LRS. Presently, the WPI is not a farmer itself (e.g. the village mayor).

In order to capture the decision dynamics of the farmers a rule-based approach was chosen. Some of the compiled decision rules could be abstracted from the storylines while others were deduced from domain expertise. Examining the decision rules of farmers revealed that the internal dimension of past economic success and the external dimension of perceived social influence appear to play an essential role. Therefore, we decided to explore the effects of contrasting social influences and economic success in an isolated way. Accordingly, in the model version presented in this paper, agents' decisions have been reduced to a binary decision of participating in the water partnership and hence locally maintaining the LRS or not.

In order to explicitly contrast social and economic influences on the decision making of farmers with regard to LRS maintenance two dimensions of agent perception are introduced that drive a farmer agent's decision making: *economic success* and *social support*.

- The perception of economic success is shaped by several factors: First of all, every year a farmer agent appraises its current yield as "good" or "bad" with respect to a fixed yield perception threshold. It then stores either a positive value ("good") or a negative value ("bad") – values are currently symmetrical – in its yield memory which has a fixed capacity, i.e. the agent forgets yields after some time. The extent to which agents attach importance to economic factors can be influenced by increasing or decreasing the so-called *economic sensitivity*, i.e. the weight given to the values for "good" and "bad" yields. The *economic success* is simply the sum of all yield appraisals stored in memory.

- The perception of social support is a function of the agreement/disagreement between farmer and acquaintance concerning LRS maintenance, i.e. whether it receives support or negative pressure, weighted by the individual level of social influence of each acquaintance.

On the basis of these two factors farmer agents decide on their LRS maintenance strategy, changing it if their perceived economic success and their perceived social support fall below a certain level (see pseudo-code below). Thus, in addition to the impact of the actual yields the model also reflects general opinion dynamics amongst farmers (cf. Latané, 1981; Friedkin, 1998). This exertion of social influence is strictly symmetrical in the sense that each farmer agent supports each farmer agent in its acquaintance network that uses the same strategy by the same amount as it imposes pressure on each farmer agent that uses the opposite strategy.

```
Farmer:

if(socialSupport + economicSuccess < 0) switch_LRS_strategy();

for(allAcquaintedFarmers) {
        if(otherLRSStrategy == myLRSStrategy) then supportOther(AMOUNT);
        else putPressureOnOther(AMOUNT);
}
```

The opinion dynamics are extended to account for the social influence of WPIs on the pervasiveness of the LRS maintenance strategy and thus on the formation of a working water partnership (WP). A WPI agent exerts its social influence in favour of LRS maintenance once it perceives at least three farmers who have big losses; it does not exert any influence otherwise. The WPI's level of social influence is independent from that of the farmers. The institution of the water partnership is active as long as at least three farmers maintain their respective LRS; it is inactive otherwise. Farmers are automatically members of the WP as long as they maintain their LRS (see below). However, at present, WP membership does not have any effect and there are no costs modelled for LRS maintenance.

```
Farmer:

if(exists(WP) AND (myLRSStrategy == MAINTAIN)) then beMemberOfWP();
else doNotBeMemberOfWP();
```

Model execution cycle, sequence of events

For each year the model executes the following sequence of events: In month five the biophysical model simulates the planting of crops for each land parcel and in month ten it simulates the harvesting of these crops. Finally, at the end of every year the agent-based model is run performing the following sequence of steps: all agents perceive and memorise their individual yields, exert their social influence, perceive the social influence exerted on them, revaluate their economic success and then make their decisions for the next year. It is important to note that agents are synchronised at every step. Above all, this means that they take their decisions simultaneously.

Simulation results

This section provides an overview of the simulation results reported here that were produced with the described model. We present three scenarios: The first scenario functions as a baseline by showing the behaviour of the biophysical model on its own, i.e. without any intervention on the part of the agents. The second scenario then looks into the effects of having agents decide on LRS maintenance annually and with the perceived economic success as the sole basis for that decision. Finally, in the third scenario both economic success and social support take effect as criteria in the agents' decision making.

All simulations are initialised with rows of ten land parcels that are located along one channel. It is assumed that each land parcel is owned and managed by exactly one farmer and that each farmer owns and manages exactly one land parcel. The model is scaled up to simulate 100 farmers in order to have a more realistic population size for the underlying acquaintance network. It is important to note that we scale up the model by increasing the number of channels instead of increasing the number of land parcels per channel, because the latter is not backed by observation, i.e. it is unrealistic to assume a channel size well in excess of ten parcels. All three scenarios start off with no LRS maintainers. The same weather sequence is used throughout: Two years with normal weather conditions are followed by one year of wet weather. This pattern is then repeated for the whole run.

In all performance diagrams the time axis shows months, since they are the smallest simulation step considered in the model. Data points in the diagrams below are displayed every twelfth month and thus represent one respective year.

Due to the model's level of abstraction, it has to be stated that the simulation results shown here do not claim to be exact predictions or forecasts of future developments. E.g. when results are discussed in terms of years until a certain process has finished, this should be interpreted as being in reference to an abstract time span of "model" years. Nevertheless, scenarios may be compared with respect to differences in temporal dynamics.

