Modelling cooperation in Bali irrigation

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***Abstract*— In social-ecological systems research the use of natural resources is typically studied on either a conceptual (theory) or a detailed level (case studies). We use agent-based modelling to take an approach that is situated in between. With this we aim to generate understanding that goes beyond the case, while being sensitive to contextual aspects of a given social dilemma situation. Our model combines a theoretical model of norm-driven cooperation with a case-specific model of an irrigation dilemma. The theoretical model is contextualised by using case empirics to investigate the role of cooperation for the performance of a rice growing community. Particularly, for this conference, we focus on the effect of introducing ecological complexity by embedding empirical based resource dynamics.**

I. Introduction

The behaviour of humans affects and is affected by the natural environment and other living beings. Human behaviour strongly shapes ecosystems while at the same time being dependent on them. This makes human-environment systems tightly coupled social-ecological systems (SES). SES studies typically focus on real world problems, such as sustainable use of natural resources with a complex adaptive systems lens. However, much SES research is often based on either simple abstract models or complex, rich descriptive case studies. This limits our capacity to develop solutions to real world problems that take both complexity and context of a SES into account while being applicable to a wider range of SES. There is thus a need to generate understanding that taps from both theories and case studies. Particularly, to identify what level of complexity and what contextual factors are relevant.

We apply agent-based modelling (ABM) to connect theoretical explanations with real world problem situations in complex SES to respond to the need for context sensitive approaches [1]. We require our model 1) to address a challenge that is common across a wide range of SES, 2) to incorporate relevant theoretical explanations and 3) to include relevant contextual variables, without losing the ability to systematically explore the challenge [2].

· This work was supported by the European Research Council under the European Unions Seventh Framework Programme (FP/2007-2013)/ERC grant agreement no. 283950 SES-LINK.

In this talk we will present this approach using an agent-based model that combines a theoretical model of norm-driven cooperation (CP-norm) [3] with a model of an irrigation dilemma that captures the main features of irrigation in Bali [4], where farmers (self) manage their water resources to grow rice while avoiding pest outbreaks by synchronising their cropping schedules [5]. We contextualise the theoretical model using Bali empirics [5] to investigate the role of cooperation for the performance of one irrigation community. We do so by slowly adding relevant contextual details, such as aspects of the natural resource dynamics or social interactions to the theoretical model. Particularly, for this conference, we focus on the effect of introducing ecological complexity by embedding empirical based resource dynamics from the Lansing-Kremer model [4] reproduced by Janssen [6] in CP-norm.

II. Background

A. SES challenges exemplified by the Bali case

The Bali case was selected because it represents a classical SES challenge, namely a social dilemma that has already been intensively studied empirically [5]. The Bali case represents a case of successful resource management. It is in that sense an example of a solution to avoid a 'tragedy of the commons', through a self-organised process that restrains actors from taking the amount of water that would be (short-term) optimal for an individual, but harmful for the collective [7]. However, despite its successes on watershed level, on the level of individual farmer communities (subaks) differences in performance can be observed in situations with similar social and ecological conditions [8]. Our hypothesis is that the ability to engage in collective action is a major factor explaining these differences [2]. The combination of available empirical knowledge and an open question exploring the circumstances for successful self-organisation allows us to develop and test our approach to develop context sensitive (not too generic, not too specific) understanding of SES social dilemmas.

B. Theory of cooperation & the CP-norm model

The capacity for collective action, particularly with respect to sticking to a chosen cropping plan (cooperation), has been identified as a possible factor explaining differences in performance of communities in Bali. Cooperation research studies how people decide to act cooperative or not and how this arises/adapts over time, i.e., evolution of cooperation, see [9]-[13] for an overview. We are particularly interested in theories identify mechanisms that can sustain cooperation in a social dilemma (see e.g. [14]). .

CP-norm is an agent-based implementation of an evolutionary game theoretic model [15] that explores the conditions under which a social norm enforced through ostracism (social punishment driven by disapproval) facilitates sustainable use of a common-pool resource, see Fig. 1. Cooperator agents need to restrain from selfish profit maximization to achieve socially optimal resource extraction levels. Defectors that extract higher levels are punished if the frequency of cooperators is large enough, hence when the community has the social capital to act against defectors. The strength of punishment depends on the level of cooperation and the degree of norm violation. Under certain conditions full cooperation, full defection or a mixed equilibrium can be sustained.

