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Combining participatory approaches and an agent-based model for better planning shrimp aquaculture

Olivier M. Joffre [a,*], Roel H. Bosma [a], Arend Ligtenberg [b], Van Pham Dang Tri [c], Tran Thi Phung Ha [d], Arnold K. Bregt [b]

[a] Aquaculture and Fisheries Group, Wageningen University, 6700 AH Wageningen, The Netherlands
[b] Laboratory of Geo-information Science and Remote Sensing, Wageningen University, P.O. Box 47, 6700 AA Wageningen, The Netherlands
[c] College of Environment and Natural Resources, Can Tho University, Can Tho City, Vietnam
[d] Department of Sociology, School of Social Sciences and Humanities, Can Tho University, Vietnam

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ABSTRACT

In the Mekong Delta coastal zone, decision makers must weigh trade-offs between sustaining the shrimp sector and thus ensuring economic development, while also promoting sustainable, environmentally friendly practices and planning for climate change adaptation. This study investigates future scenarios for development of shrimp aquaculture using a spatially explicit, agent-based model (ABM) simulating farmers' production system choices. A role playing game (RPG) with farmers was used to calibrate and validate the model. Four scenarios, representing different visions of aquaculture in the next 15 years, were elaborated with decision makers before discussing the different outputs of the model. Iterative consultation with farmers helped to fine-tune the model and identify key parameters and drivers in farmers' decision-making. The recursive process allowed us to construct a model that validly represents reality. Participants stated that use of the RPG improved their insight for planning. Results of the scenarios indicate that (i) intensification of production is unsustainable, (ii) market-based incentives are too limited to stimulate development of an integrated mangrove–shrimp production system and (iii) climate change will cause rapid decline of production in the absence of adaptation measures. RPG appeared to be a valuable method for formalizing local farmers' knowledge and integrating it into the planning approaches used by decision makers. The ABM, thus, can also be considered a medium or communication tool facilitating knowledge-sharing between farmers and decision makers.

1. Introduction

Shrimp farming is part of a complex socio-ecological system involving high risk and rapid changes of land use. Expansion of shrimp farming in the late 20th century modified coastal landscapes in many tropical countries. These changes have been driven by potentially high returns on investments in shrimp farms. As a result, mangrove forests and rice fields have been converted to make way for shrimp culture, though this in many cases has led to bankruptcies and abandoned farms when aquaculture failed (Lebel et al., 2002; Luttrell, 2002). Shrimp farming came to the Mekong Delta in Vietnam in the late 1990s and early 2000s, fueling rapid conversion of rice fields (Tuong et al., 2003) and mangrove forests (Hong and San, 1993; Phuong and Hai, 1998; Luttrell, 2002; Nguyen et al., 2013), while improving local farmers' livelihoods and providing a source of growing earnings for the nation.

The transformation from mangrove to shrimp culture is often described as the spread of intensive shrimp farms. However, the shrimp farms are not all intensive. Farms within the same landscape vary from small-scale extensive to large-scale commercial (Joffre and Bosma, 2009) to a farm type called "integrated mangrove–shrimp", in which forest cover and shrimp production are combined. Each shrimp production system has its own characteristics regarding production, operating budget and returns, as well as environmental and social costs (Ha et al., 2013; Ha et al., 2014).

The Mekong Delta, specifically Ca Mau Province, provides an interesting example of the complex trade-offs involved in land use choices. Decision makers here seek to achieve both sustainable economic growth and ecosystem conservation by influencing farmers' choices of production system. Researchers and local government have developed various land use planning methodologies employing participatory approaches that bring in local knowledge, as well as methods incorporating socioeconomic aspects, hydrology and soil science to optimize resource use (Tuong et al., 2003; Hoanh et al., 2003). These planning

* Corresponding author at: Aquaculture and Fisheries Group, Wageningen University, PO Box 338, 6709 PG Wageningen, The Netherlands.
E-mail addresses: olivier.joffre@wur.nl (O.M. Joffre), roel.bosma@wur.nl (R.H. Bosma), arend.ligtenberg@wur.nl (A. Ligtenberg), vpdtri@ctu.edu.vn (V.P.D. Tri), ttpha@ctu.edu.vn (T.T.P. Ha), arnold.bregt@wur.nl (A.K. Bregt).

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methods have yielded valuable outcomes regarding specific objectives, such as productivity or economics. However, they have failed to incorporate the diversity of farmers' decisions and the impact of these at the landscape level. The difficulty of devising reasonable scenarios that integrate political and economic objectives and are appropriate for the local context, including farmers'decision-making, was recently illustrated in Ca Mau. The government here planned two rather oppositional objectives for the shrimp sector: conversion of all integrated mangrove–shrimp farms to certified organic systems (Ha et al., 2012a) and in the meantime increasing the existing 984 ha of intensive shrimp farms in 2005 to 10,000 ha by 2010 (Ha, 2012b). Neither of these targets came near to being achieved, with only 1300 ha of intensive shrimp farms found in this province in 2010 and less than 1000 integrated mangrove–shrimp farms enrolled in an organic certification program.

Existing models to capture trade-offs in coastal aquaculture decisions (Schmitt and Brugere, 2013) are based on expert consultations, thus bypassing farmers' knowledge and the considerations by which farmers' make production decisions. However, there are a few analytical tools for coastal aquaculture planning that incorporate the diverse factors influencing farmers' behavior (Mialhe et al., 2012).