Scenario 1 – Baseline scenario

The baseline scenario simulates one hundred land parcels along ten channels. This scenario excludes both effects of social influence between agents and agents' rating of their economic success. Thus, agents do not change their LRS maintenance strategy (they never maintain). Because of that, the results of all ten channels are equal; so only one channel is depicted here (see figure 2). The results shown here demonstrate the implicit spatial dependencies between the farmers as generated by the coupled biophysical model.

Figure 1 shows the farmers' yield statistics over the simulation period. Because all farmers keep to their passive LRS strategy, a repeated pattern of yield losses every third (i.e. wet) year can be observed. Furthermore, under wet weather conditions the mean deviation of the farmers' yields is much greater than in normal years. As can be seen in figure 2, in cases of flooding and all farmers neglecting their LRS, yields of farmers at the top of the channel are considerably worse than the yields of those further at the bottom. Thus, the biophysical model shows that under flooding conditions farmers located further downstream obtain a certain degree of implicit flood protection if upstream neighbours neglect their LRS and absorb most of the effects of flooding. Moreover, the farmers at the bottom experience only minor differences between normal years and wet years in this scenario.

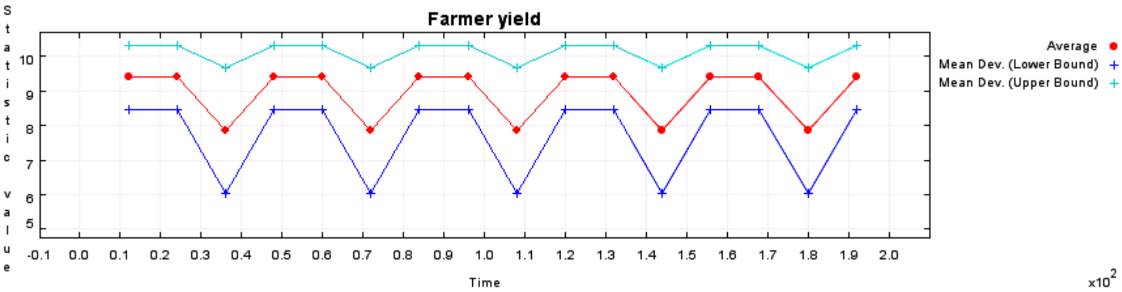


Fig. 1. Average yields of farmers bounded by the mean deviation. The time axis shows months*100 as ticks. Each dot thus marks the average yield for one year, i.e. sixteen years in total are shown.

Scenario 2 – The influence of economic success

The second scenario differs from the baseline scenario only in that the farmer agents now appraise their economic success in the way described in the model setup. Again, social influence is excluded. Although farmers' decision making in this scenario is based solely on their internal and subjective perception of their respective economic farming success, farmers' decisions may well affect other farmers' economic success (due to the hydrological dependencies).

Figure 3 shows the development of LRS strategy adjustments over time, i.e. the proportion of farmers who change their opinion about LRS maintenance in either direction. This volatility indicator rises for about 8 to 9 years of simulation time and then falls back to zero. Figure 4 depicts the corresponding convergence of the number of LRS maintainers to a stable state of 80% after 20 years (240 on a months scale). Figure 5 shows the resulting increase in the average of farmers' crop yields.

