Agent-Based Case Studies for Understanding of Social-Ecological Systems: Cooperation on Irrigation in Bali

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Abstract. This paper describes the design phase of an ABM case study of Bali irrigation. The aim of the model is to explain the differences in the ability of rice paddy farmers to collectively adapt through cooperation. The model should allow exploring factors affecting self organisation within and between rice paddy farmer communities. The exercise of the ABM case study aims to move abstract models (theory) closer to real world phenomena, which requires contextualisation. This paper focuses on the first steps in model contextualisation: model selection and specification for the Bali irrigation case.

Keywords: ABM case studies, Bali Irrigation, cooperation, social-ecological systems, social dilemmas.

1 Introduction

We live in a complex world, where our actions affect and are affected by nature and other humans. Social-ecological systems (SES) research focuses on problems that involve both humans and the environment, which are tightly interconnected and in continuous interaction. For example, questions that address the impact of climate change, the spread of infectious diseases or the sustainable management of natural resources. One major challenge of SES research, with respect to sustainable use of natural resources, is to understand and manage social dilemmas, i.e., situations in which resources are shared and there is a need to individually restrain resource outtake to avoid collective over-exploitation of a common pool resource[1]. These social dilemmas can have tremendous impact on a large scale, such as, reduced water availability for food production, collapsing fish stocks or the inability to deal with climate

[1] Common pool resources are a type of resource where taking out resources (harvesting) by one user reduces the availability from a pool that is potentially available to others, i.e. subtractability, and it is difficult to exclude anybody from taking out resources, i.e., non-excludible [1].

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change. One of the main identified needs is to get basic information and understanding of SES dynamics to evaluate, learn and improve SES management [2]. Most work done in sustainability research/common pool research focuses either on rich descriptive case studies of real world cases or on highly abstract analytical models [3]. Both have their strengths by either having a strong relation to the real world phenomenon (case studies) or explorative power and clarity (generic models). Within this need of understanding we see a role for agent-based modelling: 1) to embed the complex adaptive nature of social-ecological systems; 2) to provide an insightful middle ground between (abstract) generic models and the (rich) real case studies; and 3) to provide a systematic way to discern between important general aspects of the social and ecological context of the social dilemma and case specific factors. We explore the contextualisation of concepts, mechanisms and interactions of a generic model and thereby to integrate general aspects of the social-ecological context that are relevant for explaining sustainable outcomes in complex SES. In the following we describe our first steps into an ABM case study: the contextualisation of an (abstract) model of cooperation in the case of Bali irrigation, see figure 1.

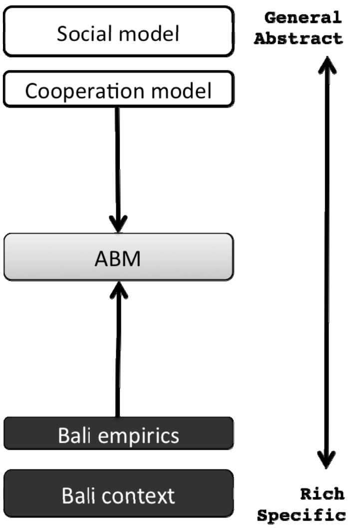

Fig. 1. The positioning of our approach in modelling an ABM case study

1.1 Bali Irrigation as an ABM Case Study

Bali irrigation is one of the well-know examples of a self-organised 'escape' of the 'tragedy of the commons' [4]. The tragedy of the commons describe the inevitable outcome of overexploiting shared resources in absence of a central authority [5]. Rice paddy farmers in Bali are part of a community-level organisation devoted to the management of the rice terraces, a subak[2], apart from being part of a village community. The rice paddy farmers in Bali demonstrate effective management of their rice fields in a bottom up manner by agreeing on an irrigation schedule *within* and *between* Subaks [6]. The irrigation schedule synchronises the cropping patterns to avoid pests and provides water for all the subaks. The success of the rice paddy farmers lie in their ability to adapt to the ecological circumstances, in other words, their capacity to engage in collective action. Any change in this ability of the farmers in a subak can potentially affect the whole system of subaks that are interconnected by the river. For instance, even short periods of lacking cooperation could have large impacts on the harvest on multiple scales. In addition, the damage that this lack of cooperation can produce takes time and effort to return to the state before cooperation was lacking, just imagine the devastating effects on ecology to recover from pests, or the long way a community needs go through in trusting each other again. The goal of our model will thus be to explore the vulnerability of a social group within the Bali context and explore on multiple scales the effect of such a system but also the role of our theories and assumptions on the understanding of such as system.

