JASSS

Sukaina Bharwani, Mònica Coll Besa, Richard Taylor, Michael Fischer, Tahia Devisscher and Chrislain Kenfack (2015)

Identifying Salient Drivers of Livelihood Decision-Making in the Forest Communities of Cameroon: Adding Value to Social Simulation Models

Journal of Artificial Societies and Social Simulation **18** (1) 3
<http://jasss.soc.surrey.ac.uk/18/1/3.html>

Received: 30-Oct-2013 Accepted: 01-Sep-2014 Published: 31-Jan-2015

Abstract

This paper describes a participatory and collaborative process for formalising qualitative data, using research from southeast Cameroon, how these results can provide input to an social simulation model, and what insights they can provide in better understanding decision-making in the region. Knowledge Elicitation Tools (KnETs) have been used to support a body of existing research on local strategies that build community adaptive capacity and support sustainable forest management under a range of socio-environmental and climatic stressors. The output of this approach is a set of decision rules which complements previous analysis of differentiated vulnerability of forest communities. Improvements to the KnETs methodology, such as new statistical measurements, make it easier to generate inputs for a social simulation model, such as agent attributes and heterogeneity, as well as informing which scenarios to prioritise during model development and testing. The KnETs process served as a vehicle to structure a large volume of empirical data, to identify the most salient drivers of decision-making amongst different actors, to uncover tacit knowledge and to make recommendations about which strategic interventions should be further explored in a social simulation and by local organizations planning interventions. It was notable that there were many common rule drivers for men and women from the same households, though they participated in the game-interviews separately. At the same time, though strategies were common to both poor and better-off farmers, differences lay in the package of strategies chosen – the number and type of strategies as well the drivers factors – and how they were prioritised with respect to each farmer's goal.

Keywords:
Knowledge Elicitation, Decision-Making, Climate Adaptation, Verification and Validation, Social Simulation, Tacit Knowledge

Introduction

1.1 There has been some progress in the last few years in linking qualitative and quantitative methods for agent-based modelling while maintaining a strong chain of evidence between models and their original data sources (e.g. through increased use of grounded theory, ethnographic and participatory methods for data collection, as well as the identification of context, scope and decision rules to structure narrative data). This evidence-to-model link is important so that agent-based models are transparent in their design and replicable by others (Edmonds 2014). The use of Knowledge Elicitation Tools (KnETs) (Bharwani 2006), which builds on ethnographic decision tree modelling (Gladwin 1989) discussed in this paper, seeks to improve the level of clarity in the pathway from evidence to model design, through rule-based output which crystallises important qualitative aspects of empirical evidence, using a 'game-interview'. In addition, the procedure itself reveals patterns in decision-making profiles, tacit[1] information and maintains a level of rigour similar to that of more traditional statistical approaches.

1.2 This paper describes the participatory and collaborative KnETs process for formalising qualitative data. To put the KnETs method in context, we firstly review a selection of other emerging approaches that use empirical evidence in models relating to social or environmental change, exploring how they generate and seek evidence, how this is linked to model design and how it is communicated. In the next section, we present a case study in southeast Cameroon, where the KnETs approach has been applied. A description of the methodology follows. The results are then presented, firstly in the form of raw decision trees, and then with additional layers of information added to them, through the verification and validation stages of KnETs. This includes a discussion the implications for communities inhabiting the case study region. The way in which these heuristics have served as input for the design of an agent-based model is then documented, and finally recommendations for further applications of the approach, limitations and challenges are discussed.

1.3 Geller and Moss (2013) find that formal model development currently under-represents "evidence" and discuss strategies for "evidence-driven agent-based social simulation" (EDABSS), noting, "case-studies that give concrete information of actor behaviour, in particular social circumstances, are of best use to EDABSS modellers". The authors present an approach of informed-intuitive model design, based on information from semi-structured interviews, case studies and reports. In this approach, the modeller decides what salient aspects of the observed reality must be included, but they do not establish a systematic way of linking case study or other evidence to agent rules. Polhill et al. (2010) also discuss different qualitative techniques for building empirical ABMs. The authors largely made use of qualitative interviewing for adapting an existing model to a particular application context, showing where evidence, i.e. new findings, suggested specific changes. In this way the evidence base and model design relationship is better documented and becomes more transparent to the reader.

1.4 Berman et al. (2004) use a variety of research data and local knowledge to construct model rules and model parameters, including interviews with key informants. However, it is unclear how the inputs shaped the rules (other than parameter values) or how feedback or validation of the model rules was done with community members. Saqalli et al. (2010) address data constraints by adopting a two-part approach in which villagers' interviews provide behavioural rules and criteria, while the economic, demographic and environmental context is modelled following relevant literature or other available data. The focus of the authors' effort in terms of establishing empirical accuracy is therefore on the former - the social rules. Their approach is to seek agreement among interviewees' accounts of the most important factors and incorporate these in the model. Other authors (Etienne et al. 2011; Simon & Etienne 2010) provide examples of participatory modelling or 'companion modelling' applied to forestry reserve management. Participatory modelling is an approach increasingly used for data elicitation; the process generates qualitative and quantitative information directly following a set of steps, conducted in a facilitated workshop/focus group study setting. A relative advantage here is the production of information directly useful in model development, as quite targeted questions can be asked about relevant interactions, trends and dynamics while the conceptual model is co-created and can evolve and be further adapted in the process. Companion modelling has applied role-playing games to elicit behavioural rules for a multi-agent simulation (e.g. Barreteau et al. 2014; Gurung et al. 2006; Simon and Etienne 2010) to share problem perspectives and understanding and to construct a social learning process amongst multiple actors. A difficulty, however, could be identifying a suitable set of participants that are representative of different views about the system to be modelled and committed to participate in the iterative process and establishing consensus among them about resulting rules.

1.5 Edmonds (2014) introduces a structure for integrating narrative data into agent-based models. Using this approach, it is argued that the chain of analysis can be followed and understood more easily. The three aspects include *context, scope* and *narrative elements*. *Context* refers to how humans recognise a situation and activate the required knowledge and behaviours, while *scope* refers to the corresponding pertinent constraints (concerning what is possible in the context). *Narrative elements* are introduced as "everyday kind of reasoning that people use to reason about action" for example cause-effect pairs, decision points, sequences, alternatives and so on.

1.6 While there are a number of innovations in this area, it remains challenging to include evidence in models using structured approaches (following a series of steps), rigorous and replicable procedures and good documentation practices. There are also additional challenges related to subjective bias, representation of 'meaning', accessibility of tacit information, transparency in the chain of evidence, predictability and consistent methods of verification and validation of knowledge elicited.

Methodology

Case study

2.1 This research builds upon a case study in the Congo Basin, which is part of the 'Climate Change and Forests in the Congo Basin: Synergies between Adaptation and Mitigation' (COBAM)[2] project on forest-based strategies that promote equitable impacts and co-benefits for both local communities and forests. In addition to reducing the vulnerability of communities in the region, an objective of the project is to study the governance of forest areas to promote sustainable use of forest resources and reduce the likelihood of deforestation and forest degradation, and thus carbon emissions. On this basis, this project aims to find strategies that could be synergistic in reducing social vulnerability while generating co-benefits for climate mitigation, which should include poverty reduction, enhancement of carbon and non-carbon ecosystem services and protection of local livelihoods and rights.

2.2 There are twelve priority landscapes in the Congo Basin where the Central African Forests Commission (COMIFAC) coordinates conservation work. The COBAM project conducted work in 5 of these landscapes, most of which are transboundary, ranging from low population density and high forest cover to high population density and low forest cover. The case study in this paper focuses on one of these landscapes located in the Tri-National de la Sangha (TNS) in the southeast of Cameroon (Figure 1). This includes three national parks: Lobéké (Cameroon), Nouabalé-Ndoki (Republic of Congo) and Dzanga-Ndoki (Central African

Republic), covering 4,520,000ha in total. The areas surrounding the national parks, approximately 3,751,800ha in total, have multiple uses including logging concessions given by the government to commercial companies, professional hunting areas and community forests units[3] (Usongo & Nzooh 2008). Research in COBAM has been conducted in several villages along the Yokadouma-MboyII axis road close to the border of the Central Africa Republic (Figure 1).

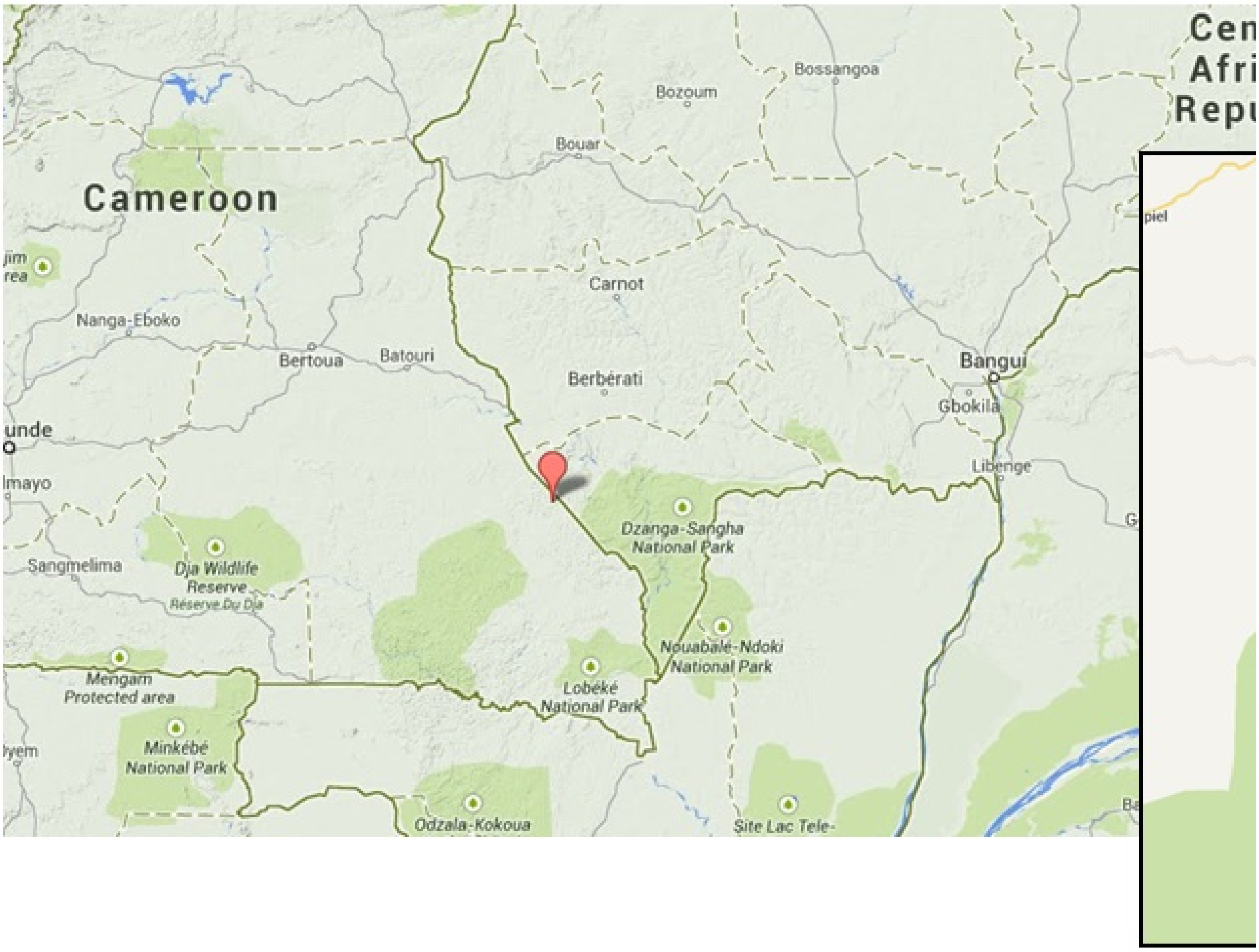

Figure 1. Yokadouma-Mbo

2.3 Since 2010 research in the COBAM project has applied a participatory approach to explore differentiated vulnerability, focusing on past trends and disturbances as well as current conditions, institutional analysis, social capital, and coping strategies resulting in a baseline vulnerability assessment (Devisscher et al. 2013, Butterfield et al. 2014). This analysis was informed and complemented by semi-structured interviews and household surveys exploring socio-environmental histories and climatic vulnerability, coping mechanisms and forest governance (Gross-Camp et al. 2014). Following this baseline assessment, Knowledge Elicitation Tools (KnETs) (Bharwani 2006) were used to explore the future vulnerability of the area and possible options for adapting to a range of potential future socio-economic and climate scenarios that may support both forest conservation and community adaptation.

2.4 In the COBAM study of the TNS landscape, the KnETs approach identified salient drivers of decision-making, differentiated by actor type (men and women from poor and better off households) as well as 'pro-poor' adaptation interventions by identifying key aspects of the empirical data collected. These were then translated to the design of a social simulation model, which will further explore the long-term impacts of these interventions on the adaptive capacity of the community and the sustainability of forests in the region.

The KnETs approach: design and application

Application of the KnETs process

2.5 KnETs is a bottom-up 'mixed-method' approach[4] developed by anthropologists and computer scientists to explore current and future decision processes guided by the 'world-view' of informants and an ethnographic and participatory 'game-interview' process. In the past, researchers have combined KnETs with social simulations to understand how decision-making outcomes are influenced by seasonal forecast information (Bharwani et al. 2005) or as a 'matching method' to the water demand WEAP model (Kemp-Benedict et al. 2010) to create a more 'holistic', systematic and transparent formalisation and linking of qualitative evidence to more quantitative models. In other 'mixed method' approaches, Forrester et al. (2014) have combined simulation modelling and 'cartoon' conceptual modelling to avail different stakeholders of the benefits of different approaches.