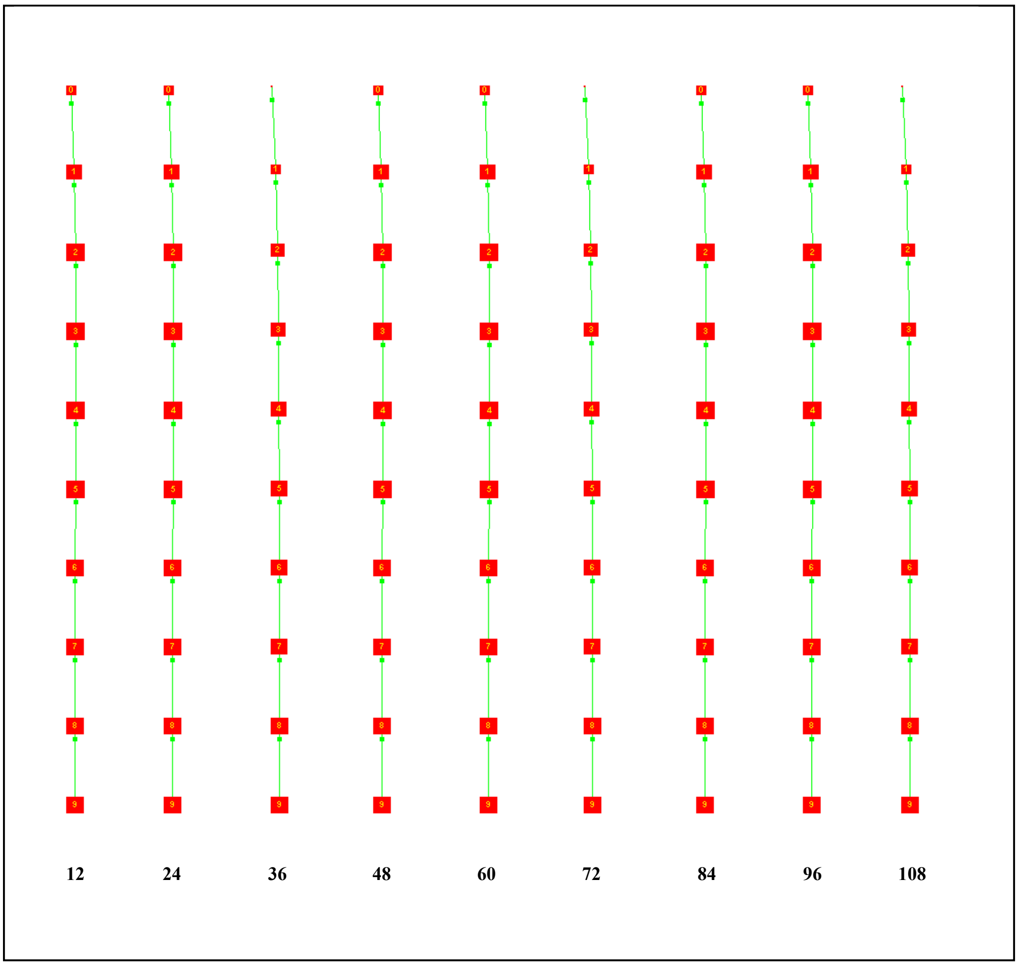


Fig. 2. Yields and LRS strategies on individual land parcels along a single channel over time (years 1 to 9, i.e. months 12 to 108). Land parcels are represented as squares connected by green lines indicating the dependency relation (flow direction from top to bottom). The size of each square is proportional to the yield for the respective land parcel. The red colour indicates LRS neglect.[4]

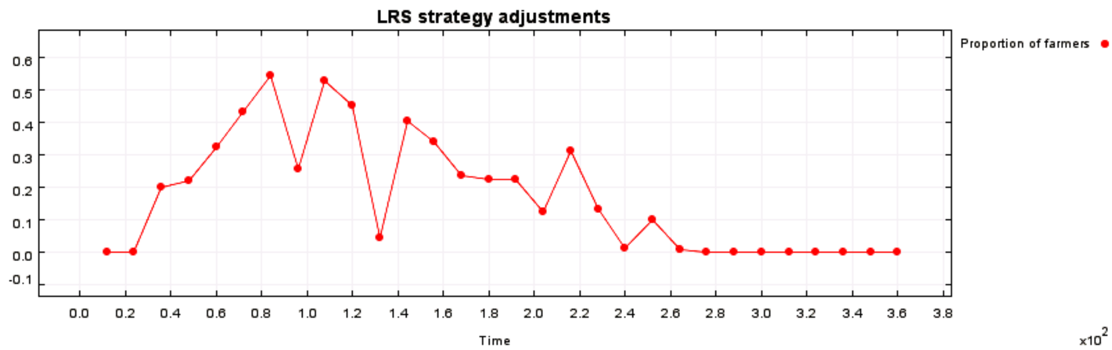


Fig. 3. Strategy adjustments over time as an indicator for volatility. The time axis shows months*100 as ticks. Each dot marks the proportion of farmers who have switched their LRS strategy in one year (30 years in total).

[4] The numbers inside the squares denote agent IDs (0-9 in scenario 1 and 2, 0-99 in scenario 3). They are, however, irrelevant for all intents and purposes.

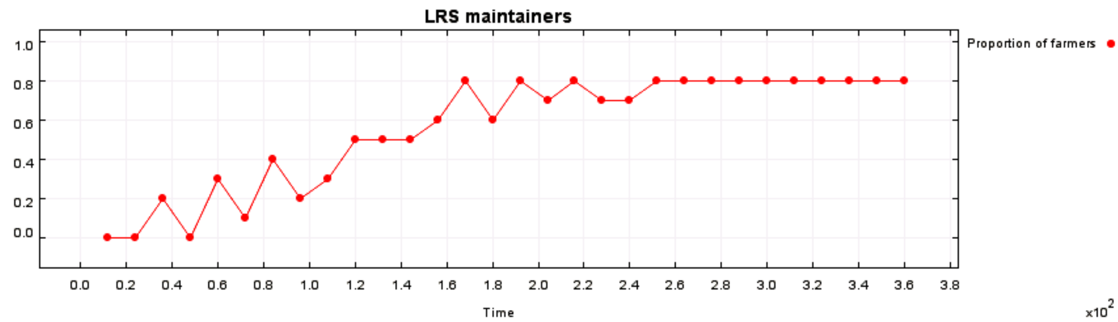


Fig. 4. Proportion of LRS maintaining farmers over time. The time axis shows months*100 as ticks.

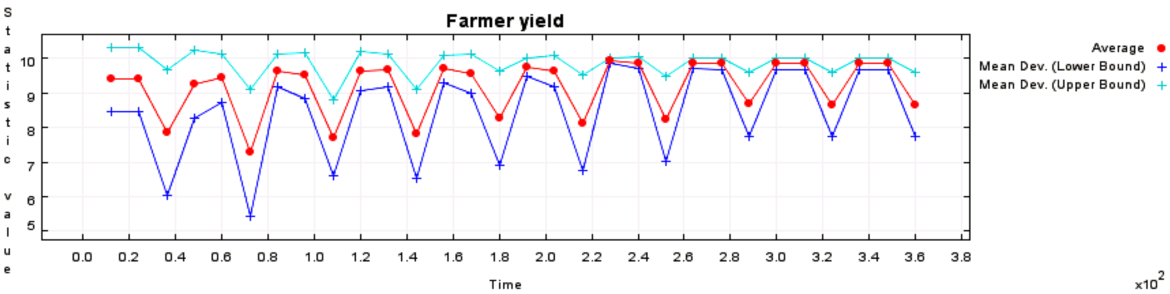


Fig. 5. Average yields of farmers bounded by the mean deviation. The time axis shows months*100 as ticks. Each dot marks the average yield for one year (30 years in total).