Recent work done by Lansing et al [7] indicate variation between subaks in their ability to adapt to environmental and social circumstances. . Lansing et al. [7] explored the age and demographic stability of subaks (their genetic diversity) in relation to their ability to adapt, i.e., to engage in collective action. Communities with lower adaptive capacity might potentially be more threatened by impacts of local or global change such as an influx of newcomers or expansion of tourism. These empirical hints of potential threats on to self organisation trigger questions: ‘ what affects the adaptive ability capacity of farmer communities?, ‘what is the effect on different scales of varying capacity to adapt?’ and in the larger frame of our project ‘what does the understanding of this case mean for general models of social dilemmas?’. Inspired by these latest findings we focus on exploring potential threats on self-organising groups and thereby on the ability to maintain the necessary ability to adapt to ecological and social circumstances. The Bali irrigation case already proved its value for understanding both the Bali case[3] and more generic reflections on cooperation and ecological feedbacks [8].

This paper zooms in on the ABM design phase: the contextualisation of a generic model of cooperation placed within the context of Bali irrigation. Although we use

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[2] The rice paddy farmers organise themselves in groups around a shared water resource, so-called subaks. These subaks are embedded in a nested network of temples matching the island’s landscape: ranging from the main temple and lake on top of this steep volcanic island, via smaller temples at rivers, canals and weirs towards the rice paddy fields, where the water ends her journey finally in the sea.

[3] For instance the model developed by Lansing and Kremer demonstrated the necessity and power of bottom-up organisation that convinced the consultants and government to continue ‘modernisation’ of bali agriculture was a big drama, (for a detailled description of the ‘green revolution, see chapter 1, [6]).

empirical data for our model design, our discussion restricts itself to model selection and specification; we do not focus on model calibration. We depart from an extensive body of work done on the Bali case, both descriptive ethnographical data and computational models. The models represent a realistic description of the important ecological functions, water availability and pest dynamics, e.g., [9-11]. The models of social-ecological dynamics in Bali focus on the level of coordination [9-11] and cooperation [6, 8] in irrigation schedules. Typically in these models the subaks are represented as the smallest dynamic entity. It is assumed that within a subak everyone sticks to the agreed rules, i.e., cooperates by executing a particular cropping plan, see figure 2. For the research aims of those Bali models this is a sensible simplification, however the recent insight of the variation in subak outcomes force us to zoom into the within subak dynamics itself, see figure 3. To represent the social dynamics, i.e., the ability of the rice paddy farmers to collectively adapt when environmental or social issues arise, guides the focus to research of cooperation. There exist a vast body of literature on cooperation, suggesting various mechanisms that lead to cooperation (that vary across the different social science fields, such as economics, social psychology and neuro-sciences). In light of our aim to connect move towards an intermediate level of the levels of abstraction, recall Figure 1. We selected to start with an abstract model of cooperation [12], an ABM reproduction of [13],. This paper will focus on illustrating some of the challenges and approaches we take to design a contextualised social-ecological model of cooperation in Bali.

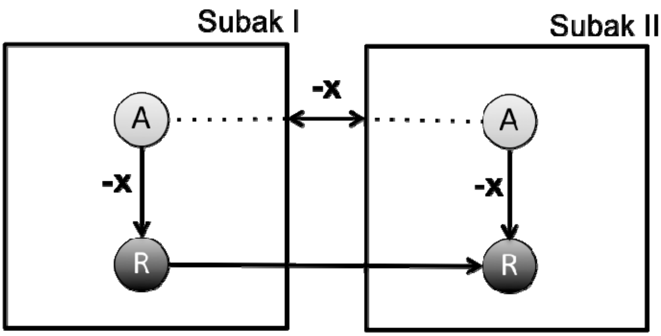

Fig. 2. Schematic overview of the focus on between subak dynamics of existing models of coordination and cooperation in Bali. The actors (A) in a subak take out x amount of water(R). The amount x is a result of the between subak coordination. It is a ‘rule’ that all actors know (dotted line) and are assumed to comply to. The subaks are interconnected via the network of rivers and canals of water (R). Where all actors have access to the water, but when actors from Subak 1 take out water (upstream) there is less water left for the actors in Subak 2, i.e., a typical common pool resource.

