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Expert based model building to quantify risk factors in a combined aquaculture-agriculture system

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ABSTRACT

In recent years, across tropical regions of the world, there has been an expansion of integrated farming systems that combine rice and shrimp production. While these systems were developed as a form of crop-rotation – growing rice in the wet season and shrimp in the dry season – some farmers grow both rice and brackish-water shrimp simultaneously during the wet season. Climatic variability has resulted in considerable crop losses in this system across many regions. Research has yet to identify the complete array of key risk factors, and their potential interactions, for integrated rice-shrimp farming. Consequently, different farming practices and environmental factors that may affect crop production need to be clarified to guide research efforts. We applied a staged, iterative process to develop a probabilistic Bayesian belief network based on expert knowledge that describes the relationships that contribute to the risk of failure of both crops in integrated rice-shrimp farming systems during the wet season. We applied the approach in the Southern Mekong Delta, Vietnam, in the context of a broader research program into the sustainability of the rice-shrimp farming system. The resulting network represents the experts' perceptions of the key risk factors to production and the interactions among them. While both farmers and extension officers contributed to the identification of the processes included in the network, the farmers alone provided estimates of the probability of the relationships among them. The network identified the challenges to minimise the risk of failure for both crops, and the steps farmers can take to mitigate some of them. Overall, farmers perceived they have a better chance to minimise risk of failure for shrimp rather than rice crops, and limited opportunities appear to exist for successful production of both. By engaging the farmers in this process of model development, we were able to identify additional research questions for the broader research team and to identify simple steps the farmers could take to reduce the risk of crop failure. Integrating additional empirical data into this network, as it becomes available, will help identify clear opportunities for improvements in farming practices which should reduce the risk of crop failure into the future.

1. Introduction

Agricultural production is affected by numerous environmental factors, some of which are within the control of producers and others that are beyond their control. Human alteration of the environment and the increasing impact of climate change combine to increase risks of crop failure in many regions across the world (Morton, 2007). The risk of recurrent crop failures is higher for integrated aquaculture-agriculture systems in landscapes influenced by brackish waters where rising sea levels and altered freshwater inflows combine to modify hydrological conditions throughout the growing cycle (Huq et al., 2015). These combined altered processes affect the hydrological and thermal regimes, ultimately influencing salinity and nutrient concentrations in pond and canal waters (Thanh et al., 2004). Subsequently, individual farmers make decisions on crop management in an attempt to reduce risks of crop failure and financial losses (e.g. Everingham et al., 2002).

Understanding and quantifying the multiple stressors affecting production, including impacts of decisions by individual farmers, is an important step to minimise risks of crop failure (Reid and Vogel, 2006).

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In relatively well-studied systems this may already be well formalised following years of research and production. However, in emerging agricultural regions, such as those in the developing world, this understanding may not yet be widely established (Godfray et al., 2010). In developing regions, documenting existing knowledge held by farmers in a systematic manner provides an avenue to incorporate such expertise into user-friendly decision support tools (Walker et al., 1995). This is particularly important given decision making by farmers is grounded in a broader socio-economic system that can be difficult to integrate in agricultural research (Joffre et al., 2015). With the development of such tools, findings from complementary empirical research are more likely to be of use to participating farmers and can complement their existing knowledge and understanding (Kristjanson et al., 2009).

The field of participatory modelling has developed to integrate the existing knowledge and expertise of practitioners into empirical research (Voinov and Bousquet, 2010). Such expertise may be in the form of traditional ecological knowledge of local and indigenous communities, lifelong experience of farmers or other knowledge developed through experience of living and working in a given system. Depending on the context, experts may be farmers, local indigenous people, scientists or other experienced practitioners. Integrating agricultural expertise allows the development of a link between science and farmers, enabling them to contribute actively to relevant research. This has several advantages including the identification of issues of research interest that are most crucial to farmers which ensures any empirical research is specifically relevant to farmers and farm management. When participatory modelling engages farmers and policy makers, it helps establish and foster a link between policy and on-farm decision making (Joffre et al., 2015), the lack of which can lead to negative outcomes for regional farmers. One avenue of such modelling is the development of probabilistic models that can integrate expert knowledge with existing data and knowledge via Bayesian belief networks (BBNs), a probabilistic graphical modelling tool.