Figure 7 illustrates the spatial distribution of opinion shifts over time. In the course of the simulation, the top-most farmer first starts maintaining LRS after a wet year. This is probably due to the combination of the positional disadvantage even in normal years (see scenario 1) and the bad yield in a wet year. As may be seen in figure 6, the perceived economic success of LRS maintainers increases substantially and then settles on a slightly higher level than the corresponding values for non-maintainers.

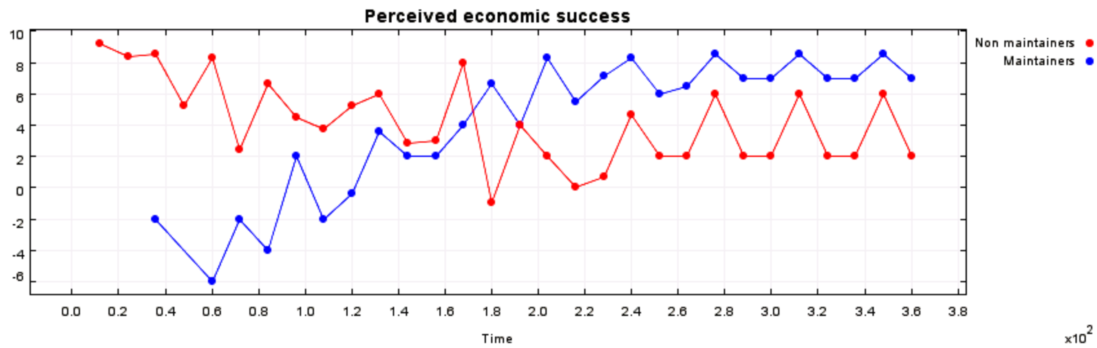


Fig. 6. Mean perceived economic success of maintainers and non-maintainers over time with the yield threshold set to 9.0, an economic sensitivity of 2.0 and a yield memory capacity of 5 years, i.e. the perceived economic success has a lower bound of -10 and an upper bound of 10. The time axis shows months*100 as ticks.

Scenario 3 – The combined influence of economic success and social support

In the third scenario agents use both their past economic success and the social influence of other agents as a basis for their decision making. As in the scenarios above, ten independent channels with ten land parcels each are considered which amounts to 100 farmers altogether. Since we now include effects of social influence in this scenario, farmers are now embedded in an acquaintance network that spans all ten channels. In addition, the WPI agent is linked to all farmers as described in the model setup.