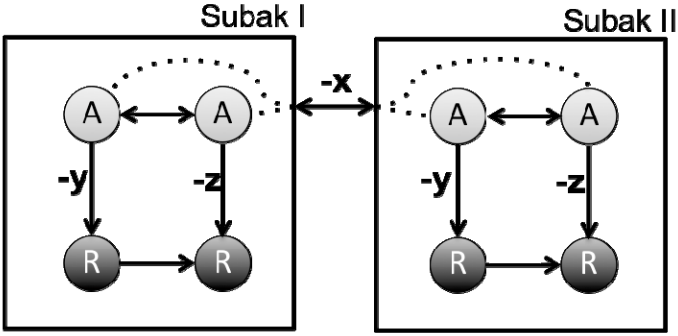

Fig. 3. Schematic overview of our focus on within and between subak dynamics in modelling cooperation of Bali irrigation. This is a variation on figure 2b, where the change in assumption is visualised. Actors in a subak all know about the agreed ‘rule’ (dotted line) to take out x but do not necessarily comply. The amount (y or z) taken out is influence by the interaction with other actors (social environment) too.

2 Modelling Subak Cooperation in Bali Irrigation

The aim of the model is to explain the differences in the ability of subak farmers to collectively adapt through cooperation. The model should allow exploring factors affecting self organisation within and between subaks. In parallel, the exercise of the ABM case study aims to move abstract models (theory) closer to real world phenomena, which requires contextualisation. Contextualisation describes a process of selecting a suitable model, specifying, sometimes calibrating, testing and starting a new design iteration: adapting a model, etc. This paper thus discusses the model design stage with a focus on contextualization. This section will discuss the first steps, model selection and specification for the Bali irrigation case.

2.1 Model Selection: Start of the Iterative Journey of Model Design

There exists a vast body of models explaining cooperation on a theoretical level [14-16]. At the same time, ethnographical observations and descriptions of subak life describe a richness of factors, actors and processes playing a role in the social cohesion of a subak [6]. Our process of developing an ABM taps from both sources. We choose to depart from a model of cooperation, the ostracism model [12, 13]. The reasons for choosing this model are as follows: a) <u>context relevant</u>, this model of cooperation is placed in the context of resource management, which matches the case context of a social dilemma; b) <u>social driver for cooperation</u> is, which we regard important to describe the adaptive capacity of a community; c) <u>allows for comparison</u>. The model is a replication of a theoretical model [12,13], which has advantages in comparing and reflecting on the case-based outcomes; d) <u>ownership</u>, it is a model created by one of us, which allows for short-links to interact about model specifics.

The Ostracism Model. This ABM model [12] replicates and further explores an analytical model [13]. Both ostracism models investigating the role of norms and social disapproval by norm followers for cooperation amongst a group of harvesters that share a common resource. If the group of norm followers that harvest the resource sustainably is large enough (i.e., social capital is high), they engage in ostracising over-harvesting norm violators. The system develops through agents imitating best performing strategies. When the initial number of norm followers and hence the social capital of the community is low, norm violators prevail and the resource is over-harvested. If the number of norm followers is high and defection of norm violators is not too large, a community of norm followers evolves. If the initial number of norm followers is high but the defection of the norm violators is large, coexistence emerges, where a small group of norm violators share the resource with a large group of norm followers. The ecological and social drivers of system dynamics balance out, e.g., the gain defectors get from higher resource levels due to high levels of cooperation is balanced with the social disapproval they experience through the community of norm followers.