2.6 An initial phase of participatory field research (stages 1 and 2 in Figure 2) is critical when applying the KnETs process as this allows the identification of domains of interest, drivers of, decision making or obstacles to implementing local strategies, resulting in a context-specific 'game'. These phases were satisfied through the participatory vulnerability assessment, semi-structured interviews, socio-environmental histories and household surveys conducted in the COBAM project. Stage 3 in Figure 2 involved a form of semi-structured discussions with individuals, where scenarios were generated by the KnETs game, to understand livelihood choices and responses in a range of situations. The game was not presented directly to informants - scenarios created were posed, by the researcher, as a series of interview questions, resulting in a semi-structured interview process - the 'game-interview'. A large volume of data was generated by exploring each possible scenario in the game-interview, with approximately 75 iterations on average, allowing a rich discussion and the early identification of salient factors in the decision-making process.

2.7 A classification algorithm, using open-source software, Weka (University of Waikato 2008), was then applied to the resulting dataset to potentially reveal complex relationships between dependent and explanatory variables in the game (stage 4 in Figure 2). This algorithm provided information on patterns or potential rules within the responses and how many responses could be correctly classified using these rules. In other words, the process of eliciting knowledge using a 'game' tailored to the local context (stage 2) allowed the transformation of qualitative information to a formalised set of decision rules with weights assigned to them, to reflect how often each rule was satisfied during interviews.

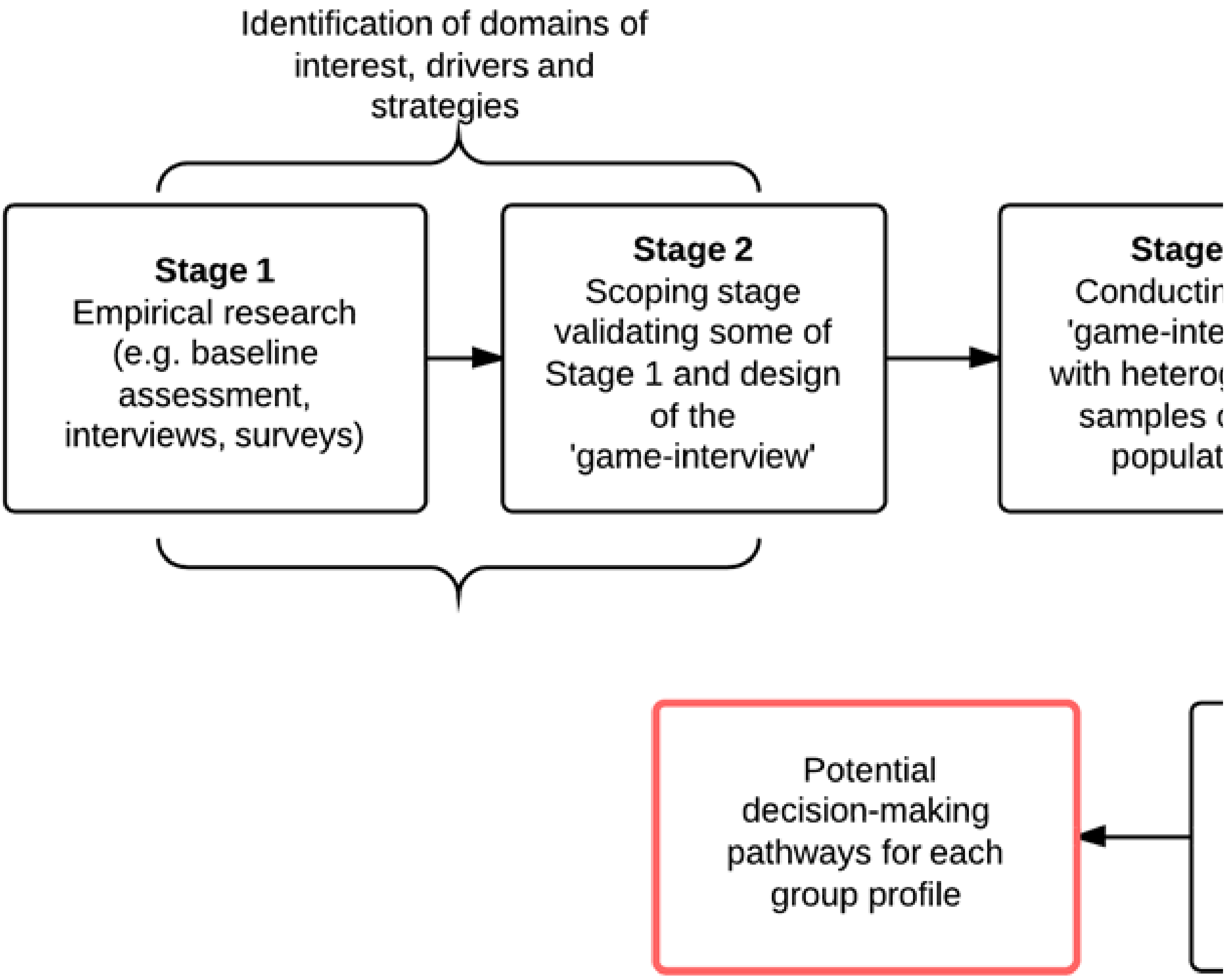

Figure 2. Stages in the knowledge elicitatio

2.8 Such patterns in the data result in classification trees that were verified (stage 5) through further discussion with key informants who participated in the 'game-interview' to check for errors, gaps and any tacit knowledge that may not have been mentioned earlier. This can lead to a revised game design or set of decision rules, which better captures important decision factors. Transparency is increased by the 'verification' stage, which allows participants to reflect on and refine the output of the game-interview and provide feedback, clarifications and justification regarding goals and strategies chosen.

2.9 The decision rules were then validated (stage 6 in Figure 2) i.e. the results were checked with key informants who were not part of the 'game-interview' process. In this study, this was achieved with informants within the same village and those from a different village, neither of whom participated in the original game-interview process.e Participatory verification and validation were key to this bottom-up exploration of decision-making, as an insightful dialogue often emerged revealing new and sometimes tacit information. Additional statistical data available in the most recent version of KnETs provided the degree of error in the classifications created from the respondent (or 'training') data, going beyond previous applications of KnETs. This also facilitated an analysis of decision-making across heterogeneous groups (see Section 3), complementing existing processes of verification and validation and the identification of the *more efficient models* of decision 'pathways' for particular group 'profiles' from a wide range of models, that will arrive at the same conclusions.

Stage 1 and 2: Incorporating empirical data and design of the 'game'

2.10 In relation to the drivers affecting decision-making and strategies employed to mitigate negative impacts, multiple lines of evidence using previous research (Devisscher et al. 2013; Butterfield et al. 2014 ; Gross-camp et al. 2014) and additional 'scoping interviews' informed the design of the game-interview. Information included the cropping choices and supplementary coping and adaptation strategies of community members, which vary in the degree to which they provide co-benefits for the adaptive capacity of local communities and for the conservation of forest resources – in other words, for climate change adaptation and mitigation respectively. Crops that provide differential co-benefits are shown in Table 1, using the perennial crop, cocoa, and annual subsistence crop, maize, as an example.

Table 1: Comparison of the adaptation and mitigation co-benefits provided by cocoa and maize crops

Crop choice	Scale	Benefits to adaptation	Benefits to mitigation
Cocoa (perennial)	Cash crop, large scale	Good income generation over medium time frame (++)	Requires shade therefore forest cover is kept to a certain extent[5](+)
Maize (annual)	Subsistence crop, small scale	Can provide supplementary income and food for household consumption but short-term (+)	Requires clearing for sunlight (-)

2.11 Luke et al. (2011) explain that cocoa cultivation maintains a higher proportion of shade trees in a diverse structure (cocoa agroforestry) and has been viewed as a sustainable land-use practice that meets social, ecological, biological and economic objectives due to the multiple products and services available from shaded polyculture systems. This means that the cocoa crop will encourage forest cover to be preserved as opposed to subsistence crops, such as maize or cassava, which would generally require more sunlight and therefore some clearing of trees. Cocoa is a "cash crop" grown by local farmers in the TNS landscape to generate an income. When integrated as part of a livelihood strategy that is not overly reliant on annual subsistence crops or NTFP collection, it can reduce household vulnerability during years when crop yields are low, if income can be saved from one season to the next. Therefore, the example in Table 1 is indicative, albeit at a simplistic level, of the differing levels of co-benefits for adaptation and mitigation from different crops.

2.12 As a result, the KnETs game design incorporated a combination of crop choices and coping (short-term) or adaptation (more long-term) strategies that are favourable for forest conservation (some crops can be grown 'within' the forest, while some require clearing of the forest) and livelihoods improvement (in terms of food security, livelihood diversification, building the assets base and improving household well-being). These are based on empirical research (Table 2).

Table 2: Crop goals and coping and adaptation included in the game design.

Goals			**Strategies**
Main crop	**Other crops**	**Non-timber forest products (NTFPs)**	**Coping and adaptation**
Cocoa	Plantain	Mempa	Collect mushrooms/wild honey
Cassava	Macabo	Njanssang, Koko, Djembe and Bush Mango *(usually mentioned together)*	Grow vegetables
Plantain	Palm oil tree	Kola	Intensify agricultural production (new seeds, fertilisers/pesticides, improved practises)
Macabo	Cassava, groundnuts and maize	Talala	Make local alcohol
Coffee	Sugarcane	Assa'a	Exchange goods/money
Palm oil tree	Pineapple	Do'gote	Artisanal mining
Maize	Potatoes		Collect caterpillars/snails

Groundnut	Beans	Hunt/fish
NTFP trees	Melon	Pisciculture / aquaculture
New seed variety	Chilli	Livestock keeping
Other	Plant NTFP Trees	
	Plant fruit trees	

2.13 The baseline vulnerability assessment (Devisscher et al. 2013) identified important drivers of decision-making, which could be grouped into climatic, economic, institutional, social, environmental and technical elements. In the climatic domain, these included changing onset, intensity and distribution of rainfall, prolonged dry periods and increasing wind, all factors that affect yields or damage crops. In the economic and institutional domain, while there were many factors that could be considered, the most salient for livelihood options in this context were access to urban markets, whether any benefit was perceived from the formalised community forest management units and investment in storage, or access to tools for agriculture. Social, environmental and technical drivers included increasing access to labour and land, increasing distances to non-timber forest products (NTFPs), availability of training on agro-forestry techniques, reduced land fertility and increased flooding. Other important factors were population growth (due to in-migration from neighbouring Central African Republic and Republic of Congo), availability of forest cover and levels of illness within the household, as the incidence of malaria and other diseases in rural areas is high (Gross-Camp et al. 2014).

2.14 The drivers of decision-making were revisited during a KnETs 'scoping phase' to inform the design of the game in May 2013, and as a result, 11 variables were included as key drivers in the final game design (Table 3). Clearly, there are issues of subjective bias when choosing what to include and exclude in the game design. However, regardless of the variables that might be selected, the goals for which crop to use as the main crop will largely remain the same, particularly within areas with similar circumstances. So although the rules will be different if the variables are different, as long as the variables fairly partition the broad categories used (climatic, economic/technical, socio- environmental here) the quality of the results should be similar (see Section 3 for further discussion).

Table 3: Drivers of decision-making included in the game design.

Climate	Economic/Technical	Socio-environmental
Longer rainy season and more wind every year	More access to urban markets (e.g. through buyers)	More labour available
Increasing dry spells in small wet season and more wind	Collective management of forest	Not enough land
Longer dry season and more wind every year	Storage, product processing and collective associations available	Training on agro-forestry and soil water conservation techniques
	Appropriate tools for agriculture or artisanal mining available	Distance to NTFP is increasing

2.15 The variables deemed to be salient for decision-making in the TNS context (Table 3) were translated to the game-interview interface (Figure 3). This allowed the *interaction* of the range of salient drivers (a *scenario*, including threats and opportunities) that shape particular decisions to be simultaneously examined. This then required informants to respond to the scenario by selecting a plausible set of livelihood goals and coping/adaptation strategies (Table 2) also translated to the game-interview interface (Figure 3). This was repeated for multiple scenarios and with several informants.

Stage 3: Conducting the game-interview

2.16 Interview sampling involved stratifying the population from one of the villages where the baseline vulnerability assessment and surveys were carried out. This was done according to socio-economic profile while also considering gender-differentiated decision-making. Group-wise comparison was done between 'very poor' and 'better-off' households to maximise the possibility of identifying different strategies and, in addition, men and women from the same household were sampled but were interviewed separately. The sample was split into a 'training set' and a 'testing set', thus verification and validation was also conducted with each group respectively while an additional level of validation was conducted in a separate village.

2.17 A total of 18 men (9 from poor households and 9 from better-off households) and 12 women (6 from the same poor households and 6 from the same better-off households) participated in the 'game-interviews'. Although this is a relatively small sample, it builds upon the broader scale research conducted in the same case study village and surrounding villages (Devisscher et al. 2013; Butterfield et al. 2014; Gross-Camp et al. 2014). Each 'game-interview', though conducted individually (requiring a 2-3 hour interview with each respondent of approximately 75 scenarios), was analysed as a set of cumulative results e.g. for the group of 'very poor female farmers' or 'better off female farmers', and thus produced between 450–650 scenarios for each group.

2.18 The game-interview (Figure 3), is a tool used by the researcher to structure the 'game-interview' questions based on the scenarios produced, and record respondents' answers. When playing the game, the informant chooses the option s/he would undertake given the scenario of three drivers proposed. S/he also chooses any strategies that would be necessary to support this choice under the given set of drivers/conditions. This is repeated many times to cover all possible scenarios.

