OVERUSE OF NATURAL RESOURCES: FINDING SOLUTIONS WITH AGENT-BASED SIMULATION

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ABSTRACT

A computer simulation will be presented, which allows studying populations of 10,000 resource-using people. Simulation experiments can be conducted with populations whose initial parameters lead to resource depletion over the long or short term. Systematic experiments using this approach make it possible to determine which measures may lead to sustainable resource use.

INTRODUCTION

Today the sustainable collective use of natural resources is a greater challenge than ever before. Since the seminal contribution of Garrett Hardin on "the tragedy of the commons" (1968) social scientists have investigated the determinants of individual consumption behavior and developed models to explain individual behavior in collective resource management (e.g., Kopelman, Weber, & Messick, 2002). Despite intensive scientific efforts, the problem of sustainable collective consumption of natural resources has become even bigger today, and it is expected to grow in importance in the future, with further depletion of the world's resources and simultaneous increasing demand due to widespread modernization and over-population.

To study sustainable collective consumption, experiments with different populations under different conditions would be needed, which is nearly impossible to realize within real human populations. A computer simulation, on the other hand, requires only effort to test many different measures designed to encourage sustainable resource use by a population.
There are a lot of studies utilizing the method of computer simulation to study resource dilemmas (e.g. Nowak & Sigmund, 1992; Liebrand & Messick, 1996; Macy, 1996; Grant & Thopson, 1997; Deadman, 199; Castillo & Saysel, 2005; for an overview see Jager, 2000). Ernst & Spada (1993), for example, designed a computerized knowledge-based model of action and interaction in social dilemmas by constructing a model from their own dilemma game data. Jager (2000) simulates consumers using a multi-theoretical framework that integrates various theories that appear to be relevant in understanding consumer behavior. Their simulations investigate the long-term dynamics of resource dilemmas (Jager, Janssen & Vlek, 2002).
For our purpose an agent-based computer simulation was designed based on social science literature. A basic model of an agent was constructed, which serves as the basis for the simulated influencing and resource-use processes. The population has 10,000 identically structured copies of this agent, equipped however, with different individual characteristics. The agent model yields information about the internal psychological processes that occur when people use environmental resources.
The agent-based model is founded on the Social-Ecological Relevance model (the SER model) of Mosler & Brucks (2003). This model assumes that certain individuals set greater store by ecological information, while others attach more importance to social information. This weighting naturally influences their resource use behavior, since there may be considerable disparity between ecological and social information concerning the resource. Aided by this core concept, various findings of social dilemma research were integrated in the model. In the simulation, single agent's behavior corresponds with research findings concerning the variables resource use of others, social values, resource size, resource uncertainty, perceived cause of resource abundance or scarcity (attributions).
The agents in the populations have at their disposal differently structured social contact nets (number of friends, acquaintances, neighbors, and strangers they observe). These personal contacts both influence the individual, and are influenced by him or her.
Experiments can be conducted with populations whose initial parameters lead to resource depletion over the long or short term, e.g. a population containing a high proportion of uncooperative individuals, a population with a higher average resource uncertainty, or populations with unfavorable combinations of parameter values. The measures investigated were advertising campaigns and the employment of

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promoters. It is assumed that an advertising campaign affects certain variables across a sector of the population. In the case of promoters, selected and specially trained individuals exert pressure on their social surroundings. Systematic experimentation using the simulation approach makes it possible to determine which measures applied to which populations could lead to sustainable resource use.

AN AGENT-BASED MODEL OF RESOURCE USE

The structure of the model is displayed in Figure 1. Arrows show the variables with their names. The variables are calculated in the numbered blocks.

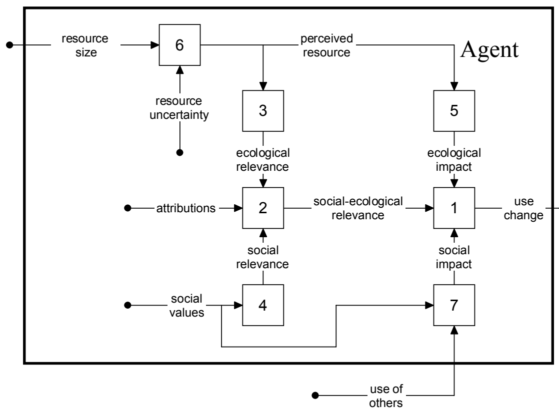

Figure 1: Block diagram of the social-ecological relevance model.