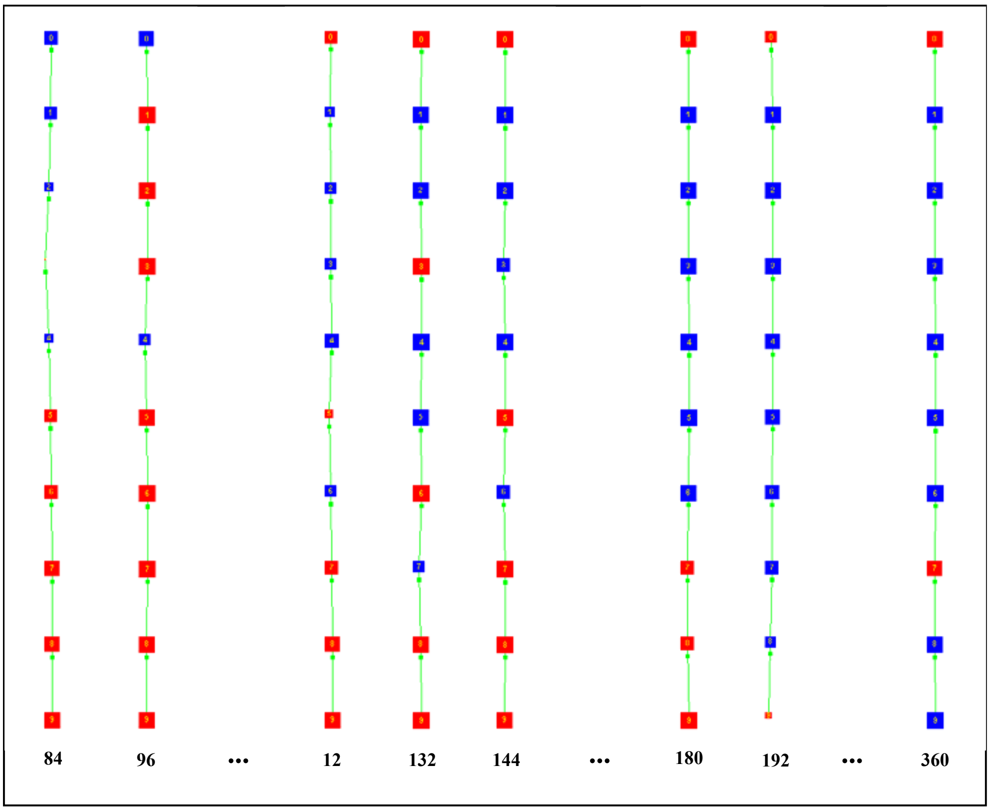


Fig. 7. Yields and LRS strategies on individual land parcels along a single channel over time (years 7-30; numbers refer to months). Land parcels are represented as squares connected by green lines indicating the dependency relation (flow direction from top to bottom). The size of each square is proportional to the yield for the respective land parcel. Red squares indicate LRS neglect, blue squares LRS maintenance.

While in earlier simulations (Ernst, Krebs & Zehnpfund, in press) acquaintances networks were generated as Small-World networks with the algorithm of Watts and Strogatz (1998) in the simulations shown here a scale-free network topology with an average node degree of 10 is used. The assumption of a scale-free topology is supported by Odra case study narrative storylines and by many other studies on social networks (cf. Barabási, 2002; Newman, 2003). The scale-free network used in the simulations is generated by an algorithm described by Ebel, Davidsen and Bornholdt (2002). This algorithm allows generating a sufficient proxy of a scale-free network for 100 nodes and an average node degree of 10.

As before, Figure 8 shows the proportion of farmers that change their opinion about LRS maintenance as an indicator of the system's volatility. Since the WPI agent exerts its social influence this activity slowly pushes opinions towards LRS maintenance. Figure 10 shows the corresponding convergence of the number of LRS maintainers to a stable state of 100% after 34 years. Around year 20 (month 240 in the diagram) the proportion of LRS maintainers exceeds 50% which triggers an avalanche pro LRS which is reflected in figure 9 as a much higher opinion shift towards maintenance. Figure 11 again shows the resulting increase in the average of farmers' crop yields.

Figure 12 contrasts the development of economic success and social support over time (average values over the 100 agents are shown). The perceived economic success starts off with unrealistically high values because agents' yield memories are initialised with 5 "good" years. This value decreases as soon as agents have experienced the first years of the simulated weather sequence. When the shift in LRS strategies starts (see figure 12, years 3 and 4) the average social support indicator falls steeply from 4 to below 2. These low values of social support persist throughout the phase of high volatility. As more and more agents switch to LRS maintenance social support rises again until month 360 when the WPI becomes passive (see figure 12). Social support parallels the perceived economic success in that it, too, rises continuously.

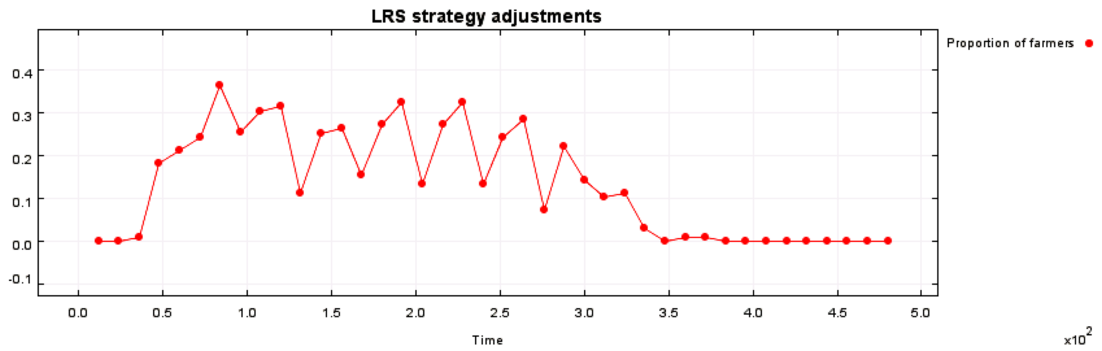


Fig. 8. Strategy adjustments over time as an indicator for volatility. Each dot marks the proportion of farmers who have switched their LRS strategy in one year (40 years in total). The time axis shows months*100 as ticks.

Fig. 9. Proportion of strategy changes to maintenance and to non-maintenance strategy over time. The time axis shows months*100 as ticks.

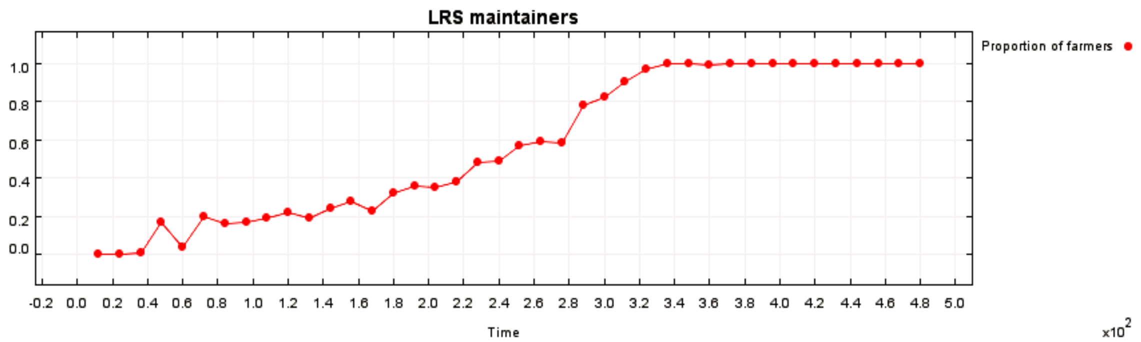


Fig. 10. Proportion of LRS maintaining farmers over time. The time axis shows months*100 as ticks.