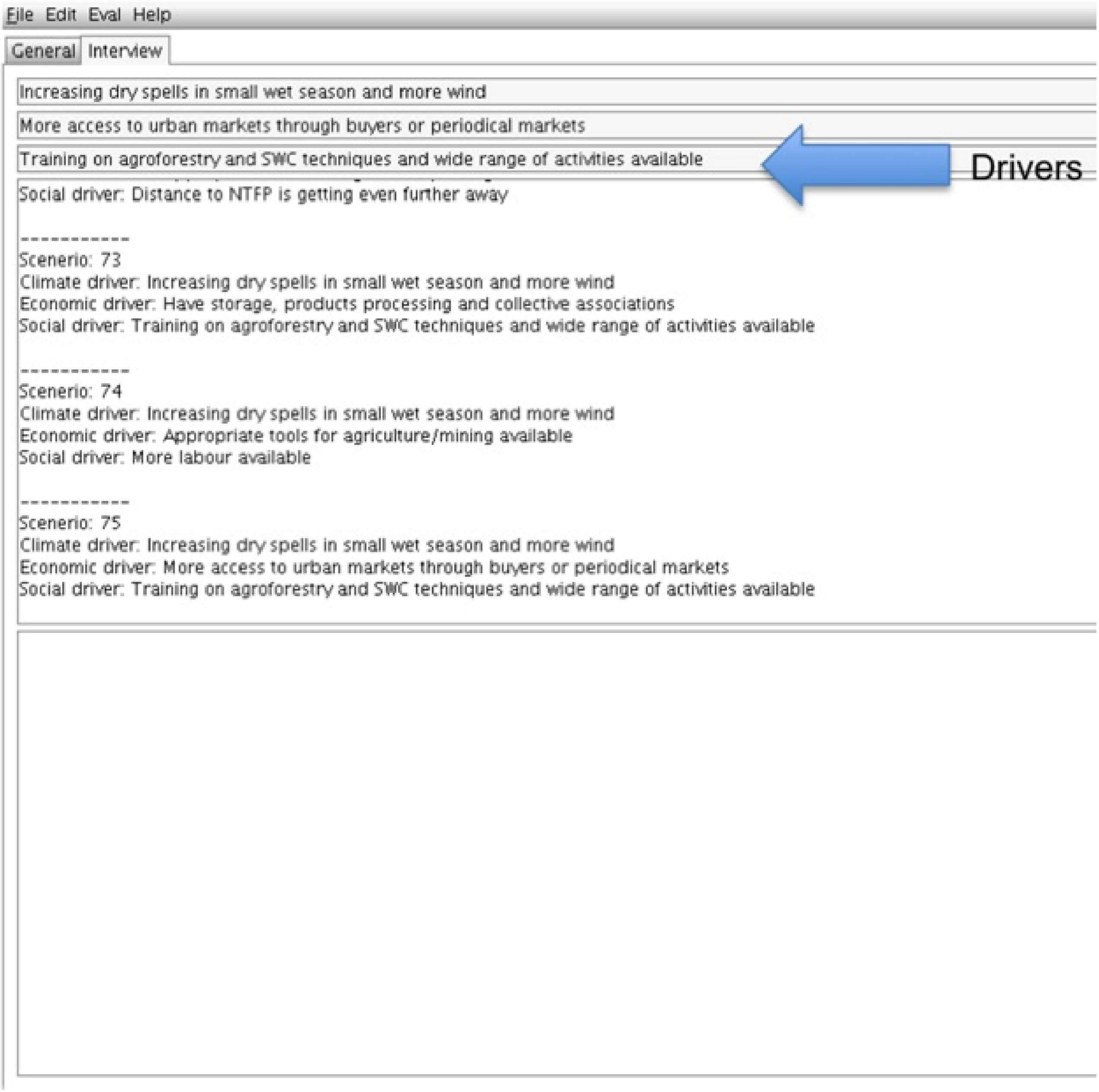

Figure 3. KnETs game: the basis of the 'game-interviews' with fore

Stage 4: Application of the classification algorithm and rule creation

2.19 The large set of responses that are recorded can result in patterns and these are identified in KnETs using the J48 classification algorithm, which is a public domain implementation of the C4.5 algorithm (Quinlan 1993), using open-source software, Weka (University of Waikato 2008). The basic algorithm recursively splits the data into two groups based on each candidate attribute and measures the information gain for each. The attribute that maximizes the normalized information gain for the data being classified is chosen and each segment is then subjected to the same procedure recursively until every outcome is classified by having a unique sequence of classifiers that precede it (a classifier string), progressively generating J48 decision trees[6]. It is common that a given outcome, say cocoa cultivation, will be classified by more than one unique string of classifiers. This simply indicates that a string of classifiers is sufficient to classify some of a given outcome, but not necessary for classification of that outcome. Other classifier strings may also be sufficient and classify some of the remaining cases of an outcome. Only if an outcome is classified by a single unique classifier string, can we conclude the classifiers in the string is both sufficient and necessary. The relationship of the final set of classifier strings can be represented as a decision tree. The J48 algorithm also generates a confusion matrix, which indicates the number of cases for each outcome where a classifier string selected the correct and incorrect goals.

2.20 The hierarchical sequence of classifier strings are presented as decision rules/heuristics and, after further processing and analysis, can be areas for further exploration with informants during the verification and validation stages (stage 5 and 6). Therefore, the output of the KnETs process is a set of classification trees (stage 5 and 6 in Figure 4), which are produced after a minimum of 10 iterations with one individual.

```
If Intensify agr. prod. (seeds, fert/pest, improved practices) eq p then New seed variety +11 -0
When: Intensify agr. prod. (seeds, fert/pest, improved practices) eq na and
 When: Cocoa (add crop) eq p and
  If Livestock Keeping eq p then Plant NTFP Trees +3 -0
  When: Livestock Keeping eq na and
   If Chilli (add crop) eq p then Plant Cassava +4 -/1
   When: Chilli (add crop) eq na and
    When: Hunt/fish eq p and
     If Climate driver eq Longer rainy season and more wind every year then Plant NTFP Trees +2 -/1
     If Climate driver eq Increasing dry spells in small wet season and more wind then Plant Cassava +4 -/1
    When: Hunt/fish eq na and
     When: Do artisanal mining eq p and
      If Economic driver eq Appropriate tools for agriculture/mining available then Plant Cassava +2 -0
      If Economic driver eq na then Other +2 -0
     If Do artisanal mining eq na then Other +15 -0
 When: Cocoa (add crop) eq na and
  If Chilli (add crop) eq p then Plant Cocoa +8 -/1
  When: Chilli (add crop) eq na and
   If Social driver eq More labour available then Plant Cocoa +1 -0
   If Social driver eq Not enough land for agriculture then Plant Cocoa +2 -/1
   If Social driver eq Distance to NTFP is getting even further away then Plant NTFP Trees +4 -0
   When: Social driver eq na and
    When: Economic driver eq More access to urban markets through buyers or periodical markets and
     If Climate driver eq Increasing dry spells in small wet season and more wind then Plant Cassava +2 -0
     If Climate driver eq Dry spells getting longer and more wind every year then Plant Cocoa +2 -0
    If Economic driver eq Have storage, products processing and collective associations then Plant Maize +1 -0
    If Economic driver eq na then Plant Cassava +10 -0
```

Figure 4. Screenshot of rule-based classification of game-interview responses using the J48 algorithm.

2.21 Translating raw classification trees (Figure 4) into a set of meaningful rules that can be verified and validated with informants requires further annotation and analysis. There is a common error in creating decision rules which look very simple and appear to classify the decisions of informants to a very high degree of accuracy because they are often based on very general criteria and not on what informants claim *their* decision criteria to be, i.e. the actual logical processes that are taking place are not being captured (Gladwin 1989). This means that the verification process is important to refine decision trees with more specific criteria and some re-ordering may be required, e.g. 'enabling' criteria should appear in positions that are logical to the context of the informant, criteria that belong in logically prior or later decision trees should be eliminated while, in some cases, redundancy can be removed by generalising criteria (Gladwin 1989).

Stages 5 and 6: Verification and validation of decision rules

2.22 Identifying gaps or inconsistencies in the annotated classification trees is the goal of the verification and validation stages of the KnETs methodology. Verification can, however, also happen as the 'game-interview' proceeds and this information can be added to the decision trees that are generated. It is also important to review information from the interview discussions to help explain any artefacts (e.g. possible misunderstandings) in the decision trees.

2.23 Verification can occur using a similar semi-structured interview process as used in the game-interview, but using the rule results as hypothetical 'if-then' scenarios, rather than the game-interview scenarios. This allows gaps to be addressed, new information to be added or errors corrected in the decision trees. In the TNS, verification was done both during the game-interview and during follow-up focus group discussions as opposed to individual interviews.

2.24 The classification trees produced from the output of the game-interview were validated through further interviews with members from the same community (the 'testing set') and with those from a different community, both of whom were not involved in the game-interview or its design. This enabled an assessment of whether the refined decision heuristics were applicable beyond the 'training group' and representative of possible decision pathways of other farmers of a similar profile in the village and surrounding area. Here, once again, participants inspected the decision trees produced in stage 4 in a semi-structured interview process, where the researcher used the rule results ('if-then' statements) as scenarios to edit, refine, correct or add information.

Linking to a social simulation

2.25 If the resulting decision rules are coded in a social simulation, there can be a clear link to the data collected in the KnETs 'game-interview' which itself can be traced back to multiple sources of empirical evidence e.g. the baseline vulnerability assessment, socio-environmental histories, surveys, etc. This provides transparency to others inspecting social simulation model design, enabling an understanding of how key decision processes have been represented, and where the evidence for different aspects of the model originates. Since entities in a social simulation are often conceptualised as the decision-making actors in a social system, important aspects of the modelling can be clarified; moreover model outputs provide another layer of validation to allow feedback by actors as well as other experts.

2.26 A social simulation model can add value as it can be used to examine the interaction of variables over time and to test the sensitivity of the system to each variable to support or negate conclusions derived from the KnETs output. In this way a social simulation can help explore synergies or co-benefits between adaptation and mitigation strategies by simulating different scenarios over the long-term using the evidence-based rules generated by KnETs. For instance, a social simulation could explore how far into the future co-benefits would be retained in a shaded polyculture system, despite other factors such as market prices, availability of inputs and future climate change. The mitigation potential of growing cocoa may be compromised if agricultural fields are consistently expanded over time to compensate for low yields resulting from drought - an observation made during the baseline vulnerability assessment (Devisscher et al. 2013), the KnETs process, and other studies (e.g. Luke et al. 2011). As an added complexity, some 'improved' varieties of cocoa require less shade (Ruf et al. 2006), or are more dependent on good soil management practices, all of which could impact the previously assumed potential co-benefits of cocoa agroforestry systems. The complex interaction of these and other factors at different temporal and spatial scales could be explored in a social simulation model.

Results

3.1 The results described below represent a selected set of decisions heuristics from the extensive KnETs data produced. Our initial assumption was that communities in this region do the same things under most conditions, because they have few alternatives and thus are not likely to invoke frequent changes in their decision-making behaviour or to do things that are dissimilar to each other. However, the results from the 'game-interviews' indicated that different groups were in fact purposefully responding to different drivers, in subtle ways. Furthermore, while the detailed information about decision making drivers collected during the baseline assessment was reduced to a more limited set of 11 drivers (Table 3), the final results from the 'game-interviews' suggest that even fewer drivers were salient to decision-making, as noted by others e.g. Murtaugh and Gladwin (1980). Finally, as expected, results showed variation between male and female decisions, but more importantly consistency in the drivers influencing their decisions. That is, drivers influencing women were the same as those affecting men, though they participated in the game-interviews separately and their goals were different to men. The goals of men from poor and better off households were different, but most goals of women were common as they perform the same particular activities e.g. growing subsistence-oriented crops or collecting NTFP), though their driving factors were different, hence there were also consistent differences between poorer and better-off households overall (men and women). However, in at least one case, at the individual strategy level there was a significant different between women from poor and better off households, which was only evident through the application of the rule induction algorithm (see Section 3.20 for more details).

Number of strategies - level of livelihood diversification

3.2 Both poor and better-off farmers appeared to have similar responses to different scenarios during the game-interview process. The results, however, once subjected to the rule induction algorithm, illustrated that differences did in fact exist in the package of strategies chosen – the number and type of strategies as well in the driving factors. While in reality, all farmers diversify their strategies to spread risk, the game-interview results showed that there were clearly many more dependent adaptation strategies chosen by poorer male and female farmers than by better off farmers. The latter were more 'cash-crop' oriented generally, and while many strategies were chosen, the main cash crop, cocoa, was not dependent on any of those strategies or drivers to grow it, aside from the climate driver. Therefore, very few conditions were required in the decision trees of better off farmers to achieve their main activity, cocoa farming (Figure 5). Poorer farmers did have a greater variety of crops as their 'main' goal and therefore they were also dependent on more corresponding strategies to meet these goals.

