Understanding coffee farmers: using games to explore future coffee agroforestry landscapes in the Western Ghats (India)

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Abstract

Deforestation and biodiversity loss in agroecosystems are generally the result of rational choices, not of a lack of awareness or knowledge. Despite both scientific evidence and traditional knowledge that supports the value of diverse production systems for ecosystem services and resilience, a trend of agroecosystem intensification is apparent across tropical regions. These transitions happen in spite of policies that prohibit such transformations.

We present a participatory modelling study run (1) to understand the drivers of landscape transition and (2) to explore the livelihood and environmental impacts of tenure changes in the coffee agroforestry systems of Kodagu (India). The components of the system, key actors and resources, and their interactions were defined with stakeholders, following the companion modelling (ComMod) approach. The underlying ecological processes driving the system were validated through expert knowledge and scientific literature. The conceptual model was transformed into a Role Playing Game and validated by 8 workshops with 57 participants. Two scenarios were explored, a No Policy Change as baseline, and a Restitution of Rights where rights to cut the native trees are handed over to farmers. Our results suggest the landscape transition is likely to continue unabated unless there is a change to the current policy framework. However, the Restitution of tree Rights risks speeding up the process rather than reversing it, as slow variables such the differential growth rate between exotic and native tree species kick in.

Significance Statement

Few elements of agroecosystems are unaffected by humans. However, the integration of human agency in models of landscape change poses challenges that classical approaches are ill equipped to resolve. This research takes place in a context of land use frictions at local and regional political levels. Our paper presents an integrated approach based on stakeholder participation and the use of boundary objects and role playing games to understand farmers' needs, aspirations and constrains in a biodiversity-rich agroecosystem. We present the complex and entangled interactions between individual decisions, collective behaviour and ecological processes happening at the farm and landscape scales and explore alternative policy scenarios and their outcomes.

Introduction

Problem framing

The Anthropocene has been defined because human agency now rivals natural processes in shaping and driving the Earth system[1]. This is particularly true of agroecosystems where, from the local to the global, the human enterprise affects directly or indirectly most if not all elements and processes [2, 3]. One of the outcomes of this stranglehold is that several proposed planetary boundaries that define the safe operating space for humanity have already been crossed, and in particular the core Biosphere Integrity boundary (formerly referred to as Rate of Biodiversity loss) [4, 5]. Conservation efforts aim at halting or reversing this trend. Considering that 13 % of the globe's 13.4 billion ha of land surface is devoted to conservation, against 11% to crop production [6-8] and that further extension of protected areas will be costly if at all feasible, biodiversity conservation should increasingly be contemplated outside protected areas [9-11].

Since human agency is of primary importance in shaping these landscapes [12], mainstreaming biodiversity conservation into agroecosystems requires careful consideration of the drivers, needs and constraints of farmers and other relevant stakeholders [13, 14]. In Indonesia, farmers do not hesitate to change their livelihood system and replace forests and agroforestry systems with alternative crops such as oil palm to respond to market incentives, despite their cultural attachment to the forest [15]. In many cases, deforestation and the loss of biodiversity are the result of rational choices, not of a lack of awareness or knowledge [16]. Failure to adequately represent agency can lead to policies that are little more than wishful thinking, or even make things worse [17, 18].

Agents [sensu 17] seeking to improve agroecosystem governance are thus confronted with seemingly intractable difficulties. (i) They need to take into account the bounded rationality of the stakeholders, with drivers of decision that might be tacit – so obvious nobody mentions them to outsiders -, cryptic – unknown to all but the most discerning observer -, or even concealed – such as freeriding or corruption [19, 20]. (ii) The system they deal with is highly unpredictable, with complex and non-linear interactions, feedback loops and delayed effects between individual decisions, collective behaviour and ecological processes [21]. (iii) Finally, the system is highly adaptive and stakeholders can quickly exhibit behavioural plasticity, finding loopholes or revising their strategies.

Models can help explore this complexity [21-23], provided they capture the full complexity of the stakeholder's decision making process. Dismissing this critical system feature and behaviour would undermine the model's validity and outputs [24]. Participatory models [25], agent based modelling [21] and scenario planning [26] have been proposed as possible avenues to help agents 'muddle through' this quagmire.