The main concepts of the model are shown in Table 1. On the macro level, the emergent pattern (target) is the level of cooperation, e.g., the proportion of norm followers that harvest sustainably. In addition, the proportion of cooperators and defectors, the ostracism costs for defection and resource volume affect the agents in their aggregated form. On the micro level the agents are characterised by their behavioural options, to defect or to cooperate. They choose the behaviour that performs best, i.e., has the highest utility[4]. The environment (the meetingList) defines with whom the

Table 1. An overview of the main concepts of the (abstract) cooperation model we depart from filtered by main ABM dimensions

Macro Level	**Emergent pattern**	**Level of cooperation**
	Aggregated variables	Proportion of Cooperators, Defectors [%] Ostracism costs Resource volume
Micro level	Agent	Behaviours options: {Cooperate, Defect} Decision-making: behaviour = imitate if other has a better strategy
	Environment (topology)	MeetingList [random]
	Interaction	Physical environment: Receive utility() Social environment: Compare utility()

[4] In the model there is a distinction between payoff and utility. Payoff represents the 'crop output', whereas utility is the final gain (in money) that an agent can receive. Ostracism affects the step from payoff to utility, which can be illustrated by an agent being blocked access to the market.

agents interact, i.e., meet randomly, to learn about the best performing strategy by comparing the utility of its own behaviour with that of another agent. The interaction with the physical environment results in receiving utility as a consequence of the chosen behaviour.

The Challenge of Matching Theory and Case. The question how well suited the ostracism model is for the Bali case guides the iterative process of model design and model adaptation. To identify whether the ostracism model matches the irrigation context in Bali, the concepts of the ostracism model are placed in relation to what we know from irrigation context of Bali [6], see table 2. Without going into detail about each concept, we can identify ‘easy’ mappings’ such as, resource is water and payoff is the rice harvest, however most concepts do not exist in an one-to-one correspondence with the real case. These notions are either more rich in the Bali context (light grey cells) or the data is not available (dark grey cells).

We see that the resource management context from the ostracism model matches the irrigation dilemma in Bali well in terms of: resource (dynamics), utility interlinked with the resource and the presents of social factors that could reflect the variation in adaptive capacity. More specifically, these social factors, relate to variables, e.g., sanctioning, norms, that are considered important to establish self organisation [17]. However, the Bali context also indicates aspects that are not addressed by the ostracism model. For instance, in simplistic representation of the physical environment: pests dynamics are not included, however play a crucial role in the Bali irrigation dilemma. Coupling the model to the existing models of Bali ecology is therefor the intended solution. Concerning the social environment (topology) is minimally existing on the micro-level, there could be good reasons to introduce a spatially dependent structure that affects how the agents meet. Another example would be (heterogeneous) agent attributes in which the role of caste could play a role in the way agents from different caste interact with each other.

When comparing these missing elements with other models of cooperation [14-16], we can identify some mechanisms that target some of the missing components addressed above to explain cooperation[5]. For instance, spatial explanations, such as network reciprocity, graph selection, or set selection, describe the influence of the network topology of an agent on the cooperation. Other explanations focus more on explaining cooperation based on the group that one belongs to, e.g., green beard, group selection or kin selection, which could be an option for representing the role of being heterogeneously part of a caste. Overall, most models of cooperation focus on one or a few mechanisms/drivers of cooperation. Probably the ABM model will result in a merger of theories/mechanisms. For now we consider the ostracism model good enough to continue, it is up to the next model specification phase to define what seems to be a good fit of model & context.

[5] Theories that describe the evolution of cooperation focus on identifying mechanisms.

Table 2. An overview of the main model concepts of the ostracism model the related available empirical data from the Bali context and some first ideas for the ABM of Bali irrigation

ABM dimensions	**Abstract model**	**Bali context**	**Contextualised ABM**
Emergent pattern	level of cooperation	Difference in ability to adapt to social and environmental challenges	Assume 'adaptive capacity' = level of cooperation
Aggregated variables	Resource volume f(constant)	Water availability (local) f(upstreamOuttake,rainfall)	Water availability
	Proportion of Cooperators, Defectors [%]	Number of cooperators	Number of cooperators
	OstracismCost OstracismCost = F(coopRatio, inequityEffect[6])	There is no empirical evidence for farmers knowing the overall cooperation/defection ratio (social capital) or the relative difference in size of defection. The age and demographic stability of the subak are indicators for effective sanctioning.	
Agent	Behaviour options {Cooperate, Defect}	Behaviours - Take out X water to farm land on time t - Perform rituals - Maintain canals - Perform Agricultural labour - Attend weekly subak meetings - other	
	Decision-making: imitate if other has a better strategy	This is a theoretical assumption of human decision-making. No empirical evidence about the imitating when others perform better.	