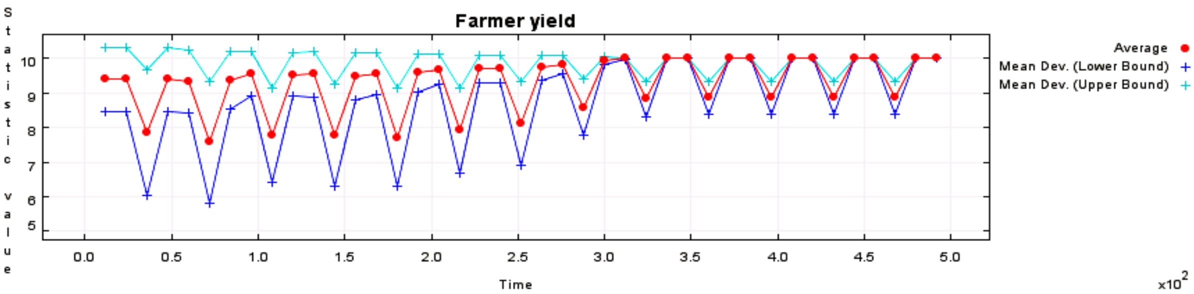


Fig. 11. Average yields of farmers bounded by the mean deviation. Each dot marks the aver-age yield for one year (40 years in total). The time axis shows months*100 as ticks.

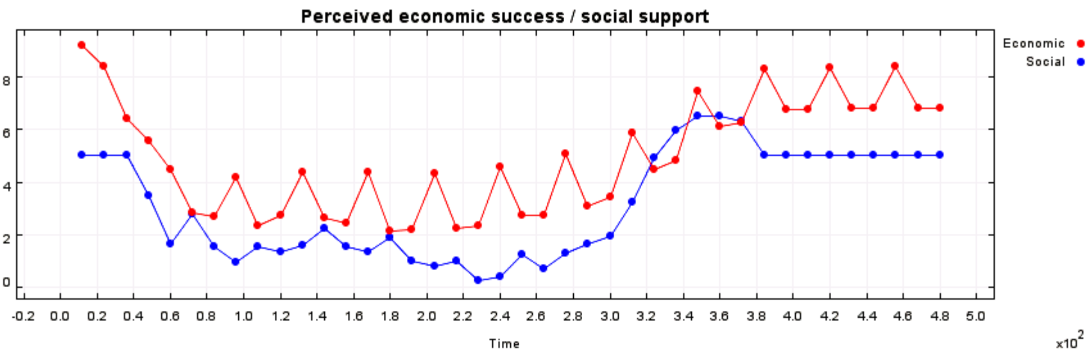


Fig. 12. Mean perceived economic success and mean perceived social support over time. The time axis shows months*100 as ticks.

Figure 13 shows the development of the perceived economic success of maintainers and non maintainers. LRS maintainers start with very little economic success: this is what caused them to shift to maintenance. After that and similar to figure 12 maintainers become more and more successful. Figure 14 contrasts the perceived social support of LRS maintainers and neglecters. As expected, during the phase of volatility both economic success and social support are on very similar levels for both groups of agents.

Finally, figure 15 displays the spatial distribution of opinion shifts along the ten channels over time. We show 4 snapshots at months 36, 48, 168, and 300. The general dynamics is that agents begin maintaining LRS from top to bottom. This reflects the perception that topmost agents are in general more severely affected by flooding.

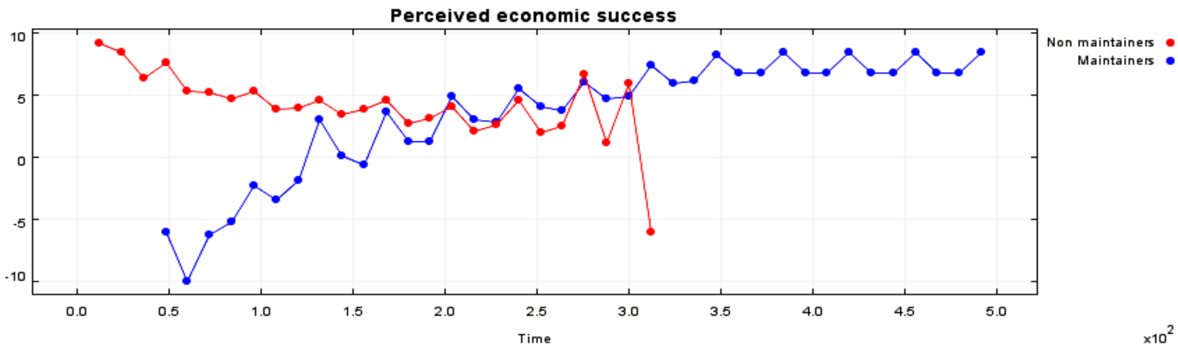


Fig. 13. Mean perceived economic success of maintainers and non-maintainers over time with an economic sensitivity of 2.0 and a yield memory capacity of 5 years, i.e. the perceived economic success has a lower bound of -10 and an upper bound of 10. The time axis shows months*100 as ticks.