We present here a participatory modelling study run (i) to understand the drivers behind a documented landscape transition that entails a significant loss of biodiversity [27] and (ii) to explore the livelihood and environmental impacts of a contemplated policy change seeking to halt or reverse this trend. We associated participatory modelling, the use of boundary objects and role-playing games, and socio-economic scenario definition and exploration, following the companion modelling (ComMod) approach [28, 29]. We discuss how this allowed us to explore hidden or often overlooked drivers of landscape change, and unveiled surprising behaviour, as well as the limits of the approach.

Case description

The district of Kodagu in the Western Ghats (India) is located in a major biodiversity hotspot [30], and farmers there produce one third of the Indian coffee [31, 32], in addition to rice and other cash crops such as cardamom, ginger and areca nut [33]. The resulting landscape is a dynamic mosaic of terraced rice fields, evergreen and mist deciduous forest fragments, some of them sacred [34, 35], and coffee farms (Fig. 1). These coffee farms, locally referred to as Estates, produce mostly Robusta coffee (*Coffea canephora* var *robusta*), under complex, multi-storeyed agroforestry systems [16, 36]. In addition, the landscape is dotted with water tanks used to irrigate coffee to induce flowering, increase yield and reduce the need for dense shade cover [37, 38].

Figure 1: Kodagu Landscape : mosaic of terraced rice fields in the lowlands dotted with water tanks used to irrigate the coffee and coffee plantations on the slopes, with a great variety of tree cover,. Google Earth Map. Position 12°10'10.97"N 75°46'13.42"E

Land use and land cover change, and the consequent loss of biodiversity in this landscape result primarily from the decisions individual coffee farmers are making in their estates. Time series have shown that most changes to the tree cover happen inside privately owned land, leaving the area under the direct control of the government and the Forest Department of Karnataka largely untouched [16]. Tree cover changes mainly because of three different management interventions: when coffee farmers (i) replace forest habitats with coffee plantations, (ii) remove shade trees to increase coffee productivity, and (iii) replace a rich and diverse evergreen and moist deciduous canopy cover by planting Silver Oak (*Grevillea robusta*), a fast growing tree originating from Australia [39, 40]. Of these three practices, the slow conversion to Silver Oak is the one that has received most attention, and the reasons advanced by the coffee farmers are well documented [39-41]. This species can be logged and traded easily, as it lacks any specific protection rights, while harvesting native species is restricted and the full value of the timber cannot be recovered by the coffee farmer [16].

For over 10 years, coffee farmers and their representatives have been actively advocating a policy change, demanding full ownership rights over all trees on their land and the lifting of restrictions on tree harvesting [41, 42]. Over the years, this issue has led to considerable friction between coffee farmers and the Karnataka Forest Department, opposing the demand for fear of the environmental impact this lifting of restrictions would have on the tree cover of the district [43, 44]. Unsurprisingly, vocal representatives of the coffee farmers have denied that the granting of tree rights would result in a loss of tree cover or conversion [45], a position that has some support in the literature which states that privately owned resources are better managed than public resources. This polarized debate has led to a long-lasting standoff between the opposing parties, representing an all-too classical conflict situation between conservation and development.

Objective and Approach

To (i) better understand the drivers of decision making of the coffee farmers, explore their coping strategies, and (ii) contribute to the resolution of this standoff, we developed a three-step participatory process using companion modelling [46], building upon our previous research in the area [47]. This adaptive process started in 2009 and continued until 2012, bringing together academics, representatives of the Central Coffee Board of India, local NGOs, private coffee trading companies, and community leaders representing coffee farmers.

Through workshops and structured/ semi-structured interviews with coffee farmers and other key stakeholders, we first co-constructed a conceptual model, identifying the critical actors, resources, processes and interactions that shape tree management in the coffee estates of the Kodagu district [28]. The model was then translated into a role-playing game that could act as boundary object [48, 49], allowing us and stakeholders to grasp the complex web of interactions described by the model, and its emerging properties. We define *gamescape* as the combination of physical tokens and their distribution, created by players throughout a game session, to distinguish it from the real physical *landscape* it represents. The game was then used to run 8 workshops organised in different localities of the district, bringing together groups of 5 to 8 coffee farmers. Each of these game sessions lasted one full day and allowed us to explore two alternative scenarios based on the policy options contemplated by the stakeholders. Scenario 1 was "No Policy Change", where the rules for transporting and selling Jungle Wood (the collective name given to the group of native tree species) mimic the restrictions currently in place. Scenario 2 was called "Restitution of Rights", where restrictions were lifted and the Forest Department lost its enforcing powers over private lands. These game sessions allowed coffee farmers to develop and elicit their strategies. The social, economic and environmental outcomes of their decisions were recorded and used as basis for discussions, using the gamescape so created to critically reflect on their landscape present and future.