[6] The bigger the difference between the defector and cooperator payoff, the bigger the ostracism. Can be regarded as another type of gradual sanctioning: small offence, small punishment. Large offence, big punishment. In addition to the standard description of gradual sanctioning that describes an increase in punishment over time when the defection is repeated.

Table 2. (*continued*)

Environ-ment	MeetingList [random]	- Farmers are part of a Subak, they meet weekly in a Subak meeting. - Farmers own land (spatial location), and have neighbours - Farmers live some where (spatial location) and have neighbors - Farmers are part of a caste[7]	Options: - Network topology - fixed interaction group. - Local interaction with the same farmers neighbouring land - Maybe also interaction with farming neighbours of home-surrounding
Interaction	'Environment': Receive utility() Payoff = f(waterOuttake) Utility: f(payoff, ostracismCost)	- Rice harvest Harvest/payoff = f(waterAvailability, pestDamage,riceType) - Not aware of data on earnings.	Rice harvest - Including pest dynamics in the payoff function
	Other agents: compare utility()	Not aware of data on the knowledge of farmers on each other's harvest and income. Apart from utility, - There is a continuous tension between castes and the hierarchical position they belong - Sanction might affect utility comparison.	Option: - Find/Collect Data or include theories on other potential moderators on utility comparison (sanctioning, caste membership, ..)

[7] We have to investigate what this means for their interactions. However, when they interact, the caste determines the language. Low Balinese when talking to someone in a lower caste, high Balinese in a higher caste. The subak meetings are in this sense egalitarian, regardless of the caste everyone talks high Balinese to each other.

2.2 Model Specification[8]

Table 2 doesn't only give a first lead for model matching, it also forms a valuable source for model specification. In the last column (contextualised ABM) we indicated some first ideas of for the contextualised ABM. Particularly, the grey cells point out the focus for us as modellers to make decisions. The first type of decisions concern which factors to include and which not, since the context indicates more richness (light grey cells). It could also imply that these are the factors for manipulation in the simulation to explore their influence. The second form of decisions concern concepts in the theory (model) of which no data is available (dark grey cells). This is where we can choose to formulate assumptions or to collect data.

In a first version we will adopt the assumptions from the ostracism model, to have a baseline model to compare with while adapting the model gradually by adding contextual factors.

3 Conclusion

In this paper we highlight a story of contextualising models in which we typically start from a theory/model and relate it to empirical data to see which aspects of a social-ecological context matter and to derive focus points for model specification. Our aim is to open the discussion about the design stage of our model and share reflections among peers to increase the quality of (our) model(s) in a fundamental stage of modelling. Discussions could involve:

- Alternative options or suggestions for contextualising ABM (column 4)
- Assumptions in models
- Empirical data for model specification

The larger idea behind developing an ABM case study of Bali irrigation is to move the body of generic theoretical models closer to particular group of real world phenomena. These are phenomena where the collective interests of resource use, like water, are in conflict with individual interests, i.e., social dilemmas. Social-ecological research that is concerned with these dilemmas is provided with abstract theoretical models with strong analytical power, however little relation to real world social dilemmas. On the other hand, there exists an abundance of rich and descriptive case studies on real world social dilemmas that are case-specific. The use of ABM case studies is a way to discern between factors that are case specific and social dilemma specific. Enriching generalised models with these context sensitive social dilemma

[8] What we do here touches content wise with what [18] discuss. However, our focus lies on combining existing theoretical models in and contextualising it with empirical data. Where we agree with the communicated importance of empirical embeddedness, particularly also on the micro foundations of a model (model design). We focus on covering the first stages of model selection and model specification. Where Boero & Squazzioni [18] touches upon model specification the focus and research attention in general goes more to model calibration and output validation with empirical data.

factors allow for a stronger explanatory power, more realistic and more useful insights into the dynamics of this particular class of social-ecological systems.

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