Bayesian belief networks provide a very powerful tool for management and decision-making in agricultural settings (Cain et al., 2003; McCann et al., 2006). They have been used widely in many different natural resource management contexts because of their inherent flexibility and capacity to quantify complex social, economic and ecological relationships (McCann et al., 2006; Stewart-Koster et al., 2010; Phan et al., 2016). By using BBNs, it is possible to develop a probabilistic model that reflects the conceptual understanding of the system under study in the form of an influence diagram; this can then be populated with the available data from multiple sources, including empirical data and expert knowledge (Korb and Nicholson, 2004). This approach can be applied where empirical data may be lacking but where considerable expert knowledge exists in the form of traditional ecological knowledge or accumulated experience of farmers and scientists (Liedloff et al., 2013). Such knowledge can be incorporated into the model to form the network structure and the relationships it quantifies.

Developing BBNs from expert knowledge requires a systematic expert elicitation process, usually involving a series of workshops, to formalise the knowledge and experience into a suitable model (e.g. Johnson et al., 2010; Bashari et al., 2009). The goal of such a process is to extract information from experts while overcoming potential pitfalls associated with bias and subjectivity (Kuhnert et al., 2010). Such pitfalls include strong personalities dominating the process and subsequent outputs, unclear statements of the causal relationships in the system, and language barriers leading to misunderstandings between BBN developers and experts (Renooij, 2001). Failing to account for these issues can lead to the development of a BBN that does not accurately reflect the system and the experts' understanding of it, potentially leading to poorly informed decision making (Kuhnert et al., 2010).

There are many different workshop approaches to develop BBNs based on expert knowledge or opinion (e.g. Smith et al., 2005; Ticehurst et al., 2007; Johnson et al., 2010; Schmitt and Brugere, 2013). These workshops may involve various numbers of experts, though typically a small group is engaged, for example, Schmitt and Brugere (2013) relied on twelve experts to fine tune a BBN for shrimp farming in Thailand. In some cases experts may spend several days with workshop facilitators and BBN developers (e.g. Smith et al., 2005; Johnson et al., 2010), while in others such elicitation may be done over email (Kuhnert et al., 2010). The process may focus solely on developing the network structure or include the additional step of deriving the strength and nature of the relationships within the network. Importantly, several stages of validation are included to identify any miscommunications and ensure the resulting network accurately reflects the knowledge and understanding of the participating experts, which may be particularly important when language barriers are present during the process (Johnson et al., 2010; Kuhnert et al., 2010). These approaches have been very successful in developing BBNs across a range of systems, however, they require a substantial time commitment by the experts, which is something that may not always be available. These kinds of demands on experts can create a challenge for the development, implementation and uptake of the BBNs by potential end users. Additionally, making use of only a small number of experts may lead to a narrow view of a system that does not reflect the broader understanding that may exist within the given community (Kuhnert et al., 2010).

Given the potentially prohibitive time commitments required of experts for BBN development, it is clear that an expert elicitation that requires less time in any one sitting would be advantageous. We developed a staged process of BBN development to incorporate the expertise of multiple groups of experts in relatively short workshops. We applied this process to quantify key risk factors to production faced by local farmers in the Mekong Delta, Vietnam, who practice integrated rice-shrimp farming during the wet season when conditions may not be optimal for both species simultaneously. The experts consisted of local farmers and government extension officers from three neighbouring provinces, who were participating in a broader research program into the sustainability of rice-shrimp farming systems. Much of the region has been converted to rice-shrimp farming during the previous 10 years and already is facing severe risks to production, leading in some cases to crop losses, from anthropogenic and climatic factors. However, research has yet to identify key risk factors, and their potential interaction, for both rice and shrimp farming. Consequently, the process and effects of different farming practices and environmental factors need to be elucidated to guide the ongoing research.

Our process was based on the Iterative Bayesian Network Development Cycle, developed by Johnson et al. (2010), to ensure the input of each group of stakeholders was cross-validated by all others. Consequently we derived a regionally applicable and internally-validated BBN based on the expert knowledge of farmers across several provinces. The final network model provides an avenue to incorporate empirical data on processes affecting farm production that are identified as relevant to the farmers themselves. This also provides an avenue to engage farmers in ongoing research and identify key knowledge gaps among farmers that will provide the greatest opportunity for improvements to production.

2. Materials and methods

2.1. Study setting: rice-shrimp farming

Integrated rice-shrimp farming in coastal regions is an integrated agricultural system that emerged as a mechanism to derive some production from fallow rice fields during the dry season when water salinity rises with decreased freshwater flows and rainfall. Salinity also increases due to higher evaporation during the dry season. Typically, rice is sown on a platform for wet season production with a deeper ditch surrounding the platform in which shrimp may be raised simultaneously if conditions allow. During the dry season, when water salinity rises, production moves to shrimp that inhabit both the ditch and rice platform. We developed the BBN for rice-shrimp systems with farmers