The agent gets as input the size of the resource from the state of the resource and the resource use of others from the contact with other agents in his network. As internal input variables the agent has his estimation of resource uncertainty his attributions and social values. Attribution means that the agent sees the reason of the state of the resource either in the behavior of the population or in the resource itself (e.g. self deterioration). Social values mean that the agent is either cooperative or non-cooperative. The perceived resource defines the ecological relevance which means the importance the agent poses to resource issues. Social values determine the social relevance indicating the importance the agent gives to social issues. The social impact results from social values and use of others and together with the ecological impact it is weighted according to the social-ecological relevance and the change in use is calculated.
The values of all variables range on a scale from 0 to 100. Besides the two end points of 0 and 100, the value of 50 is very important for the bipolar variables (social values, attributions, social-ecological relevance), for it represents the point of neutrality. In the following, the transition functions in the blocks of figure 1 are explained according to Mosler & Brucks (2003).

Block 1
use_change = social_weight * social_impact + ecological_weight * ecological_impact.
social_weight = social_ecological_relevance / 100
ecological_weight = 1 - social_ecological_relevance / 100

The output of the model is use change, which represents the individual’s change in resource use. Negative values of use change indicate a decrease in use; positive values show an increase. Zero indicates unchanged use. Use change is dependent on ecological impact and social impact. First, both of these impacts are weighted by an ecological and a social weighting factor, respectively. These weighting factors are computed from social-ecological relevance. Due to the one-dimensionality of social-ecological relevance, the sum of these complementary weighting factors always equals one. The social and ecological impacts, modified by the respective social and ecological weights, determine use change.

Block 2
social_ecological_relevance = (social_relevance – ecological_relevance + 100) / 2 + influence_of_attributions
influence_of_attributions = (50 – attributions) / A.

Parameter A determines the strength of the influence of attributions. Social-ecological relevance is calculated as the average of social relevance and ecological relevance plus the influence of causal attributions (which belongs neither to the ecological nor to the social factors but stands in between them). We assume that the impact of attributions on use change is not direct, but indirect, via social-ecological relevance. People who attribute blame for the state of the resource to others place more weight on social factors, while persons who see the cause for the state of the resource in the resource itself (such as a natural shortage) weigh ecological factors more heavily. It has been shown that when people see the group as the cause of the state of the resource (operationalized by Messick at al., 1983), their use behavior is different than when they hold the resource itself responsible (operationalized by Samuelson et al., 1984). This was demonstrated clearly in an experiment by Rutte, Wilke, & Messick (1987), who found that subjects harvested more from the resource in abundance condition than in the scarcity condition. Furthermore, the difference in harvest size between scarcity and abundance conditions was greater in the resource-caused condition than in the group-caused condition. In accordance with these considerations, social-ecological relevance can be modified by attributions, up or down to a given degree.

Block 3
ecological_relevance = 100 – perceived_resource

Ecological relevance is calculated from perceived resource (the individual's perception of the state of the resource) on the theoretical assumption that ecological relevance increases with a decreasing perceived resource. This assumption means that the worse the state of the resource, the more relevant people find ecological information. This implies, due to the one-dimensionality of social ecological relevance, that with ecological uncertainty and a higher value of the variable perceived resource, social information will be used more. This agrees with empirical findings by van Dijk, Wilke, Wilke, & Metman (1999), where group members avoided basing their use decisions on environmental information that they were not sure about.

Block 4
social_relevance = social_values

The influence of social values (cooperative vs. non-cooperative) on social-ecological relevance bases on the assumption that non-cooperators disregard ecological factors in a resource crisis. Cooperators, in contrast, are much more likely to adapt their use to ecological factors; they reduce use when resource size decreases in order to prevent depletion of the resource. By postulating for non-cooperators that ecological factors are less important, our model at the same time (due to the one-dimensionality of social-ecological relevance) postulates that they find social factors more relevant. As non-cooperators always place less significance on the meaning of ecological factors, they care less about the resource size as well. Thus they decrease their use less than cooperators when the resource is in a poor state and also increase it less when the state of the resource is good. Overall, non-cooperators harvest more than cooperators do. This corresponds quite well with experimental findings reported by Parks (1994). In the model, therefore, social relevance increases (or ecological relevance decreases) the more cooperative the individual is.