We have selected this theoretical model because it includes the mechanisms that we consider most relevant for explaining the capacity of Bali farmers to collectively adapt and manage their resources. Ostracism or social disapproval has been hypothesised as an important mechanism facilitating collective action in Balinese communities [16]. Additionally, graduated sanctioning has been identified as an important variable for self-organisation in empirical research on common pool resources [17], [18].

III. A MODEL OF COOPERATION IN BALI IRRIGATION (COBA-I)

The agent-based model of cooperation in Bali irrigation (COBA-I) aims to capture relevant contextual details in the Bali case while addressing a social dilemma.

In COBA-I we adopt the social mechanism for cooperation of the CP-norm model and gradually introduce complexity. In other words, we gradually introduce more details of both the social and ecological contexts, using the descriptive knowledge of the Bali context [5] and elements of the Bali3/Kremer-Lansing model of Bali irrigation [4], [6]. As a first step we test the role of the social mechanisms of cooperation within an environmental context that is based on the ecology of Bali. The ecological dynamics are represented by the water flow variability and pestdynamics. Water availability is affected by rainfall-scenarios as well as the characteristics of the landscape (elevation, groundwater flow). Pest dynamics that affect rice harvest depend on the level of synchronisation among the farmers (having crops and fallow periods at the same time).

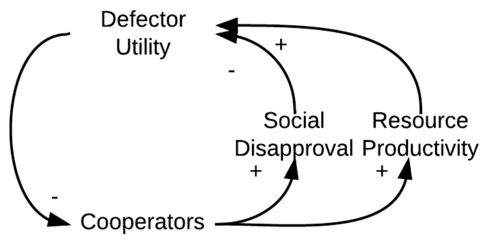

Fig. 1. The main feedback mechanisms of the CP-norm model. The inner positive social feedback loop leads to an increase in cooperators, while the outer negative ecological feedback loop leads to an increase in defectors.

The main elements of the model are the resource (water), the agents (farmers) and the world they live in (Balinese irrigation context). The group of farmers represents one farmer community, i.e., Subak. Farmers can choose between one of two behavioral strategies: the cooperative strategy where they stick to the agreed upon cropping plan of the community and the non-cooperative strategy where they choose a different cropping plan with an additional crop rotation. Fig. 2 describes the main processes of the COBA model. *Each month* (= time step) the farmers have a water demand determined by the needs of the crop (rice) depending on where they are in their cropping plan. The water availability is determined by rainfall (scenario-based) and groundwater flow (elevation based). Water is either extracted or flowing out downstream. The rice crop grows according to the amount of water each farmer can extract. *Once a year* (every 12 time steps) two farmers meet randomly and evaluate their behavioural strategy, i.e. cropping plan, by comparing their success with that of the other. The success or utility of each farmer is calculated based on the returns from its rice harvest and the incurred costs. Rice harvest is a function of water availability, i.e. water scarcity leads to less rice to harvest. Costs may arise when a farmer is ostracised (sanctioned) because it deviates from the agreed cropping plan, i.e. followed the non-cooperative behavioural strategy. Sanctioning, however, only occurs if the group of agents following a cooperative strategy is large enough (social capital) to collectively sanction the farmers that deviate from the agreed cropping plan. Costs can also arise due to the outbreak of pests. Pests can only be ‘managed when fallow periods are synchronised. The non-cooperative strategy farmers can