Decision makers are thus left to design policies without a proper understanding of the range and magnitude of the consequences that their new policies might bring at the farm level. Farmers' make their decisions largely based on farm characteristics and on drivers external to the farm (Bush and Marschke, 2014; Ha, 2012a, 2012b). Shrimp farming is highly dependent on biophysical, social, economic and regulatory factors at the local, national and international level. Farmers' interpretations of and responses to these drivers depend on their own (local) knowledge. This latter, however, is rarely taken into account in scenario-development for coastal planning. Moreover, the decisions that farmers make do not always reflect what researchers, practitioners and decision makers know about how farmers decide (Moss, 2008).

Agent-based modeling is a tool used to represent, simulate and analyze the dynamics of adaptive systems such as aquaculture. Agent-based modeling represents human behaviors and decision-making processes through "agents", which are single, autonomous entities that interact among themselves and with their environment to achieve their goals (Ferber, 1999; Valbuena et al., 2008; Naivinit et al., 2010). The tool can be used to promote dialog between stakeholders, researchers and decision makers (O'Sullivan, 2008). Authors refer it as a "social learning tool", as it can facilitate discourse and discussion among stakeholders (Greiner et al., 2014). Modeling with stakeholders is known to enhance their ownership and trust in a model (Voinov and Bousquet, 2010; Lagabrielle et al., 2010), to deliver a decision-making tool that better responds to the needs of end users (Matthews et al., 2007) and to improve decision-making under conditions of uncertainty (Puig et al., 2009). It provides participants a greater understanding of complex systems at a larger scale (Krueger et al., 2012), allowing them to consider other stakeholders' perceptions and to reframe their own thinking about a situation (Barnaud et al., 2013; Pooyandeh and Marceau, 2013). Rather than predicting the future, agent-based modeling expands understanding of land use changes based on actors' decisions, opinions and viewpoints. It thus also serves as a medium for communication, to test hypotheses and to trigger discussion (Geertman and Stillwell, 2009).

Role playing games (RPGs) are a method of both conceptualizing and validating agent-based modeling. The RPG set-up is similar to a computerized model (Bousquet et al., 1999; Gurung et al., 2006). Knowledge acquired during an RPG can subsequently be implemented in agent-based modeling to test policy measures. Combining RPGs and agent-based modeling might therefore yield an instrument to improve understanding between stakeholders. However, issues remain, such as acquiring sufficient empirical knowledge about agents' decision-making behavior and developing adequate understanding of interactions within the agent population.

The current research investigates the merit of combining RPGs and agent-based modeling to improve communication and bridge gaps between farmers and policymakers. This paper explores and demonstrates the value of this method and identifies remaining knowledge gaps. The method is demonstrated by a case study in Dam Doi District, Ca Mau, Vietnam.

2. Materials and method

2.1. Overview of the approach

The method presented here is based on a participatory modeling approach described by Voinov and Bousquet (2010). Underlying the approach is an agent-based modeling exercise developed for this study and labeled *Coastal Aquaculture Spatial Solutions* (CASS), which aims (i) to integrate local and stakeholder knowledge with knowledge at higher levels of planners and policy makers; (ii) to analyze effects and consequences of planning scenarios on the landscape, agricultural potential and livelihoods of shrimp farmers; and (iii) to present the results to the stakeholders and actors involved.

To obtain meaningful insights on farmers' behavior and to define and refine behavioral rules, surveys were supplemented by RPGs with farmers. Fig. 1 presents the scenario-development process used in this research, beginning with acquisition of model inputs and their validation by stakeholders. This was followed by construction of the model and iterative loops to update and calibrate it. Thereafter, scenarios were elaborated and discussed with stakeholders to test the model structure and outputs and further fine-tune the model in response to end users' needs.

2.2. Agent-based model specification

The aim of the CASS agent-based model (ABM) is to simulate and analyze production system changes resulting from decisions made by shrimp farmers. The CASS model is parameterized with empirical data on social, policy, economic and biophysical drivers, and refined and calibrated through RPGs. The model uses a GIS-based detailed cadastral map showing the location and size of each individual farm, as well as outputs of hydrological modeling to estimate the suitability of plots for different shrimp production systems. The CASS model was developed using Gama 1.6 software (Grignard et al., 2013).

Two types of entities are defined in the ABM: farmers and plots. The farmers, or agents, manage their plots, and each farm is composed of a single plot. The plots are described by their production system(s), area, suitability for each type of production, potential yield, risk of disease outbreak due to a virus and financial situation (operational cost). Four production systems are possible: extensive (EXTS), improved extensive (IES), intensive (INTS) and integrated mangrove–shrimp (IMS). These correspond to different levels of intensification (Fig. 2 and Table 1). INTS represents the greatest intensification, as it uses the highest levels of inputs, labor, equipment and stocking densities, and also has the highest risk of disease. This system requires significant investment capacity and is costly to operate. It has both the highest cost and the greatest potential economic returns. At the opposite end of the spectrum, EXTS is based on low input use, frequent water exchange, low economic returns and a lower risk of disease. IES is an intermediary system, with a substantial risk of disease outbreak and intermediate operational costs and economic returns. Finally, IMS is a shrimp production system in which half of the farm is covered by mangrove forest. This system is low cost and low productivity, and presents the least risk of disease outbreak.

Plots can also be hybrid, for example, combining INTS and EXTS (or IES and EXTS). Our model investigates shifts of production systems implemented by agents over time. A shift implies a move from EXTS or IES to INTS or IMS, or from INTS or IES to EXTS if severe losses were incurred in the preceding production cycles.

Based on earlier participatory assessments and information from agents, the following assumptions are made: (i) shifting from IES and