Block 5
ecological_impact = perceived_resource – 50

A number of experiments have demonstrated that use decreases with decreasing values for perceived resource. While this can be explained in terms of people's motivation to preserve a resource (see Messick et al., 1983), supporting empirical evidence is also available. In an international comparison, Samuelson et al. (1984) were able to demonstrate that subjects harvested less in the overuse condition than in the optimal-use or under-use conditions and that harvest sizes tended to increase through time in the latter two conditions but little or not at all in the overuse condition. The agents in the model therefore use the resource in relation to perceived resource. They reduce their use when perceived resource is below the optimum and increase it when perceived resource is above that optimum.

Block 6
perceived_resource = resource_uncertainty * resource size
(uncertainty is calculated through a tabular function)

Resource size is a dynamic variable that is calculated in the simulation model at every point in time. It is modified to become perceived resource through multiplying it by the uncertainty factor resource uncertainty, which is calculated interpolatively using experimental values from Rapoport et al. (1992) with the aid of a tabular function. The uncertainty factor can range from 1 to 1.5. This means that with maximum uncertainty, the resource will by overestimated by 1.5 times.

Block 7
IF social_values > 50 AND use_of_others > 50
DO social_impact = 50 – (100 – use_of_others)
ELSE social_impact = 50 – use_of_others

In addition to temporal dynamics, social dynamics have to be modeled too. To this purpose, we allow any number of individuals in the model to interact with each other in an agent-based simulation (compare Gilbert & Troitzsch, 1999). As a logical consequence of allowing for social dynamics, the use of others (feedback to the individual on how much the others are using) is included in the model. Experimental investigations have demonstrated that knowledge of the resource use of others in a resource crisis has a strong influence upon a person's own behavior. If others show either under-use or optimal use (sustained use), the findings are quite clear, because harvest behavior in both the under-use and optimal-use conditions tends to increase over time (Messick et al., 1983). An experiment by Kramer et al. (1986) also revealed a clear tendency for personal use to increase under sustained use conditions. In the model, therefore, an agent reduces use when others overuse, but increases use when others use less than the optimum. The situation changes if the resource is overused by the group and is in danger of being depleted in the future. It seems that in this case, the individual characteristics of the user play a greater role in influencing use than under sustained use conditions. Individual characteristics include social values, as was established by Kramer et al. (1986) as follows: When the future of the common resource was threatened by collective overuse, non-cooperators' behavior showed virtually no adjustment to decline of the resource level across trials. Cooperators, on the other hand, demonstrated personal restraint, and the magnitude of this restraint increased until the final trial block. Our model accords with these experimental findings by assuming for non-cooperators that instead of reducing their use, they increase use when they note that others are overusing.
The model was implemented in THINK PASCAL on a Macintosh computer.

VALIDATION OF THE MODEL

The complete model was validated by analyzing whether or not it is possible to replicate the findings of real experiments in the literature. Tests to date have shown that the model replicates the following experimental findings successfully (see Mosler & Brucks, 2003): for resource size, the findings of Samuelson et al. (1984); for resource uncertainty, the findings of Budescu et al. (1990) and Rapoport et al. (1992); for social values, the findings of Kramer et al. (1986); for use of others the findings of Messick et al. (1983); and for attributions, the findings of Rutte et al. (1987). Because the model appears to implement the effects of the variables adequately, it follows that the model is a valid representation of the findings on these variables.

THE POPULATION MODEL

A population with 10,000 agents is simulated (see figure 2). The parameters of the agent variables are assigned at random according to a normal distribution around a predefined mean and standard deviation. Each agent makes a decision and uses the resource. Resource use problems within this population are caused by the behavior of these many agents. The using behavior of each agent is perceived by the other agents and influences their decisions. The range and number of the agent’s network can be defined differentially; this means that each agent can have 1 - 50 contacts.

Each agent uses a certain rate of the resource; all the rates are summed up and give the total use of the population of the resource. In each run after the total use is subtracted from the resource it regenerates with a certain factor (in the presented examples the regeneration factor is 1.2). As the resource is used by the whole population its size changes and this is also noticed by the agents. In dependency of the changed resource size and the use of the other agents the agent decides on how to change his use of the resource for the next run.