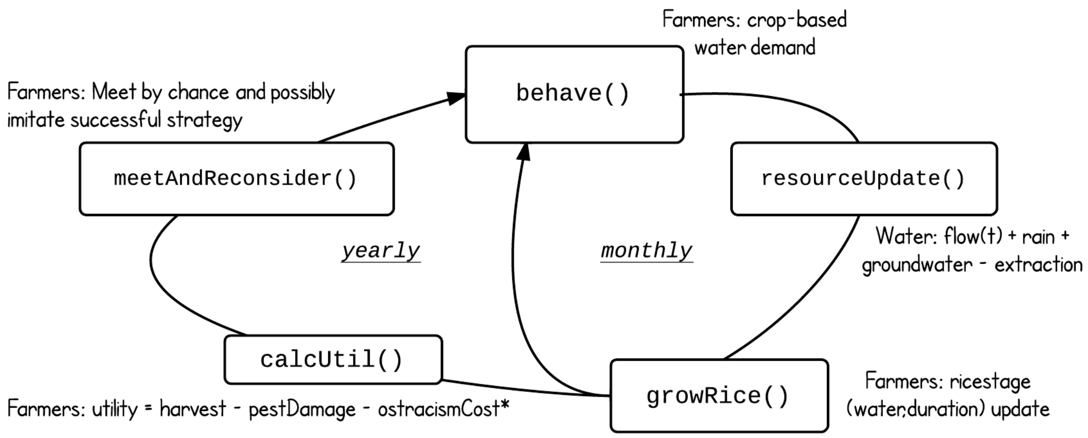

Fig. 2. Proces diagramme of the COBA-I model. Every time step (a month) farmers behave (take out water), resource is updated and rice grows. Every 12 time-steps (a year) each farmer calculates its harvest and has a chance to meet and update its behaviour strategy.

choose favors pest growth that affects every agent (regardless of their strategy).

When introducing the Bali rainfall patterns we expect that the model will still show the 3 outcomes of the theoretical model (full-cooperation, full-defection and a mixed equilibrium), however given the fluctuations of the system state regions will differ. The model is currently in its verification stage. This includes tests of the reproduction of the resource dynamics from the Bali3 model as well as the cooperation mechanisms of the contextualised CP-norm. The social mechanisms are of particular interest. Fig 1 illustrates some first explorations of these interactions. The cooperation behaviour strategy becomes dominant (blue line on top) in the community over time when the initial proportion of cooperative strategies in the community is high. The rainfall scenario, however, seems to effect the speed at which a dominant cooperative strategy converges. Particularly, the presence of waterstress (low rainfall scenario) increases the convergence to a cooperative strategy (compare Fig 1a and 1b). This is consistent with the unpublished findings of CP-norm [3]. Under water stress the costs of non-cooperation weigh in stronger, as returns from harvesting are reduced.