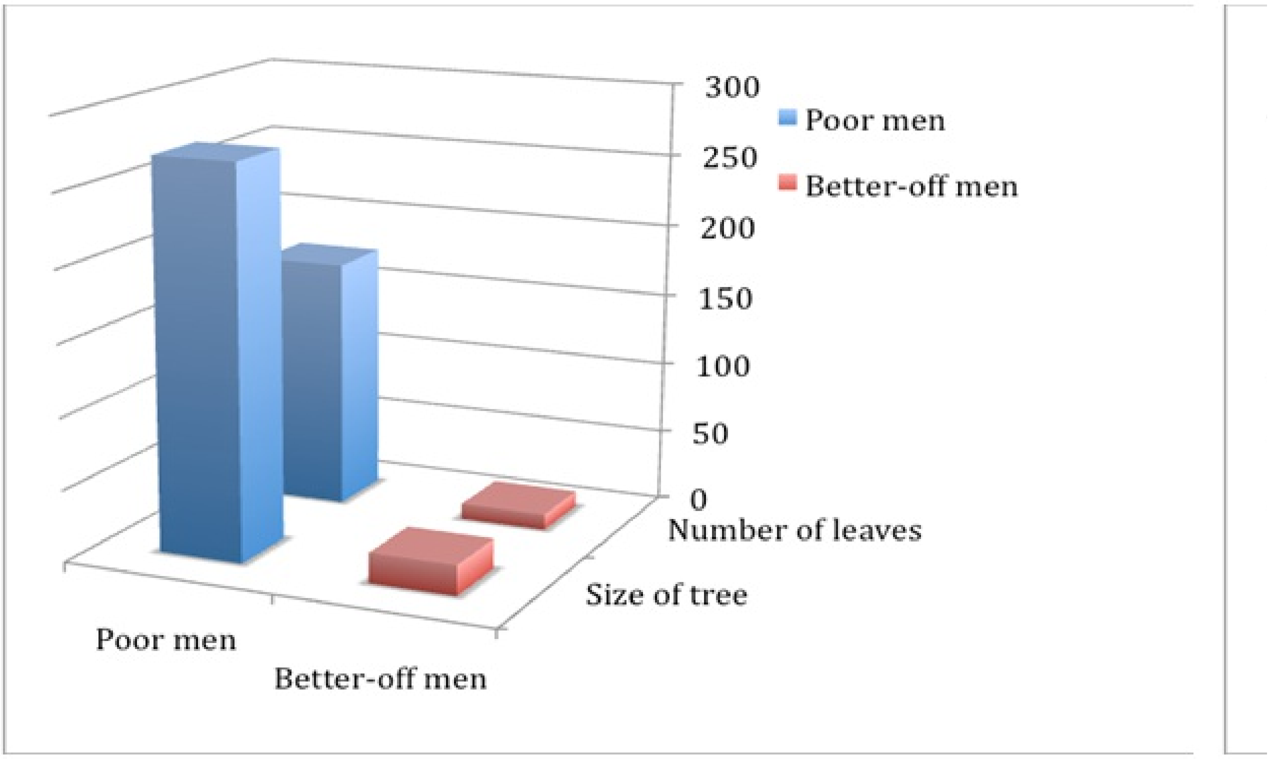

Figure 5. Comparison between size of trees (number of strategies) and numbe

3.3 Thus, although better-off households may invoke many strategies to spread risk, the game-interview results indicated that growing cocoa was not dependent on many other accompanying strategies, and furthermore, the only real driver that affected it was climate (Figure 6), due to its potential negative impact on yield. Better off farmers can sustain losses created by most other factors, but would most like to avoid climate related losses, as these would be largest direct effect on their income. Therefore, climate-related drivers were the only 'patterns' identified as 'rules' *per se*. Plantain grows well alongside cocoa, and so this was also chosen sometimes and was therefore reflected as condition in some rules[7].

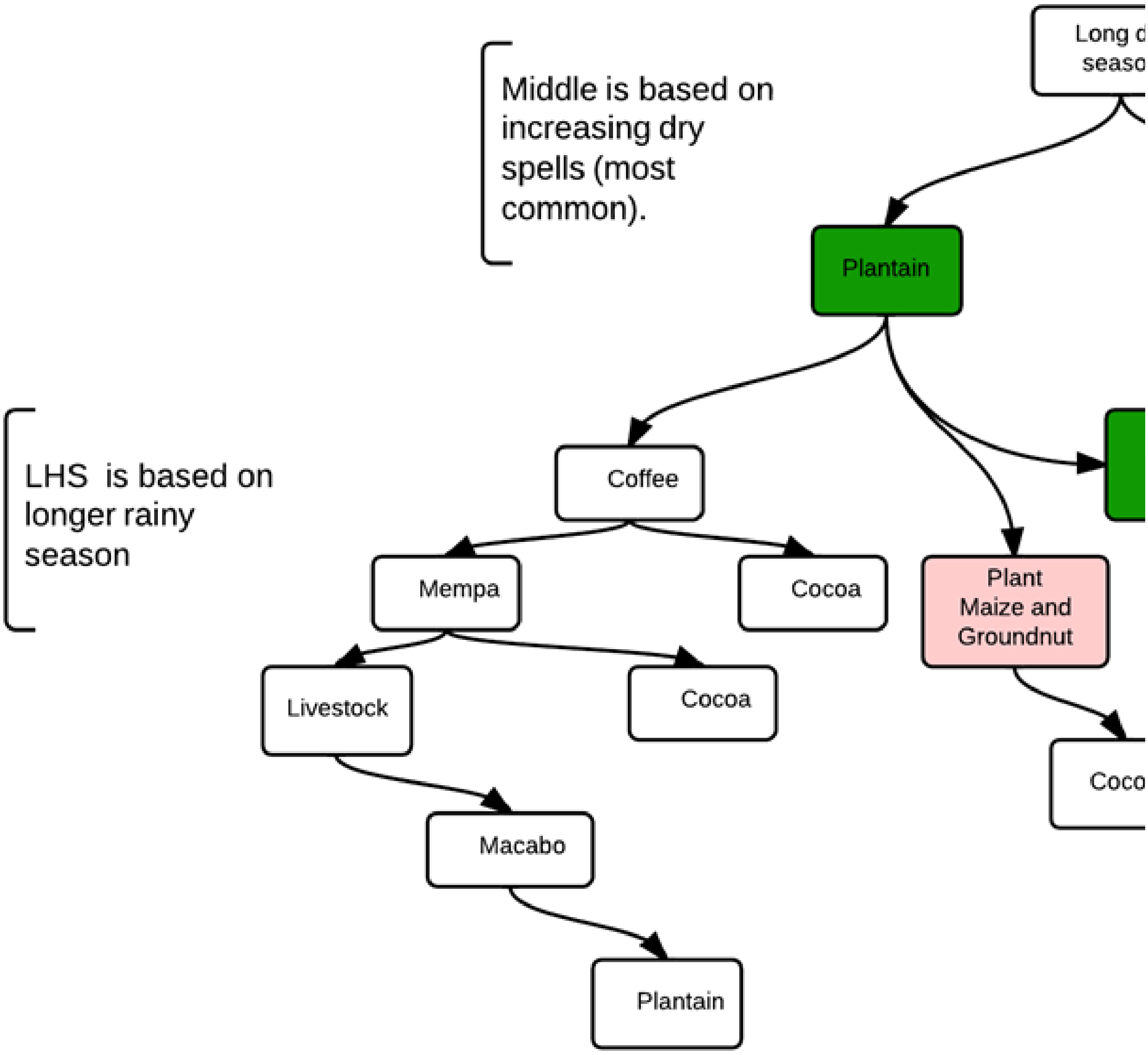

Figure 6. Comparatively less complexity in better-
Green = currently observed conditio
Pink = female choices only included if based on

3.4 In contrast, analysis revealed that poorer farmers try and do everything in terms of 'goals', making them dependent on more drivers and strategies, as they are concerned with generating a minimum level of subsistence through both cash and subsistence crops. As there were significant patterns connecting drivers to strategies and choices they made, the responses of poor households did generate more decision-making 'rules' - a greater number of 'main' crop goals, meant they were dependent on a larger number of conditions to satisfy them. A decision tree showing the classification for poor male households is shown in Figure 7, which is more complex than that of better-off men, which mainly denotes climate drivers (Figure 6), though, as mentioned, many strategies were chosen during the game-interviews. These strategies however, do not affect the likelihood of planting cocoa.

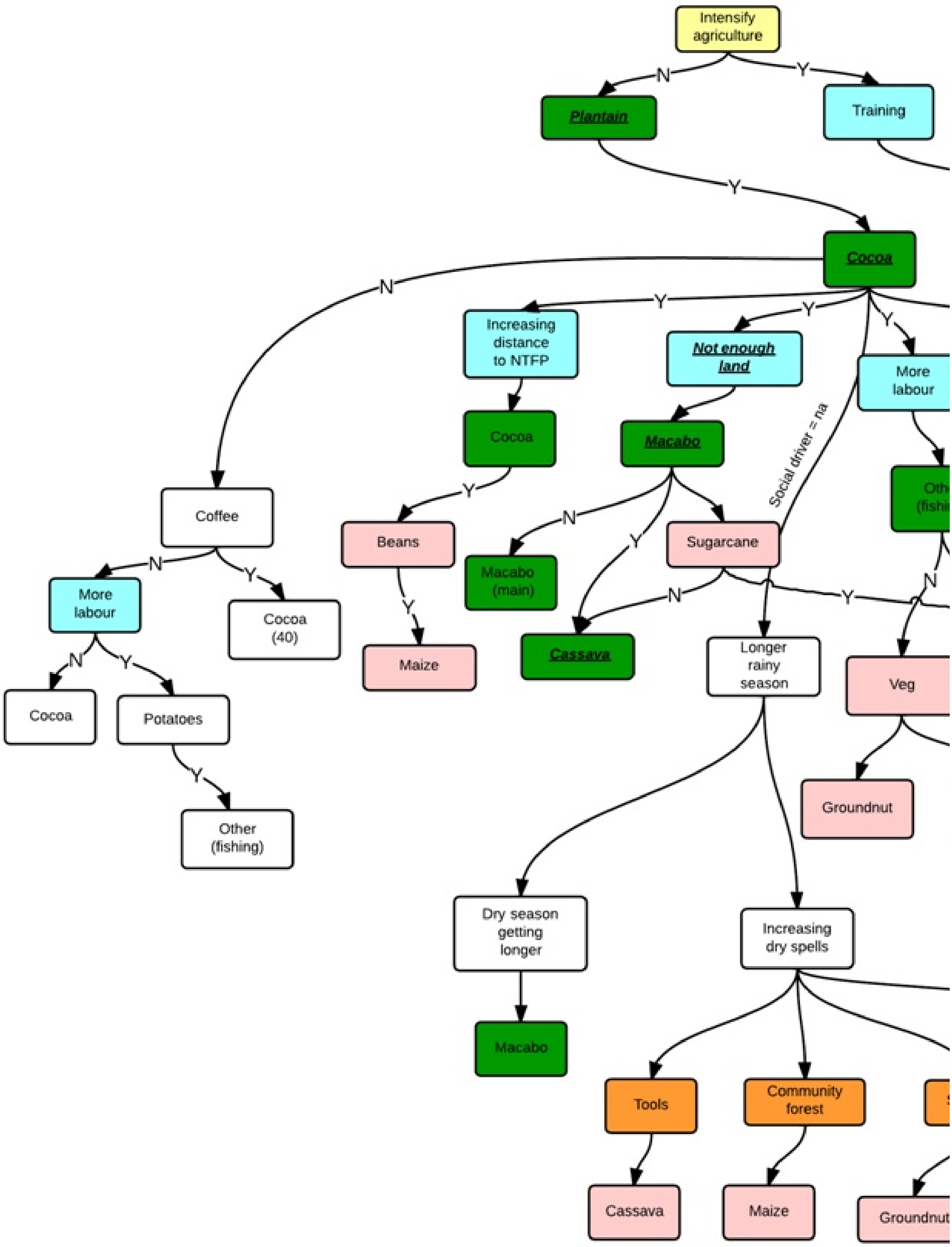

Figure 7. Complexity of poor household decision-making prior to verification.
Green = currently observed conditions and decisions
Pink = female choices only included if based on same drivers as male choices
Blue = socio-environmental drivers
Orange = economic/technical drivers
Yellow = future choices (based on training opportunities).

3.5 It is important to note that there were many common drivers for poor men and poor women, allowing their decision trees to be combined, though they participated in the game-interviews separately. Similarly as noted, in better-off households, the only driver of any generated rules was climate-related and it is significant that this was the case for **both** better-off men and women[8].

3.6 Follow-up discussions and analysis of game-interview data revealed that a clear driver for poor farmers was their perception of a *lack of existing land,* which was often linked to several goals and strategies by **both** men and women (Figure 7). Should *more labour* be available (Figure 9), this would result in a desire to '*expand*' their cocoa fields for their children's inheritance, but also to compensate for the quantity and quality of harvest produced per season due to climate-related impacts (e.g. increased number of dry spells during the rainy season), soil infertility and resulting food insecurity (Devisscher et al. 2013).

3.7 The opportunity to intensify farming techniques through *training* on better agro-forestry and soil water conservation techniques was also a salient driver for poorer households. The *distance to collect NTFPs* was cited as an influential factor as was *access to storage and to labour*. Hunting is also more prominent among the poor households than the better off, as the latter would buy/exchange their meat with the poorer households. Both household types would only consider artisanal mining under conditions that were completely unfavourable for agricultural production (e.g. long dry season), which was their first priority. Mining is perceived as a very difficult task, providing only short-term income at the beginning of the season and using time that could be more valuably used for agriculture. Poor households do consider it as a last resort and where better off households mention it (e.g. Figure 6), they would normally employ poor households to carry it out.

3.8 In short, for better-off farmers all options are choices that can be exercised, and when possible they chose cocoa, and only then considered alternatives (Table 4). Poorer farmers choices were more dependent on relationships between crops, response to market considerations and ensuring a considerable amount of effort (and land) was invested in subsistence crops. While the rule induction algorithm was invaluable in identifying hidden patterns in the data, this observation was only possible due to the participatory part of the process. i.e. better off farmers were observed to be making a large selection of choices while playing the game, though only small rule set emerged in the results - they had a priority activity and that choice was not limited by many other factors.

Table 4: Confusion matrices for main crop choice by different households [9].