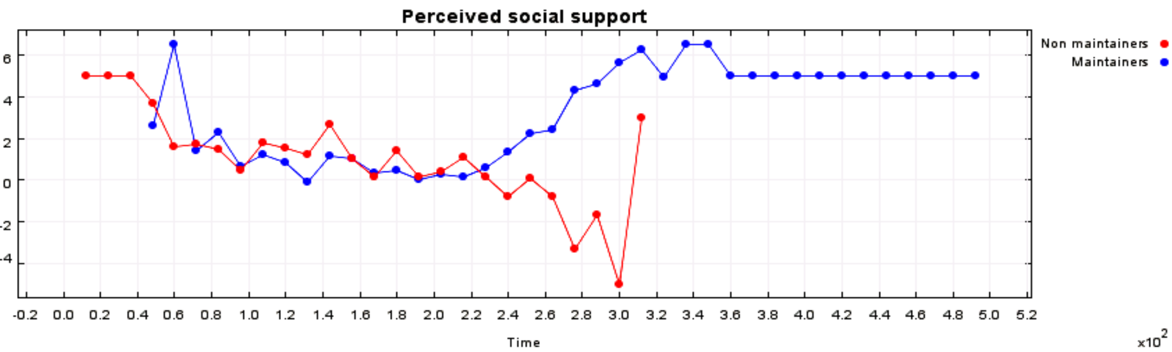


Fig. 14. Mean perceived social support of maintainers and non-maintainers over time with a social influence level of 0.5 for farmers and 1.5 for the WPI and an average acquaintance degree of 10. The time axis shows months*100 as ticks.

Discussion

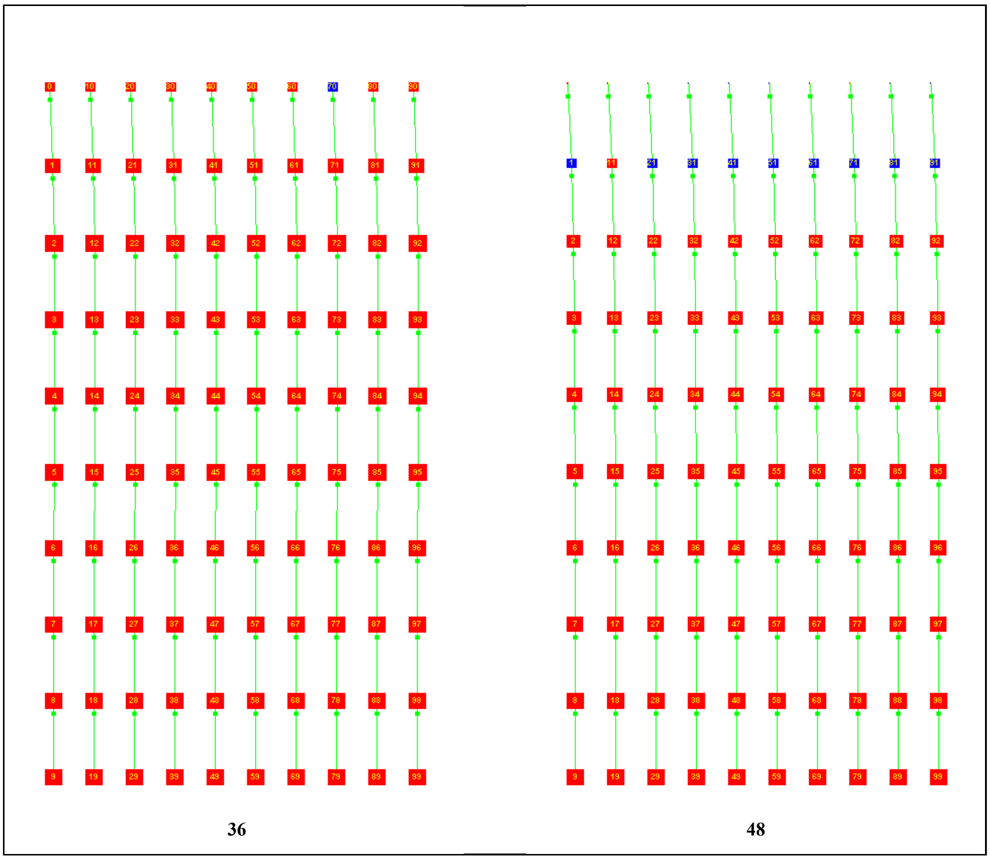
In the work reported here, it has been a guiding assumption that it is fruitful to build models on a medium level of abstraction, i.e. to keep just between too much detail and too much abstraction. On one hand, there has to be a certain amount of recognisable empirical characteristics of the domain being modelled. On the other hand one has to make sure the model is interpretable in terms of complexity indicators, network characteristics, and basic theoretic or phenomenological structures, like social dilemmas. The SoNARe model has made a step in this direction. It comprises a social dilemma structure derived from a geographical structure, a lean yet sufficiently powerful geo-physical model, stylised behavioural rules represented in actor types and well-founded psychological assumptions about social influence, memory span and social networks. While the model is being tested with only a smaller number of actors, it is easily scalable to several hundreds of actors without losing the basic environmental or social structure.