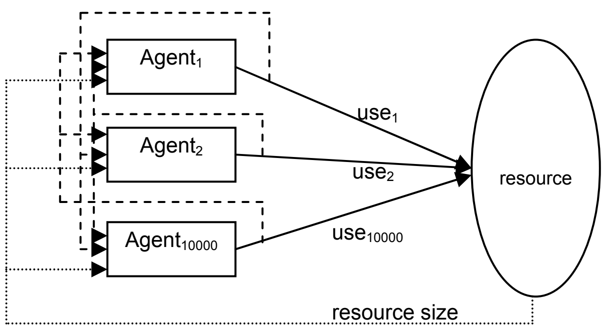

Figure 2: A population of 10’000 agents uses a resource. The solid arrows indicate the use of the agents of the resource; the dotted arrows indicate the perceived remaining resource size after the use of the population and the regeneration; the dashed arrows indicate that the agent perceives the use of other agents in his network (use of others).

INTERVENTIONS IN POPULATIONS

For the experiments presented here those cases were chosen which are likely to be found in reality and in which the behavior of the population is detrimental to the resource. The baseline experiment (see figure 3) is conducted with a population which is on average non-cooperative (value 60) this leads to a constant depletion of the resource until its value drops down below 10, which means that the resource is destroyed (as for example fish stocks which under a certain population number cannot reproduce).

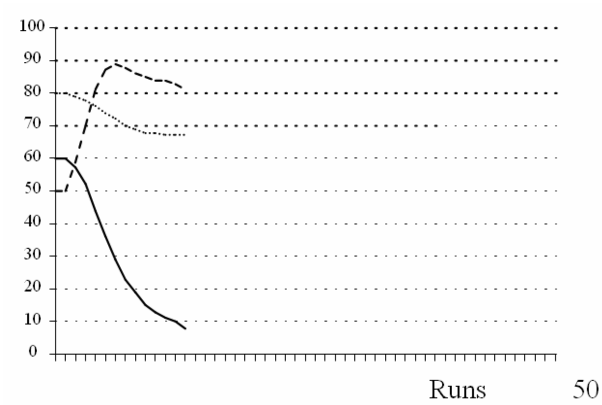

Figure 3: A population of 10'000 that is non-cooperative (social values=60) and with attribution 'group' (20); the resource size starts with 60 (solid line), the average use with 50 (dashed line), and the relevance with 80 (dotted line)

In the following experiment (see figure 4) the same population is used with the same starting values but now we have 20% of the agents which attribute the decline of the resource to the resource (attributions=90).

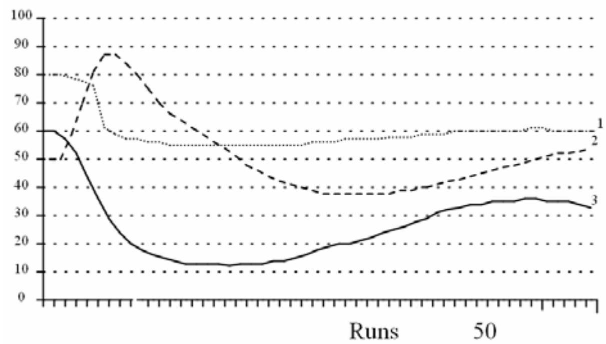

Figure 4: Same population as in figure 3 but 20% of the agents acquire an attribution 'resource' (90); the resource size starts with 60 (solid line), the average use with 50 (dashed line), and the relevance with 80 (dotted line)

This could be the case when parts of the population come to the conclusion that the decline of the resource happened rather due to causes in the ecological system than to social reasons. With this measure it is possible to stop the detrimental development and to improve the size of the resource in a sustainable way.

To demonstrate the importance of the social network another experiment was carried out where the network of the agents was reduced from 5 to only 1 contact agent (see figure 5).