Household type	Main crop choices

Poor females

=== Confusion Matrix ===

a	b	c	d	e	f	g	h	i	j	k	l	<-- classified as
0	0	0	0	0	0	0	0	0	0	0	0	a = na
0	0	0	0	0	0	0	0	0	0	0	0	b = Plant Cocoa
0	0	178	3	4	0	0	1	4	0	0	0	c = Plant Cassava
0	0	6	79	2	0	0	0	0	0	0	0	d = Plant Plantain
0	0	4	1	36	0	0	0	0	0	0	0	e = Plant Macabo
0	0	0	0	0	0	0	0	0	0	0	0	f = Plant Coffee
0	0	0	0	0	0	0	0	0	0	0	0	g = Plant Palm oil tree
0	0	3	2	2	0	0	39	0	0	0	0	h = Plant Maize
0	0	5	0	5	0	0	1	46	0	0	0	i = Plant Groundnut
0	0	0	0	2	0	0	0	2	15	0	0	j = Plant NTFP Trees
0	0	0	0	0	0	0	0	0	0	0	0	k = New seed variety
0	0	0	0	0	0	0	0	0	0	0	3	l = Other

Better-off female households

=== Confusion Matrix ===

a	b	c	d	e	f	g	h	i	j	k	l	<-- classified as
0	0	0	0	0	0	0	0	0	0	0	0	a = na
0	0	1	0	0	0	0	0	0	0	0	0	b = Plant Cocoa
0	0	271	1	0	0	0	15	0	0	0	0	c = Plant Cassava
0	0	4	20	0	0	0	0	0	0	0	0	d = Plant Plantain
0	0	1	0	0	0	0	0	0	0	0	0	e = Plant Macabo
0	0	0	0	0	0	0	0	0	0	0	0	f = Plant Coffee
0	0	2	0	0	0	0	0	0	0	0	0	g = Plant Palm oil tree
0	0	19	2	0	0	0	105	0	0	0	0	h = Plant Maize
0	0	0	0	0	0	0	0	0	0	0	0	i = Plant Groundnut
0	0	0	0	0	0	0	0	0	0	0	0	j = Plant NTFP Trees
0	0	0	0	0	0	0	0	0	0	0	0	k = New seed variety
0	0	4	1	0	0	0	0	0	0	0	0	l = Other

Poor male households

=== Confusion Matrix ===

a	b	c	d	e	f	g	h	i	j	k	l	<-- classified as
0	0	0	0	0	0	0	0	0	0	0	0	a = na
0	90	0	0	0	0	2	1	0	1	1	0	b = Plant Cocoa
0	2	49	0	0	0	0	0	0	0	0	1	c = Plant Cassava
0	2	0	52	0	0	0	1	0	1	0	0	d = Plant Plantain
0	0	0	0	32	0	0	1	0	0	0	0	e = Plant Macabo
0	2	0	0	0	13	0	0	0	0	0	1	f = Plant Coffee
0	1	0	0	0	0	9	0	0	0	0	0	g = Plant Palm oil tree
0	2	7	1	0	1	1	41	0	3	0	4	h = Plant Maize
0	0	0	1	0	0	0	0	8	0	0	0	i = Plant Groundnut
0	0	1	1	0	0	0	0	0	23	1	1	j = Plant NTFP Trees
0	0	0	0	0	0	0	0	0	0	16	0	k = New seed variety
0	2	0	0	1	0	0	0	0	0	0	56	l = Other

Better-off male households

=== Confusion Matrix ===

a	b	c	d	e	f	g	h	i	j	k	l	<-- classified as
0	0	0	0	0	0	0	0	0	0	0	0	a = na
0	350	0	0	0	0	1	0	0	0	0	0	b = Plant Cocoa
0	4	0	0	0	0	0	0	0	0	0	0	c = Plant Cassava
0	0	0	72	0	0	0	0	0	0	0	0	d = Plant Plantain
0	1	0	0	0	0	0	0	0	0	0	0	e = Plant Macabo
0	3	0	0	0	0	0	0	0	0	0	0	f = Plant Coffee
0	1	0	0	0	0	25	0	0	0	0	0	g = Plant Palm oil tre
0	0	0	0	0	0	0	0	0	0	0	0	h = Plant Maize
0	0	0	0	0	0	0	0	0	0	0	0	i = Plant Groundnut
0	0	0	0	0	0	0	0	0	0	0	0	j = Plant NTFP Trees
0	0	0	0	0	0	0	0	0	0	0	0	k = New seed variety
0	0	0	0	0	0	0	0	0	0	0	4	l = Other

Verification with the 'training group' in the community

3.9 The size of the classification trees (number of conditions) and the number of leaves (goals) were higher for poorer households reflecting a large, yet consistent (Figure 8) range of adaptation strategies chosen for the different scenarios presented. In addition, the accuracy of the classification of strategies for individuals in all groups is quite high at around 89%, with Poor Females being a bit lower, and Better Off Men being a good bit higher. Despite this high level of agreement (89%+), it was important to verify the results of the classification trees with respondents of the game-interview.

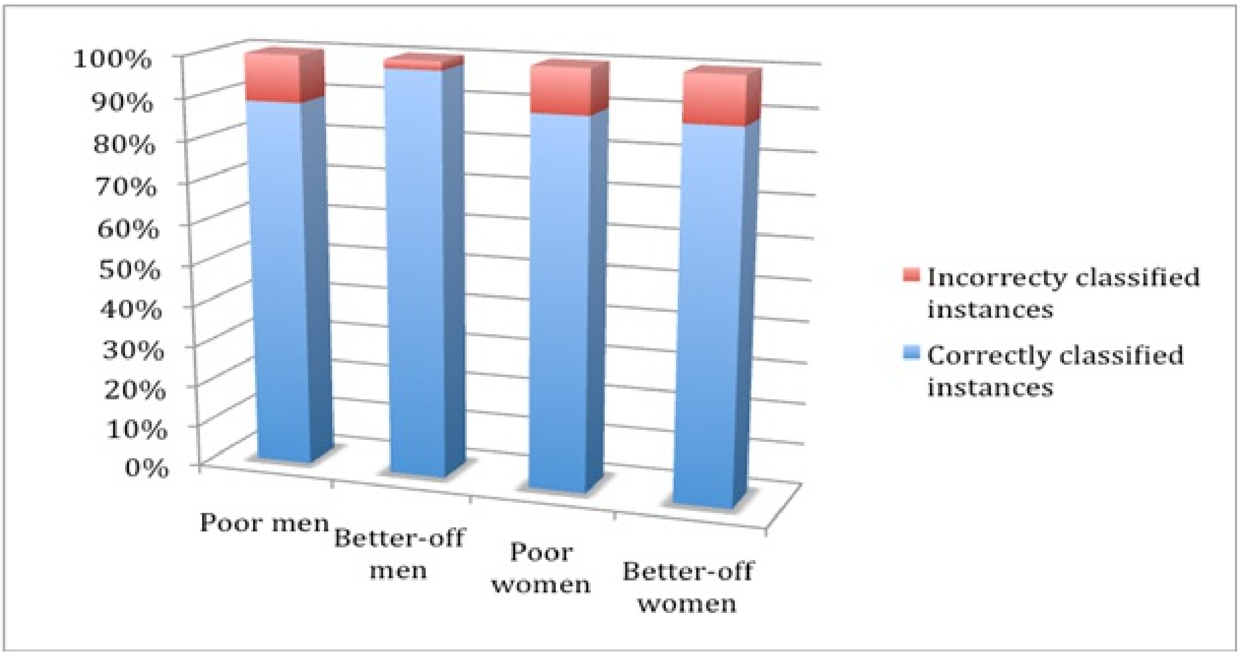

Figure 8. Percentage of correctly and incorrectly classified responses for each group.

3.10 The verification process was useful to refine and clarify information on particular strategies with community members who had participated in the game-interview. Much additional (and sometime, tacit) knowledge was gathered such as *cultivation of crops near the water sources in dry scenarios*, decreas*ed rotation periods in fallow areas to compensate for reduced land area*, *planting of macabo, plantain and fruit trees*within *cocoa fields* and *the expansion of cocoa fields based on particular drivers*.

3.11 This new information is shown in the annotated decision trees in green in Figure 9 and Figure 10 where rules also cluster around the climate variables (i.e. longer dry season, longer rainy season or increasing dry spells in the rainy season), branching out to include other factors. However, the *existence of a community forest governance unit*(that would ensure sustainable extraction of timber and increased biodiversity) is currently perceived by community members as adding pressure on already limited land availability, due to restrictions on the ability to clear land. This could in turn result in reduced rotation time of subsistence crops (as mentioned in KnETs game-interviews) and agricultural intensification. In the long-term this may degrade soil fertility and lead to declining production if not well managed. It will be important, therefore, that the benefits of community forest units are well communicated to community members if further implemented in this region.

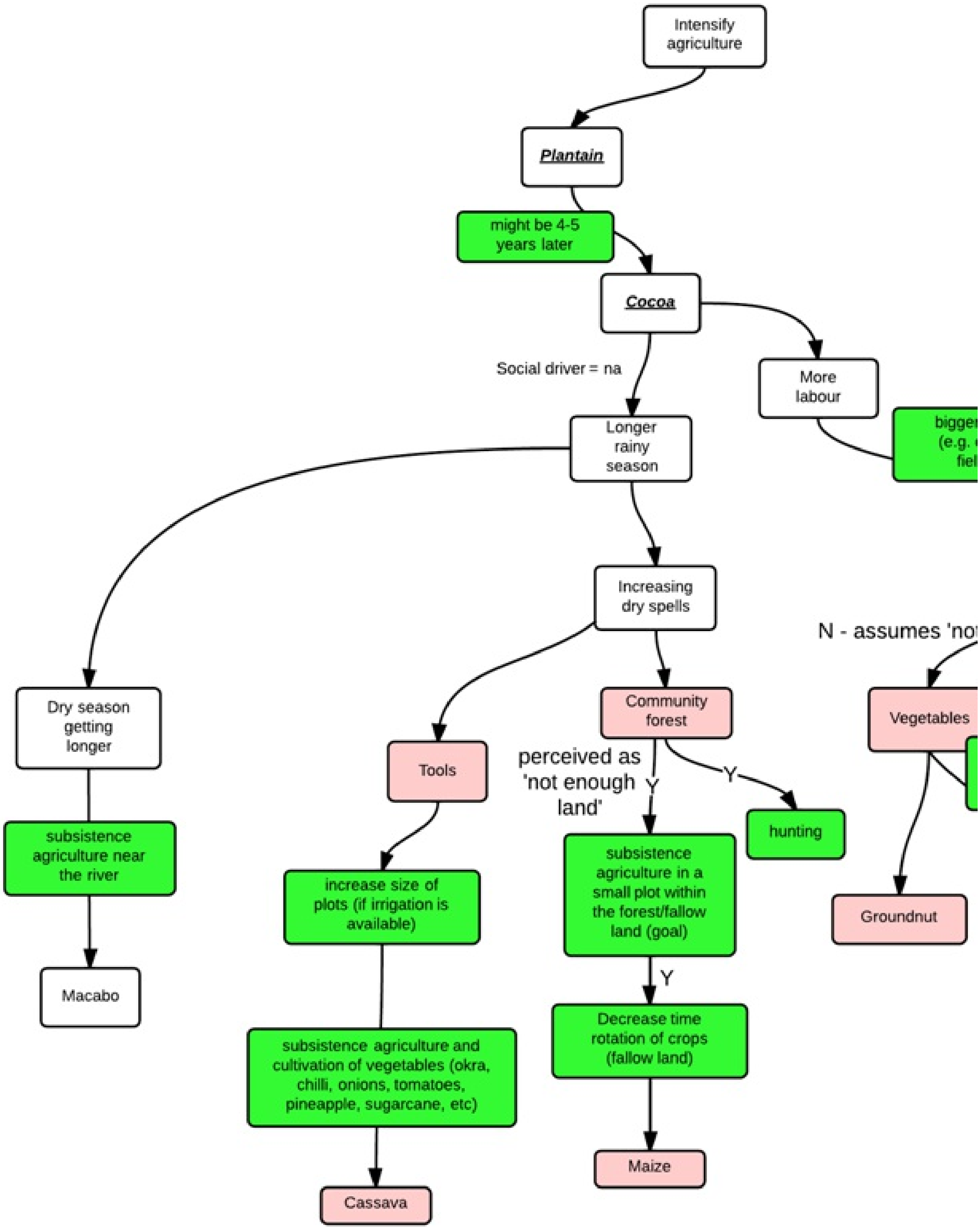

Figure 9. Poor household heuristics (where pink nodes represent womens' choices) and green nodes represent new (sometime
Green = new, annotated information.

3.12 Notably, *markets, labour/land availability* and *access to agricultural tools* were the most salient drivers triggering different livelihood strategies amongst poor households, and to a lesser extent, climate drivers. However, as mentioned, some of these drivers could introduce negative cascading effects on sustainable forest use, e.g. if the availability of agricultural tools or extra labour led to a faster expansion of cocoa fields at the expense of virgin forest. While cocoa farms support a higher level of biodiversity than most other tropical crops, where a diverse shaded canopy is used, planting cocoa under the residual shade can also give way to a practice where the forest is cleared-felled, burnt and the cocoa planted leading to a thinning of the forest and over time. This method of cocoa establishment has been identified as a major cause of deforestation in Ghana, for example where despite the fact that some trees are left for shade, as cocoa growing expands into virgin forest, these areas are eventually depleted of trees (Luke et al. 2011). Thus, in the TNS it could also be the case that if all farmers continued expanding cocoa plantations, the costs would outweigh the mitigation and livelihood benefits, due to a net forest loss, resulting in maladaptation instead. A sustainable approach would be if farmers were also introduced to better soil conservation techniques to allow them to intensify their shaded cocoa agro-forestry systems in the same parcel of land they use. They seemed to desire such training opportunities, as shown in the KnETs results, and therefore this could be an intervention strategy worth further exploration to address both *unmanaged expansion* and *reduced rotation*.

3.13 Amongst better off households (Figure 10), climatic factors (particularly precipitation) are important determinants of whether farmers grow cocoa (if rainy season is longer) or whether they focus on a different activity like artisanal mining, as a last resort (prolonged dry period when agriculture would not be as viable).