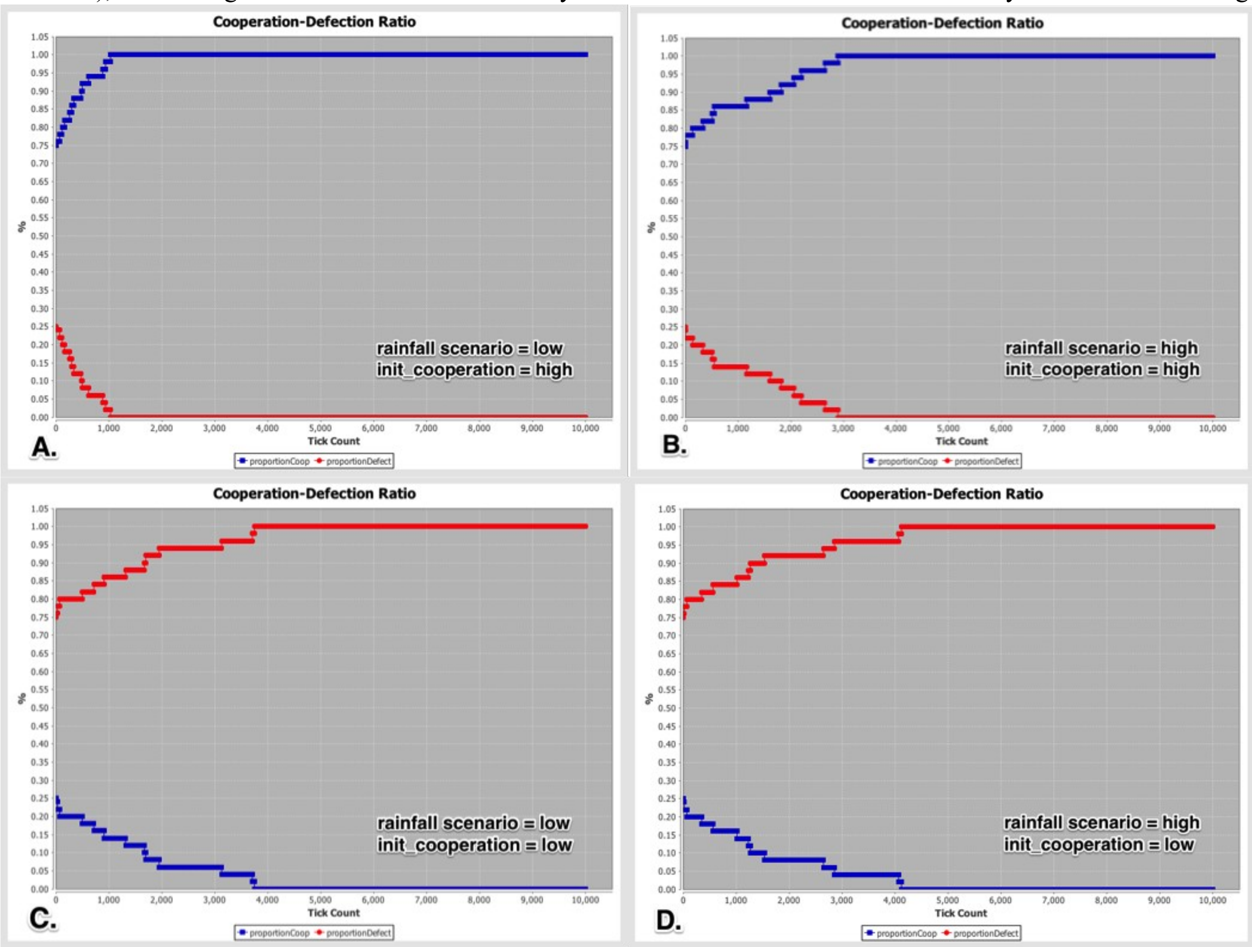

Fig 3. First explorations of the COBA-I model varying the rainfall_scenario {low, high} and the initial amount of farmers with a cooperative behaviour strategy {low, high}.

Although these are just initial explorations, they are a sneak preview for our further explorations. These explorations will focus on reflecting on the cooperation mechanism in CP-norn by contextualising. For instance, CP-norm shows overall high dominance of the non-cooperative strategy. Particularly, when relaxing the strength of the ostracism, with low resource variability CP-norm converges to non-cooperative behavioural strategies. In general, COBA-I behaviour is consistent with CP-norm by reproducing the importance of the size of the initial proportion of a particular behaviour strategy (affecting the ability to ostracise) as well as the response to low levels of resource affecting all and particularly taking away the advantage of the non-cooperative strategy. We were able to reproduce the community patterns of all cooperative strategies, all non-cooperative strategies and a mixed equilibrium, however the regions seem to differ. We will explore under what conditions cooperation arises in COBA-I,compare the difference with the conditions of CP-norm and reflect on the role of context in explaining these differences between the theoretical model (cp-norm) and the contextualised model (COBA-I).

IV. Conclusion

Our presentation at the conference aims at demonstrating our approach of developing tools to understand the dynamics of coupled social-ecological systems at a level of complexity that does justice to real world contexts while still allowing us to draw some more general conclusions. The iteration between abstract, general models and a given context raises a lot of food for thought in reflecting on the consequences of model design choices.

The process of contextualising CP-norm triggers both theoretical and empirical questions. On the theoretical side exploring the effect the increased complexity of the resource dynamics has on CP-norm in itself, e.g. it might explore situations that were outside of the scope of the theoretical context. The other way around, the choices we make in for instance operationalising cooperation raise empirical questions. For instance, what is 'cooperation' in the case? It can refer to different types of processes in groups, can be studied on many levels. Which aspect of cooperation in resource use is most relevant for explaining performance differences in the Bali context? For instance, in the Balinese context cooperation involves more than just sticking to a particular cropping plan. It also involves attending weekly subak meetings, perform rituals, maintain canals etc. [5]. Furthermore, cooperation in our model only refers to the community level. In future it will be important to investigate different (possibly conflicting) levels of cooperation (within community, between communities and system level).

Our immediate next steps involve more systematic sensitivity analysis and experiments to understand COBA-I. From there we will continue with gradually increasing the richness of the context so that we can explore what level of complexity is needed to explain the observed differences in performance between communities. Particularly, we will focus on including more realism on the social side by for instance, introducing social structure. This will directly affect who the farmer is more likely to meet and thereby the reconsideration of the behaviour strategy will be based on the social vicinity.

Acknowledgment

We would like to thank Steve Lansing for many valuable discussions and for sharing his expertise and data on the Bali Subaks with us.

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