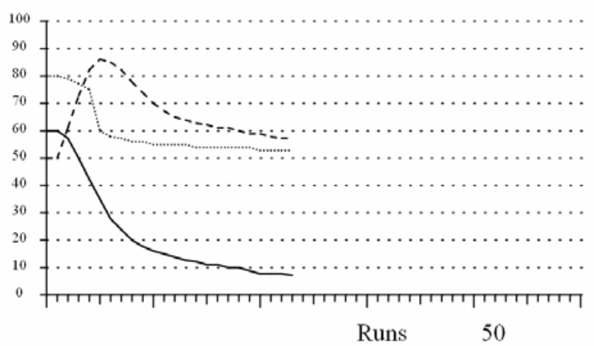

Figure 5: Same population as in figures 3 and 4 and 20% of the agents acquire an attribution 'resource' (90), the agents have only one contact; the resource size starts with 60 (solid line), the average use with 50 (dashed line), and the relevance with 80 (dotted line)

Here it is not possible to stop the detrimental process because the 20% of agents with a changed attribution have no far-ranging effect on their social surrounding.

With another series of experiments the effect of uncertainty is demonstrated. The population is also mainly non-cooperative (social value=60), with attribution ‘group’ (20), and with high resource uncertainty (85); the resource size starts with 50, the average use with 50, and the relevance with 20 which means that the state of the resource is more important for the decision to use the resource than the social variables. As a result, the size of the resource is kept at a constant but low level (see figure 6).

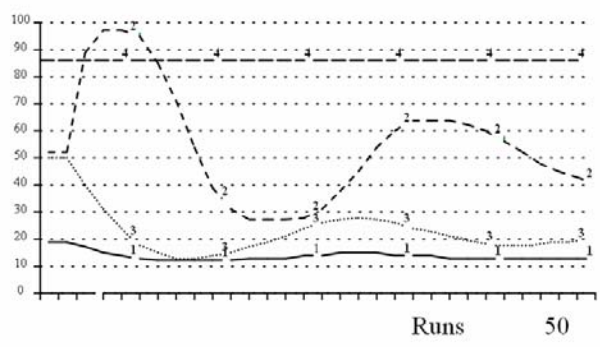

Figure 6: Population of 10,000 which is non-cooperative (social value=60), with attribution ‘group’ (20), and with high resource uncertainty 85 (dashed line-4); the resource size starts with 50 (dotted line-3), the average use with 50 (dashed line-2), and the relevance with 20 (solid line-1)

By reducing the uncertainty of the population about the size of the resource (see figure 7) the resource can be used more adequately and it is transferred continuously into a higher size which is beneficial for the entire population. The decisive effects of uncertainty can thus be demonstrated.

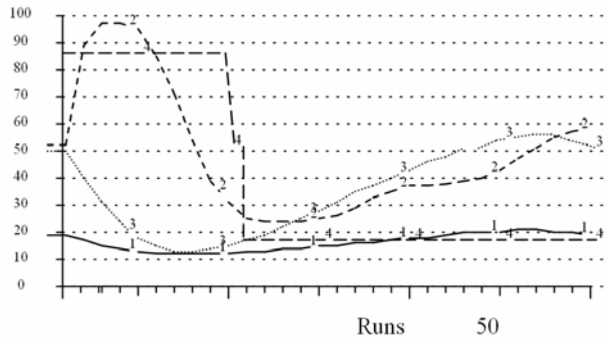

Figure 7: Same population as in figure 6 but resource uncertainty (dashed line-4) is reduced markedly; the resource size starts with 50 (dotted line-3), the average use with 50 (dashed line-2), and the relevance with 20 (solid line-1).

DISCUSSION

An agent-based model of human resource use was built on the basis of theories found in the relevant scientific literature. This has the advantage that the model is not biased through the modeler’s preferences and moreover it can be validated by comparing the simulation results with published findings. From the successful validation it can be concluded that the agents in the simulation behave like real individuals in the experiments.

Based on this valid agent model, simulations with populations of 10’000 agents were conducted. The population simulations revealed measures with which it could be possible to bolster the detrimental effects of a mainly uncooperative population upon a resource by changing the perceptions of a certain percentage of the population. Also the essential effects of the visibility of the changed behavior in the social network could be confirmed. It could be demonstrated that the uncertainty about the resource size could play an important role for the sustainable conservation of an environmental resource.

These population simulations show the usefulness of a validated agent-based simulation. Insights could be gained into the possibly detrimental interplay between an overusing population and an environmental resource. Measures were tested which could lead human populations to a sustainable use of resources.

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