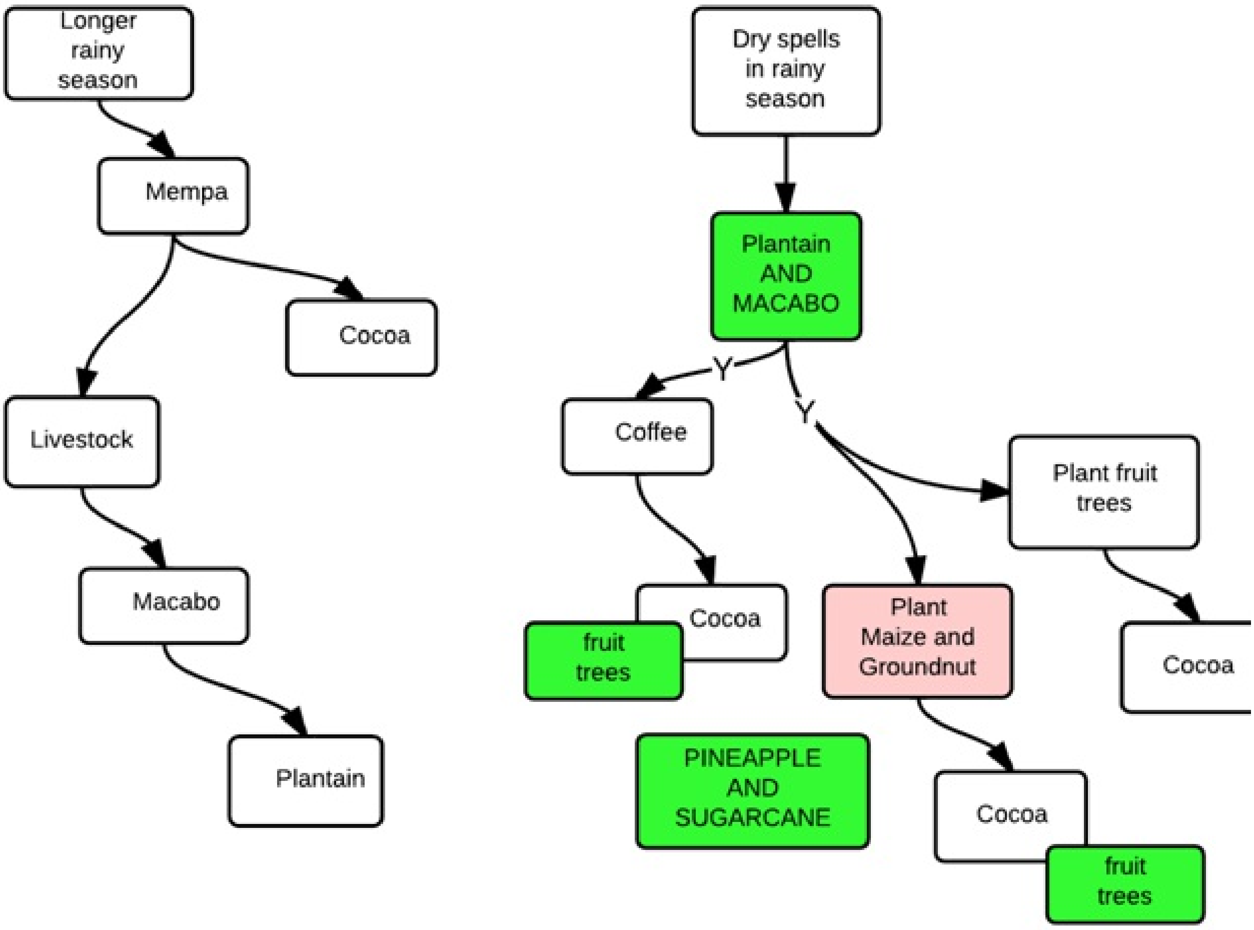

Figure 10. Better off households heuristics (where pink nodes represent womens' choices) and gre
Green = new, annotated inforı

3.14 As expected, KnETs results showed that *a longer dry season and more wind every year* was the most unfavourable climate condition for all farmers because agriculture performs poorly and NTFP collection is compromised. It was therefore common to consider activities such as mining, pisciculture, fishing and/or livestock rearing as main livelihood choices under this condition. Any attempt to pursue subsistence agriculture (or plantain, macabo or cassava in the case of men) in this case would be near the river or any other water source (Figure 9 and Figure 10).

3.15 For women, crop choices were dependant on the type of climate condition presented. Cassava was firstly considered under the scenario '*a longer dry season and more wind*', as it considered to be a drought-tolerant crop. Under the climate scenario '*increasing dry spells during small wet season*', maize and groundnuts were considered as the most convenient crop choices because they fulfil the subsistence needs at the household level. Groundnuts were considered less suitable under the climate conditions of '*a longer dry season and more wind*' or '*longer rainy season with more wind*. This was confirmed during the validation phase (see Table 5). However, there would always be attempts to grow such crops under these two climate scenarios, even though participants were aware of them not being the ideal conditions for growth, due to subsistence needs (Figure 9 and Figure 10).

Validation with 'testing groups' both within and outside the community who did not play the game

3.16 Validation is a further (iterative) step, which reveals a great deal of supplementary information, some of which could be considered 'tacit knowledge'. This was done through focus group discussions and individual interviews with community members who had not participated in the game-interviews both in the original village and in a separate village, where the game had not been introduced but where the baseline assessment had been carried out (Devisscher et al. 2013). Table 5 highlights some of this information, which verified what was found in the game-interview results or provided additional information (annotated verification in Figure 9 and Figure 10).

3.17 Village 1 refers to the community where respondents were sampled and includes both participants (verification) and non-participants of the game-interview (validation). Village 2, which has a similar profile, was only selected for validation (i.e. with non-participants) of heuristics generated through the original game. It is notable that the validation that took place in both Village 1 and Village 2 either confirmed the heuristics developed during the original game-interviews (highlighted in orange) or supplemented them with additional, sometimes tacit, information (highlighted in green) to improve the heuristic.

3.18 For example, the mention of *macabo* as well as *fruit trees* and *plantain* ([1] in Table 5) planted *in the same field* as a new cocoa plantation, because macabo and plantain come to harvest after a year or two and can be sold sooner than cocoa, was information that was tacit and only mentioned when verifying responses. When cocoa starts producing, 4-5 years later (additional information added to the rule in Figure 9), plantain and macabo stop producing so this is a very efficient use of the land. This illustrates the diversified options a cocoa landscape already offers for livelihoods improvement.

3.19 Tacit information about palm oil [2] was particularly interesting as it reinforced the reason that it was not often chosen (and, thus not often reflected in the classification trees), as part of a crop combination with cocoa, though they palm oil is used to demarcate land, important for inheritance purposes. Furthermore, the increased time and labour involved in processing NTFPs [3], mentioned during validation perhaps reinforces the absence of certain NTFPs in the classification trees of poorer households due to opportunity cost when trying to maximize time spent on agriculture. However this may also be related to the absence and preferential choice of certain NTFPs by some households (see Figure 11). Verification and validation confirmed that small-scale artisanal mining was only considered as an option [4], when agriculture - the most valued activity - was not viable. As shown in the classification tree outputs (Figure 9 and Figure 10), fishing was confirmed by all as most productive when the river is low in the long dry season [5] while groundnut cannot be grown in a longer dry or a longer wet season [6].

Table 5: Selected information from men and women that provides knowledge that is additional to the game-interview output (white), is reinforcement of the information gained (orange) or is sometimes tacit (green).

Game interview	Verification in Village 1	Validation in Village 1	Validation in Village 2
Cash crops Cocoa is the main cash crop. Macabo and plantain are planted as cash crops. Fruit trees are also chosen.	Macabo and plantain are planted **in the same field** during the creation of a new cocoa plantation[1] Plantation of fruit trees is also done in the cocoa fields for consumption and sale. [1] Cash crop cultivation is the priority, especially fast producing varieties – to sell at market. E.g. chilly.	Palm oil tree: drains a lot of water from the soil and dry land is not good for cocoa plantations. Thus, people will avoid planting cocoa where there are palm oil trees. [2] Stony soil is usually ok for subsistence agriculture (common soil near Village 1), but it is not good for cocoa. Tobacco is also cultivated as a cash crop - both for consumption and sale.	Plantain, Macabo and even Pineapple and Sugarcane can be grown in the same cocoa field before cocoa starts producing. Tobacco cultivation is also common, during all seasons. During the dry season it is close to the river, otherwise within the forest.
Market / tools / labour Continue to choose cash crops.	**Make bigger fields.** However, this requires high crop performance (potential drawback).	Make bigger fields with the same products; Every year farmers increase the size of cocoa fields.	When dry season is getting longer only consider making bigger fields if irrigation scheme is in place.
NTFPs *Njanssang* is a common NTFP selected.	*Njanssang* requires a lot of labour to process it into a product for sale. [3] *Bush mango ('igname sauvage')* is a type of NTFP that is also collected in the area and is highly valued.	Bush mango is the most valued NTFP and the one that is most consumed in the village. Then the order of preference is *mempa, djembe and kola*.	Bush mango trees do not grow everywhere; only on sandy soil.
Climate Different activities chosen under different drivers.	*Increasing dry spells during small wet season* is the most favourable season - all livelihood activities can be conducted.	The influence of climate is bad production and slow growth **(women).**	Most favourable season for crops: Increasing dry spells in the small wet season: cocoa/coffee and pineapple + sugarcane (confirms Figure 10). Longer rainy season: grow *plantain* and *macabo* (confirms Figure 10).
Artisanal mining Mostly considered under unfavourable conditions only.	Rarely considered as an option.	"Some people will never consider small-scale artisanal mining in the 'increasing dry spells during small wet season'" (i.e. the most common season) [4].	

Fishing Done during *dry season getting longer and more wind*	Fishing provides the most income at this time because the river level is low and would provide more money than any other activity if the dry season became longer.		Fishing also occurs when *increasing dry spells during small wet season* **(response from women)** [5].
Subsistence crops (women) Groundnut cannot be grown in a longer dry or a longer wet season.	Groundnut is not chosen in a longer dry or a longer wet season [6].		Groundnut will not be favourable if the dry season is getting longer [6] (Figure 9 and 10). Long rainy season: groundnuts will not produce yield [6] (Figure 9 and 10).

Variable preferences for NTFPs

3.20 Due to the inclusion of additional statistical measurements in the KnETs tool, an analysis of decision-making across heterogeneous groups was also possible. Results not only show significant variation between poorer and better-off households but also between women from poor and better off households, where they are often described as doing the same thing e.g. 'collecting NTFPs'. For example, differential preferences in NTFPs collected by women from poor and better off households were a key insight that was not evident from interviews or focus group discussions. However, the results of the game-interview indicated that women from poor households mainly collected mid-value NTFPs (for consumption) compared to better-off households who, in addition to collecting these, also collected high value, marketable NTFPs, and were not mentioned by poor households.

3.21 *Njanssang, kola, djembe* and *bush mango* (DKDB) are valued for consumption (or sale, if processed e.g. *njanssang*) and are commonly collected by all households. In addition to these, better-off women also collected *assa'a* and *do'gote* (black pepper). This was possibly due to their higher value and market potential or because they had been introduced to them through training programs from local NGOs. Figure 11 illustrates the classifications for both groups in the highlighted cells and shows error values in the cells that are not highlighted. Above 96% of responses correctly corresponded to the rules suggested by the J48. i.e. the women from each household type (poor and better-off) responded in the same way, the majority of the time, when asked to choose specific NTFP strategies.

NTFP	Poor women		
MID VALUE		DKDB	NOT DKDB
		117	2
		9	315
	Correctly classified		97.50%
HIGH VALUE		Assa	Not Assa
		0	6
		0	437
	Correctly classified		99%
HIGH VALUE		Dogote	Not Dogote
		0	0
		0	443
	Correctly classified		100%

Figure 11. Confusion matrices for NTFPs assa'a, do'gote (blac

3.22 There is some evidence to support the game-interview findings from the south-west of Cameroon. Ambrose-Oji (2003) reported that when comparing poor and better-off households '…a clear pattern emerges……for the poorer groups of people it is the income derived from farming which plays the most important role in household economics, most particularly when looked at in terms of the relative contribution these products make to household livelihoods' (Ambrose-Oji 2003: 111). It was found that NTFPs were most significant to the economies of middle-income. Reasons for this appear to be the need to maintain a level of 'status' by poor households and not to be seen to be relying on a source of income/nutrition that is unpredictable (i.e. NTFPs), especially so, when climate impacts are considered. NTFPs clearly remain an important safety net for all households but the opportunity cost in time taken to collect and process NTFPs, such as Njanssang, is a consideration (see Table 5) and for the poorest groups in Ambrose-Oji's study '·more reliable sources of cash and subsistence income were to be had from combining farming with plantation work' (Ambrose-Oji 2003: 114). NGOs in the village area plan to facilitate the production and trade of NTFPs to support local communities, but this difference in approach to collecting NTFPs may require further research, awareness raising or capacity building measures to make such an initiative beneficial to the poorest in this community. It may not have intended impacts if decision-making drivers, goals (better subsistence, nutrition or income generation) and strategies are not fully understood.

Hypotheses to explore in a social simulation

3.23 Analysis of the outputs of the KnETs process, including the classification algorithm and the iterative verification and validation processes, have produced several hypotheses that could be valuable to explore in a social simulation model to test further with communities for feedback or as an awareness-raising tool. For example, the model could explore:

1. ***Unmanaged expansion of cocoa fields*** in response to declining productivity, due to soil degradation or unfavourable climate conditions, and the perceived **lack of land** by poor farmers. This could result in a loss of virgin forest area over time and could potentially result in a loss of biodiversity and further increase distances to NTFPs (see 3). This could help to explore the thresholds at which shaded cocoa agroforestry systems become a maladaptive strategy.

   Linked to this, a further scenario is ***the existence of a community forest unit*** to promote sustainable forest use and timber extraction. However, if perceived as further reduction in potential land for agriculture, this could result in unmanaged intensification or reduced rotation of crops, resulting in soil degradation in the absence of improved crop management practices. Feedbacks could be included in the social simulation model to illustrate the benefits of shaded agroforestry systems and the biodiversity that would be supported by community forest units.

2. The impact of ***training on better soil conservation techniques*** *(with and without the community forest unit)* to create *managed* intensification of agriculture and shaded cocoa agro-forestry systems in existing cash crop and subsistence land parcels.
3. The **increasing distances travelled to collect preferential NTFPs** by poor and better off households is an interesting dimension which could result in complex rule interactions when considering the unmanaged expansion of cocoa plantations (1.) or when trying to improve adaptive capacity, through training for example (2.), about high-value NTFPs and their benefits.

Some of these rules have been incorporated into the design of the social simulation and are explained in further detail below.

Design of the social simulation

4.1 In this section we describe how the observations and rules from the KnETs process are translated to a social simulation model design. They may be further updated before implementation to reflect additional research, expert consultation and refinement.