The SoNARe model produces, besides other behavioural indices, a measure of volatility (the amount of strategy changes by the actors). When comparing the development of the volatility indicators of scenarios 2 and 3 (see figures 3 and 8) it can be seen that for scenario 2 the indicator has peaks to above 0.5, whereas in scenario 3 the indicator is always well below 0.4. As a conclusion, this might indicate that under the given circumstances the presence of an active social network and of mechanisms of social influence dampens phases of high volatility in opinion dynamics and instead lead to a coherence effect. This effect will be investigated further.

From the point of view of the underlying social dilemma structure, it is most interesting to note the emergence of a positive social lock-in. Due to the WPI's activity and the subsequent economic success of LRS maintainers, a self-sustained WP can be installed in scenario 3. In spite of the situation's underlying dilemma structure prone to free riding, a social "activity seed" together with some social and economic pressure exerted on the participants is sufficient to trigger this process and to keep it alive. The intertwining of social and economic processes and their long-term effects will have however to be investigated further. Still, it is safe to attribute some effectiveness to the modelled institution of WP and the leading WPI. This result will be discussed with the local stakeholders of the case study.

Outlook

It is intended to further approximate the situation in the case study region and press ahead with the investigation of the covariance of network properties and collective behaviour as well as possible phases of volatility.



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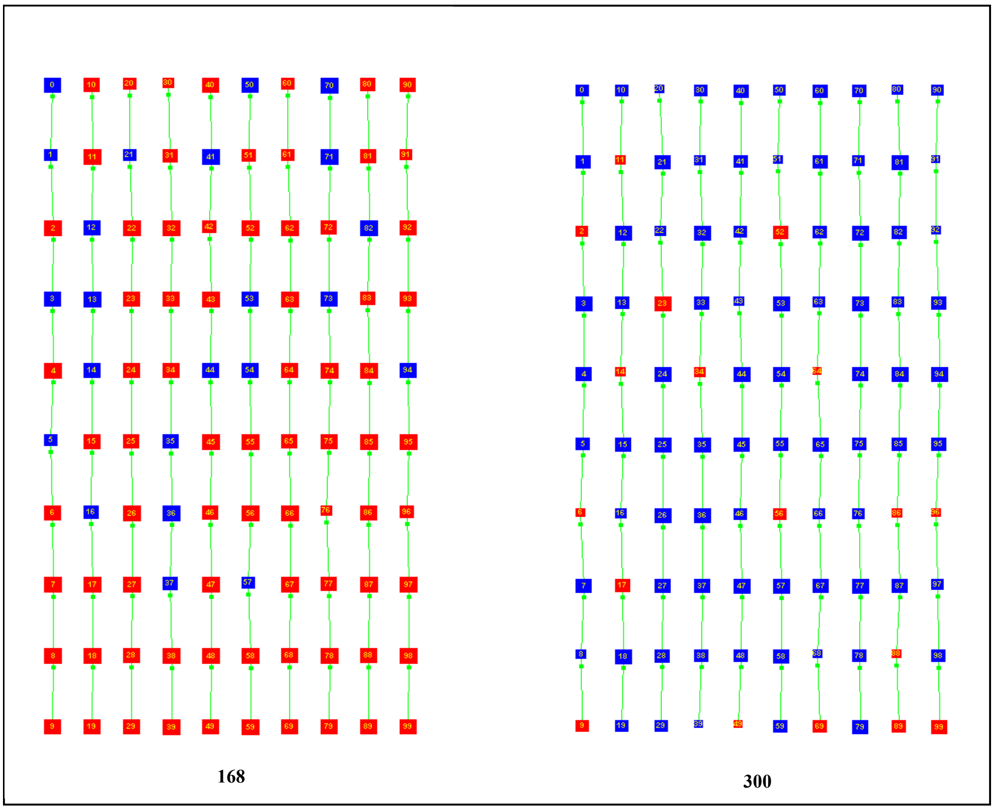

Fig. 15. Yields and LRS strategies on individual land parcels along ten channels (left to right) over time (months 36, 48, 168 and 300). Land parcels are represented as squares connected by green lines indicating the dependency relation (flow direction from top to bottom). The size of each square is proportional to the yield for the respective land parcel. Red squares indicate LRS neglect, blue squares LRS maintenance.

To these ends, we plan to enhance and study the model in a number of respects. LRS maintenance costs, allowances for LRS maintenance and compensation payments in case of yield loss will be introduced as economic factors. Moreover, additional land use types (fish ponds, in particular) are to be included and farmer types are to be modelled that differ in terms of their economic and social perception and the sets of decision rules they employ. In this context the effects of varying heterogeneous distributions of such farmer types will also be studied. Finally, it is planned to analyse possible sluice gate operation strategies of farmers on individual land parcels and their relation to LRS strategies and the general dynamics of the model. Considering the effects both of flooding and drought leads to a double social dilemma with bi-directional (up- and downstream) dependencies. Its social and economic effects will have to be investigated further.

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