Agents and entities

For brevity we describe only the two main decision-making actors modelled: Person and Household; although other entities and their associations are shown in Figure 12.

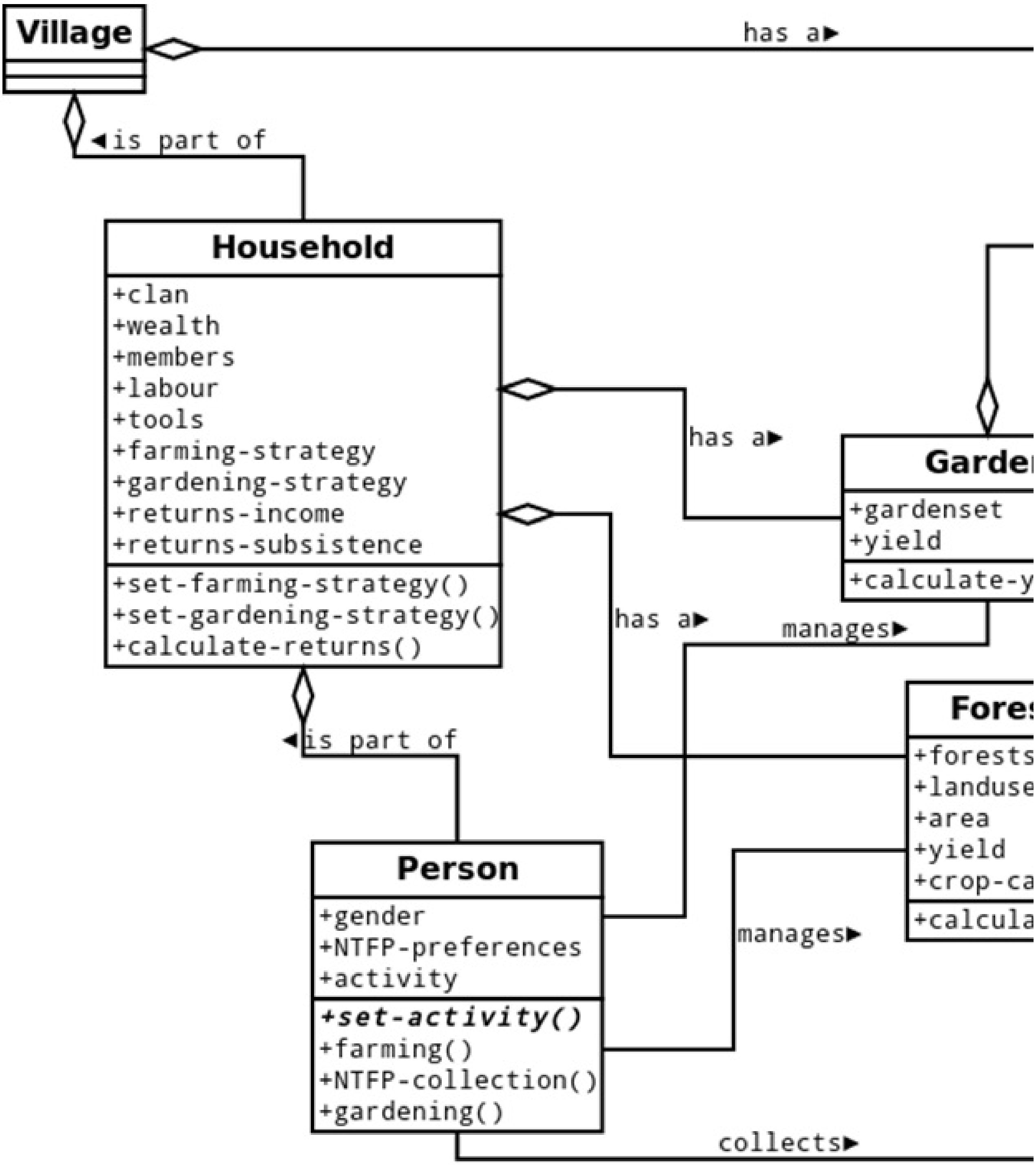

Figure 12. UML Class diagram of the social simula

4.2 Person - this agent represents a person who is both a farmer and a forest user. The relevant activities are agriculture, NTFP collection as well as hunting/fishing. Agricultural activities include management of forest plantations (cocoa crop farms) as well as (subsistence) gardens in the fallow ('jachere') area. Gender is included due to the differentiation of strategies documented in the KnETs analysis; in the model it determines activities with male agents managing forest farms and female agents the subsistence farming: the agents have procedures to carry out the respective activities according to a crop calendar (agriculture calendar). However, the strategies are set at the household level because they affect other household members too (see below). Each person has NTFP collection preferences set according to data elicited from the game-interview (i.e. respecting gender and wealth differences).

4.3 Household - the household agent is a container for a collection of Person agents: its members. Attributes at the household level include clan membership that defines which forest areas the household members have access to for these activities. Other attributes are wealth (poor and better-off, quantified), access to labour and tools, household-level returns (from productive activities) and strategies followed. Each household has both a subsistence garden and a forest farm as an available asset. Most interesting is the farming expansion strategy, which is described below.

Use of KnETs outputs in simulation model development

4.4 The modelling effort focused on implementing KnETs rules in a way that is consistent with the interpretation of results of the game-interview. Clearly, this should only be done using decision trees that were highly statistically supported and have previously been verified and validated with the respondents. This discussion follows from the research results presented above. In the following sections, selected branches of decision trees are presented in the form of pseudo code (rules) alongside further explanatory text.

1. **Agricultural expansion**
   In the context of research described here, one of the priority areas for social simulation work was to model the expansion of cocoa fields at the expense of forest areas, which is recognised as a current trend in the TNS, for several reasons. The discussion above can reduce to one key rule:

   ```
   Household agent
   if additional-labour  or has-tools and low-farm-proc
   ```

   In the social simulation 'labour' and 'tools' are attributes of the Household entity, whereas productivity is related to the 'yield' attribute of the ForestFarm agent. We model tool availability using a variable 'tools', which takes an integer value with 3 levels. If the above conditions are met, the Household agent when setting the farming strategy, will select an expansion strategy, allowing the Person agent to undertake the appropriate clearing activity and increase the 'area' of the ForestFarm. This has an impact on the availability of NTFP (see 3).

2. **Training and agricultural 'intensification'**
   One of the strategies that had a high response rate, particularly from poorer farmers, in the game-interview was the desire for training on better farm management practises, which targets sustainable 'intensification' and improved yields of the cocoa agroforestry systems. This resulted in the following rule:

   ```
   Household agent
   if low-wealth and has-training-available  -> improv
   farms
   ```

   Training is an activity that can be applied with the Household agent because both cash crop and subsistence farmers can benefit from improved soil conservation techniques. If training is available (represented as a policy parameter of the model) it is assumed that poorer households receive this in the simulation and update their respective strategies, allowing better maintenance of 'Fertility' (an attribute of Patch entities - see Figure 12). Poor households were selected for this rule, because training is one proposed intervention that is now being considered by local NGOs in the area to support most vulnerable households. Further positive consequences may be in terms of reducing the need for expansion - where this rule behaviour interacts with the former one (agricultural expansion).

3. **Distance of NTFP**
   The analysis showed that NTFP collection activities differed greatly across socio-economic groups. The interviews suggested that men would not, in general, be focusing on NTFP activities. Better-off women were shown to preferentially collect assa'a and do'gote (high value NTFPs) as well as mid-value DKDB, whereas poorer women would concentrate only on DKDB.

   Therefore, this rule had to establish the initial conditions for NTFP collection in the model:

```
Person agent
if gender = female
   if low-wealth → set-NTFP-preferences (njanss
   else → set-NTFP-preferences (assa'a, do'gote
```

The game-interview revealed that with decreasing availability people would go deeper into the forest and camp for more than a day to collect NTFPs, increasing their vulnerability and adding to their opportunity costs. Although travelling long distances, losing time from farming and other factors may be further compounded by a lower availability of NTFP at the destination (e.g. lower availability due to deforestation or climatic factors), NTFPs are always collected to some degree, as they are important safety nets for subsistence and have other uses (medicinal, cultural, etc).

The additional dimension that would be of importance to model is raising awareness about higher-value NTFPs, through training programmes, and whether poorer households would then collect these. It would be key to explore what impact this would have on their vulnerability, if for example, the local NGO were to support links to markets and the sale of such products on a larger scale. An additional scenario to explore is the interaction of (1.), and NTFP availability i.e. the distance from the village if cocoa expansion proceeds in a maladaptive way into virgin forest areas.

The interaction of these micro-level rules and their feedbacks at the system scale could provide useful insights regarding possible interventions planned by local pilot projects. Upscaling the model in Figure 12, which currently represents one village, would also be possible with further research, to explore the impacts of forest conservation, mitigation and poverty alleviation at the landscape level.

Figure 13. Social simulation model based on KnETs analysis.

Conclusions and further work

5.1 Having reviewed a selection of emerging approaches that use empirical evidence in models relating to social or environmental change, we have applied an improved version of the KnETs tool to research in southeast Cameroon to establish a systematic way of linking case study evidence to agent rules. This approach of informing social simulation design using KnETs generated rules as a starting point, is both systematic and transparent (Edmonds 2014) because it includes the specification of multiple drivers and rules of decision-making, identified and verified by participants, and is therefore linked to empirical evidence. This evidence is transposed into a social simulation model design that encapsulates the stressors, adaptation strategies and livelihood options from the game-interview.

5.2 There are very few methods that combine the advantages of both qualitative and quantitative methods to provide a rich structured process that enables the identification of factors that should be prioritised in a social simulation. The KnETs process continues to use ethnographic fieldwork to determine the terminology, criteria and perceptions of local informants to create a context-specific game reflecting their world-views and real world decisions. And, combined with new statistical measurements and a classification algorithm to verify the degree of accuracy of the resulting decision trees, this addresses some of the challenges mentioned earlier, creating a structured, rigorous and replicable approach that generates new insights into the evidence collected and identifies priorities for social simulation model development. This is possible because of the high number of responses in the game-interview and the iterative process of verification and validation.

5.3 As shown, analysis of the KnETs results not only shows significant variation between male and female farming decisions in the case study area, but also between the women of poorer and better-off households. While all households try to spread risk, poor households chose more goals and were therefore dependent on more strategies, than better off household, which were more cash crop oriented. Though they also carried out many other strategies, their goal was cocoa farming, and this was independent of most other strategies.

5.4 However, it may be that a reliance on one or two crops that have benefits in the short-term can lead to new vulnerability in the long-term. Vulnerability may increase if climate becomes unsuitable for the crop, markets are not available or there is no longer diversification in cropping patterns due to the continual extensification of cocoa fields or unsustainable land management practises. For example, this could also become an issue if farmers reduce reliance on subsistence farming and use income generated from monoculture cash crops to buy food in the market or from other farmers in the village. This can become counter-productive in the long-term. Social simulation models can be designed to test such strategies that have emerged as possible decision-making options in the KnETs game-interviews. Under differing scenarios of the future there may be particular thresholds above which an adaptation strategy that may be beneficial in providing benefits in the short-term, becomes maladaptive in the long-term.

5.5 The difference between 'game responses' and complex reality is also an interesting area for further research as it provides a lens on what people say they do (and value) and what they actually do, due to other barriers or constraints i.e. in reality, better-off households do most things that poor households do, but their ultimate motivation in this marginal environment – cocoa oriented strategies – are quite hidden. They do not reflect the dynamic, structured responses to different drivers that poor farmers do in the game-interview - they do the same things (perhaps many) no matter what the conditions are as they have more capacity to absorb loss if they are not successful but their ultimate goal is cultivating cocoa *well*, and this only depends on a suitable climate and supporting crops such as plantain.

5.6 However, despite the benefits of this approach, as in any social science based research, challenges remain (Table 6). For example, though informed as much as possible by local knowledge, the choice of which parameters to include in the game design is clearly a subjective decision and the researcher ultimately has to make a choice. A different researcher may have chosen different variables to include (e.g. legal, institutional, policy etc.), which would ultimately result in a different game design and results. However, the resulting heuristics for any part of the informant's decision-making repertoire should be complementary. To test this, a small amount of research was carried out where one, two or three key variables in the decision trees were removed from consideration in the analysis. Although the resulting decision trees changed radically (and were always more complex), the accuracy of the overall analysis remained approximately the same. This suggests there is enough inter-correlation and redundancy in the variables that there are many pathways that account for the decisions made; the wide mix of variables chosen defines a holographic projection relating decisions to focus on different main crops, and we are not finding a unique model, but rather one of the more efficient models for a given informant of a wide range of models that will arrive at the same conclusions.

5.7 Similarly, we found that we could directly merge the data from an arbitrary set of individuals, and a) produce a decision tree for the merged data set that was always larger than any one of the constituents, but b) smaller than the sum of the size of the decision trees for included individuals, and, that c) the merged decision tree was always more accurate (accounted correctly for more main crop decisions) than any individual decision tree. This suggests that a) there is consensus and consistency between people's conception of the variables regardless of their gender and wealth, and b) that some rules derived from one interview might better account for the outcomes of another where particular scenarios might have presented an alternative logic. In short, this demonstrates that different individuals judgements are not unique to themselves and that the data we collected from each individual was a sample of a much larger, shared conception of the relationship between different variables and main goals.

Table 6: Reflection on the benefits and challenges of the KnETs process.

Benefits	**Challenges**
1. Collection and use of empirical evidence	
The use of multiple lines of evidence and the richness of the iterative process made it easier to identify simple key rules for the social simulation. A direct and transparent chain of evidence is possible from the social simulation to data in KnETs, which is based on empirical research, peer-reviewed and grey literature.	Sometimes, due to human error, or because individuals are highly diversified, or strategies are complementary, respondents find it difficult to articulate responses consistently, over a long time period, especially when there are many to choose from. The process of probing informants can influence their responses and the resulting rule output.
2. Knowledge gained through the structured participatory process	
Greater access to knowledge that is tacit, implicit or not normally mentioned. Value of participatory process, which showed better off farmers employ a lot of strategies even if their main goal is not dependent on them and not output as rules.	Development of decision rules and their analysis is difficult in the field when time is limited, which impacts the time and opportunity available for verification and validation.
3. Scenarios and links to social simulation	
While future scenarios can be difficult to imagine for participants, past scenarios can be used as 'anchors' or 'analogues' and building from simple to complex scenarios based on informants' own context specific game is an advantage.	It can be difficult for respondents to think in 'separate, independent' scenarios and not cumulative ones. i.e. to view scenarios as discrete and not following on from each other can.
Identification of agent differentiation to introduce heterogeneity in the social simulation based on the empirical evidence.	Decision-making in complex scenarios can be challenging, particularly when 3 variables or drivers interact.
Simplifies the complexity of the situation to a few salient drivers that can be modelled in a social simulation.	
4. Rules	
Diversification in strategies was only identified using the rule-induction algorithm, J48, as patterns in the data were very difficult to distinguish through conversation alone, which is an added value of the KnETs process.	Rules may or may not 'generalise' and production rules in the form currently produced are quite brittle - the rule breaks easily because every condition is built into every rule, and every rule's action is terminal.
Identification of variance in decision-making of the groups sampled and across heterogeneous groups is not easily observable using other methods. E.g. both gender- and wealth-based heterogeneity, such as subtle differences in the NTFPs chosen by poor women and better-off women.	

5.8 The following tasks will be important next steps in addressing some of the challenges mentioned above:

4. Creating aggregate rule sets and locating each individual rule set within this aggregate, to create a common production system[10] architecture that is sufficient to cover all the different individual models used to make the aggregate, while creating a common context for the group, to assess whether rules can 'generalise'.

   The individual rule sets can then be converted into this new architecture, which is simpler, easier to understand, particularly in complex cases, and indicates analytic robustness when the production model corresponds closely to the original individual and aggregate models in accounting for the original data.
5. Although the current rule engine moderates the 'brittleness' of rules somewhat by treating every clause in each rule as a virtual rule whose output is setting that clause to true or false, in an optimised production system one could identify the clusters that repeat in the ruleset (e.g. IF X and IF Y appear in many rulesets, one would create an intermediate production rule IF X and IF Y then X AND Y. This simplifies most of the rules, often results in fewer overall clauses (e.g. reduces the entropic complexity of the ruleset), while dealing with greater entropy in the rules themselves, and thus is more generalisable if the rule proves to be useful in describing the original data, and thereby increasing its value for scalability and policy formulation in other real-world contexts.

5.9 In summary, KnETs rules are empirically useful, since they reflect 'our understanding' of decision-making behaviour to quite a high level of accuracy based on informants' responses. The interaction of these micro-level rules and their feedbacks in a social simulation at a system scale will be important in providing insights regarding possible implications of activities planned in local pilot projects. Once implemented, the social simulation could be validated in further workshops with communities in Cameroon to evaluate its potential in further improving our understanding of livelihood strategies that have co-benefits for both communities and forests.

5.10 Human cognition is complex and does not adhere to simplistic programming, but one can start from representing informants' own worldviews (Forrester et al. 2014; Gladwin 1989). Verification and validation together provide confidence that the rules are representative of some of the decision pathways of the small sample of 'poor' and 'better-off' farmers in the villages studied, though they are not the only pathways. The use of the participatory, collaborative KnETs process has attempted to improve the level of clarity in the pathway from evidence to model design, through rule-based output which identifies important qualitative aspects of empirical evidence, using a 'game-interview', revealing patterns in decision-making profiles, tacit information and a level of rigour similar to that of more traditional statistical approaches. This can lead to nuanced insights into the decision-making behaviour of heterogeneous groups and identify areas for further research by organisations planning local capacity building interventions.

Acknowledgements

The COBAM project was coordinated by CIFOR in Cameroon under an African Development Bank grant to the Economic Community of Central African States for financing the Congo Basin Ecosystems Conservation Support Programme (PACEBCo). The project was a collaboration between CIFOR in Cameroon, University of East Anglia (UEA) and the Stockholm Environment Institute (SEI) in Oxford. We are grateful to our local partners in the TNS landscape (ROSE), research assistants Chrislain Eric Kenfack and Sylvie Asso and to the local communities for their time and input throughout the process. We would also like to thank Anne-Marie Tiani, Denis Sonwa and Bruno Locatelli, at CIFOR for their valuable input to this research.

Notes

[1] That which may be 'sub-conscious' knowledge or culturally-specific understanding that may not be shared with the researcher (Gladwin 1989; Sinclair et al. 1993; Dixon et al. 2005) or which is so 'common-sense' to the respondent that they may not feel the need to mention it to the interviewer - i.e. it should be obvious.

[2] Supported by the African Development Bank and Economic Community of Central African States for financing the Congo Basin Ecosystems Conservation Support Programme (PACEBCo) from 2010-2014.

[3] A 'Community Forest' is a non-Permanent Forest Estate (forest area that is designated to be retained as forest and may not be converted to other land use) that can measure up to 5,000 ha and is subject to a management convention between the community of a village and those responsible for the administration of forests. Community Forests are one of the measures envisaged in the Forest Law of 1994 to enable the participation of local communities in the sustainable and equitable development of natural resources, and their access to socio-economic benefits from these resources (RIDDAC 2013).

[4] Here, we are referring to the methods that are used to construct the empirical evidence, that is: data generated from observing, interviewing, including the knowledge of or co-learning with the decision-takers that the modelling seeks to represent the decisions of, rather than a 'top-down' approach which is based on the *a priori* assumptions of researchers outside of the system.

[5] However, as noted by Ruf et al. (2006), the introduction of new hybrid cocoa varieties could lead to a gradual shift towards the elimination of shade trees in cocoa plantations, forcing farmers to eliminate forest tree species to obtain high performance of these new varieties and as a result large areas of forested land could be lost, thereby posing a threat to biodiversity conservation (Luke et al. 2011).

[6] The next version of the KnETs software will compare the outputs of several different classification algorithms to understand what impact this has on the rules that are produced.

[7] Decision rules are read by tracing through the tree to identify the set of drivers that are required for each of the possible outcomes. The right-hand side (RHS) of each tree refers to a positive outcome (TRUE) for the preceding driver and the left (LHS) to a negative response (FALSE). If there is only one arrow, it indicates TRUE. For example, Figure 6 begins – 'if there is a long dry season' THEN 'I would do artisanal mining' AND 'pisciculture' AND 'I would grow palm oil'. However, 'if I cannot do pisciculture', THEN 'I would collect bush mango and Njanssang' AND 'if I can't collect bush mango and Njanssang', 'I could grow plantain'. The latter would result in a rule for 'if there is a long dry season, do artisanal mining and grow plantain'.

[8] However, one needs to allow for the fact that this could be an artifact of the probing process used by each researcher (one for poor and one for better off households), and this would need to be verified during a further validation workshop.

[9] Each row corresponds to a different main crop choice, as does each column. If the matrix represents a totally accurate result, there will only be non-zero values along the long diagonal. Deviations (errors) are represented by non-zero values in other locations along the row.

[10] A set of rules where each rule has conditions, and when those conditions are met in a 'soup' of variables, actions are taken that amend the soup.

References

AMBROSE-OJI, B. (2003). The contribution of NTFPs to the livelihoods of the 'forest poor': evidence from the tropical forest zone of south-west Cameroon. *International forestry review*, 5(2), 106–17.

BARRETEAU, O., Bousquet, F., Étienne, M., Souchère, V. and d' Aquino, P. (2014) 'Companion Modelling: A Method of Adaptive and Participatory Research'. In M. Étienne (ed.)., *Companion Modelling*, Springer Verlag, Heidelberg, pp. 13-40.

BERMAN, M., Nicolson,C., Kofinas, G., Tetlichi, J. & Martin, S. (2004) Adaptation and sustainability in a small arctic community: Results of an agent-based simulation model. *Arctic*, 57(4), 401–414.

BHARWANI, S., Bithell, M., Downing, T. E., New, M., Washington, R & Ziervogel, G. (2005) Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. Philosophical Transactions of the Royal Society B-Biological Sciences 360(1463): 2183–2194.

BHARWANI, S. (2006). Understanding Complex Behaviour and Decision Making Using Ethnographic Knowledge Elicitation Tools (KnETs). *Social Science Computer Review*, 24(1), 78–105. [doi://dx.doi.org/10.1177/0894439305282346]

BUTTERFIELD, R. E., Coll Besa, M., Pavageau, C., Tiani, A. M., Devisscher, T., & Bharwani, S. (2014) Exploring the differential vulnerabilities of forest communities to climate and environmental changes in the Congo Basin, manuscript in preparation.

DEVISSCHER, T., Bharwani, S., Tiani, A. M., Pavageau, C., Kwack, N. E. & Taylor, R. (2013) Current vulnerability in the Tri-National de la Sangha landscape, Cameroon. Working Paper 107. CIFOR, Bogor, Indonesia. [online] <http://www.cifor.org/library/4084/current-vulnerability-in-the-tri-national-de-la-sangha-landscape-cameroon/>

DIXON, H. J., Doores, J. W., Joshi, L., & Sinclair, F. L. (2005). Agroforestry Knowledge Toolkit for Windows: Methodological Guidelines, Computer Software and Manual for AKT5., School of Agricultural and Forest Sciences, University of Wales, Bangor.

EDMONDS, B.(2014). 'Towards a Context- and Scope-Sensitive Analysis for Specifying Agent Behaviour.' In B. Kamiński and G. Koloch (eds.), *Advances in Social Simulation*. Springer Verlag, Heidelberg, pp. 319–31.

ETIENNE, M., Du Toit,D, & Pollard.S. (2011). ARDI: a co-construction method for participatory modeling in natural resources management. *Ecology and Society* 16(1), 44. [online].

FORRESTER, J., Taylor, R., Greaves, R. & Noble, H. (2014). A transdisciplinary approach to modelling complex social-ecological problems in coastal ecosystems, Complexity, early view article, published 20 March 2014 [doi://dx.doi.org/10.1002/cplx.21524]

GELLER, A., & Moss, S. (2013). "Modeling Power and Authority: An Emergentist View from Afghanistan", in B. Edmonds & R. Meyer (eds.), *Handbook on Simulating Social Complexity*. Springer

GLADWIN, C. H. (1989). *Ethnographic Decision Tree Modelling*. Beverly Hills, CA, Sage Publications.

GROSS-CAMP, N., Few, R. & Martin, A.(2014). Exploring the role of forests in rural communities' adaptive behaviours to environmental change in three African nations, manuscript in preparation.

GURUNG, T. R.., Bousquet, F. and Trébuil, G. (2006). Companion modeling, conflict resolution, and institution building: sharing irrigation water in the Lingmuteychu Watershed, Bhutan. *Ecology and Society*, 11(2) 36.

KEMP-BENEDICT, E. J., Bharwani, S. & Fischer, M. D. (2010). Using Matching Methods to Link Social and Physical Analyses for Sustainability Planning. *Ecology and Society*, 15(3), 4. [online] <http://www.ecologyandsociety.org/vol15/iss3/art4/>

LUKE, C.N. Anglaaere, Cobbina, J., Sinclair, F.L., & McDonald, M. A. (2011). The effect of land use systems on tree diversity: farmer preference and species composition of cocoa-based agroecosystems in Ghana. *Agroforestry Systems*, 81, 249–265. [doi://dx.doi.org/10.1007/s10457-010-9366-z]

MURTAUGH, M. & Gladwin, H. (1980). A hierarchical decision-process model for forecasting automobile type-choice. *Transportation Research Part A: General*, 14(5–6), 337–47. [doi://dx.doi.org/10.1016/0191-2607(80)90053-9]

POLHILL J.G., Sutherland, L., & Gotts, N. M. (2010) Using Qualitative Evidence to Enhance an Agent-Based Modelling System for Studying Land Use Change. *Journal of Artificial Societies and Social Simulation*, 13(2) 10:http://jasss.soc.surrey.ac.uk/13/2/10.html>

QUINLAN, R. (1993). *C4.5: Programs for Machine Learning*. Morgan Kaufmann Publishers, San Mateo, CA.

RIDDAC. (2013). Portail des Forets, de l'Environnement, et du Developpement Durable en Afrique Centrale, 2013. <http://www.riddac.org/>

RUF F, Deheuvels O, & Sarpong D. (2006). Intensification in cocoa cropping systems: is agroforestry a solution for sustainability? The case of Manso Amenfi, Western region. *15th International conference on cocoa research, vol 1. San Jose, Costa Rica* (pp. 355–364)

SAQALLI, M., Bielders, C.L., Gerard, B. & Defourny, P. (2010) Simulating Rural Environmentally and Socio-Economically Constrained Multi-Activity and Multi-Decision Societies in a Low-Data Context: A Challenge Through Empirical Agent-Based Modeling. *Journal of Artificial Societies and Social Simulation*, 13(2) 1: http://jasss.soc.surrey.ac.uk/13/2/1.html>.

SIMON, C., & Etienne, M. (2010). A companion modelling approach applied to forest management planning. *Environmental Modelling & Software*, 25(11), 1371–1384.

SINCLAIR, F. L., Walker, D. H., Joshi, L., Ambrose, B., & Thapa, B. (1993). Use of a Knowledge-Based System Approach in the Improvement of Tree Fodder Resources on Farmland in the Eastern Hills of Nepal., School of Agricultural and Forest sciences, University of Wales, Bangor.

UNIVERSITY OF WAIKATO (2008). *Weka 3: Data Mining Software in Java*. University of Waikato, New Zealand. <http://www.cs.waikato.ac.nz/ml/weka/>

USONGO & Nzooh (2008). *Chapter 9. Sangha Tri-National (TNS) Landscape* In: de Wasseige C., Devers D., de Marcken P., Eba'a Atyi R., Nasi R. and Mayaux Ph. (Eds), State of the Forest 2008. *The Congo Basin Forest Partnership Priority Landscapes.* Luxembourg: Publications Office of the European Union, ISBN 978-92-79-13210-0, [doi://dx.doi.org/10.2788/32259]