Results

Boundary Objects: Conceptual Model and Board Game

The conceptual model was constructed to answer the question "What drives tree management in the coffee estates of the district of Kodagu?" (Fig. 2). Central to the model is the link between coffee yield, shade level and the presence of irrigation. The shape of this interaction was discussed with the coffee farmers and its equation defined based on scientific literature [50], allowing us to merge scientific knowledge with the coffee farmers' empirical knowledge. The management practices, described by coffee farmers as important, were represented as interactions between the Coffee Farmer and the resources on his Estate, and the other actors of the system. The model was co-constructed over a period of nine months. It evolved considerably during this period, to accommodate for the feedback received by participants at each step of the process, as described in the following section.

Figure 2: Conceptual Model of the Kodagu Role Playing Game – The system components are either Resources (round squares) or Actors (ovals). Resources are spatial units (blue), physical elements (violet), sets of norms (pink) or natural elements (green). The Actors are either autonomous (yellow) or scripted (orange), meaning that in our model, their behaviour is restricted. In practice, orange actors were played by members of the research team. Actors and Resources are connected by one or two-sided arrows that represent the main interactions between them. Each arrow can be understood as a verb linking two components to create a sentence. For example, a Coffee Farmers plants a Silver *Oak. For* the sake *of clarity*, we have omitted the interactions between Coffee Farmer and Jungle Wood, *identical to* the *ones* between Coffee Farmer and Silver Oak.

The conceptual model, though simplified, has 5 different actors, handling 13 different resources, and more than 19 interactions. To allow players to handle this complexity, we produced a toy model translating the conceptual model into a boardgame that could be played with coffee farmers, academics and other stakeholders (Fig. 3). Both the conceptual model and the boardgame act as boundary objects [48].

Figure 3: Creating a toy model. In order to allow stakeholders to understand, manipulate and explore the behaviour of the conceptual model, we transformed it into a physical toy model. All the Resources identified in the conceptual model were represented. The Actors became players of the game, and the Interactions were detailed as the rules of the game. In addition to the resources listed in Fig. 2, we used fake bank notes to act as currency and allow for economic transactions during the game sessions.

All the elements of the conceptual model were used to define the game. The resources became the tokens (Silver Oak Stem, Silver Oak Canopy, Irrigation, Pepper Vine, Selling Permits, etc.) or the board itself (the Estates). The actors whose strategies we were interested in became the roles played during the game – Coffee Farmers (Fig. 4). The others were represented by members of the research team and their behaviour scripted according to the common understanding of this actor by the participants of the design process. Finally, the processes and interactions became the rules of the game, dictating what should happen when, in which order, and what options the players had at their disposal. The ecological processes form the core engine of the game – natural regeneration and yield – dictating the outcome of the interactions between the joint decisions of the coffee farmers and the physical constraints we had described in the model.

Figure 4: Playing the game. The combination of the board, the tokens, the players, the research team impersonating the scripted actors, the set of rules that define the steps and the outcomes of the actions taken, and the room where the game is played constitute a incarnation of the conceptual model, allowing the participants to manipulate and explore the behaviour of the model and the researchers to record the outcomes and generate discussions.

Unlike commercial games where victory conditions are given to the players, nothing here was imposed except the need to achieve a mininum income of 80 CINR (game currency, for CAFNET Rupee) to cover recurring costs. This threshold was low enough that it would easily be fullfilled with the sole income from coffee. Beyond that, players were free to decide what they wanted to aim for. The ensuing discussions allow the research team to elicit these “victory conditions”, and through them, discuss the values and objectives that drive the changes in the landscape.

Taken together, the tokens, the board, the rules, the research team, the players and the physical location where the game session is run, constitute an embodiment of the conceptual model presented earlier (Fig. 2). Through the process of playing, the participants get to explore the behaviour of the model, gather information, make choices, observe the outcomes of their actions and adjust their strategies accordingly. The research team can gather data during this process via three channels: (1) documenting the decisions made and their outcomes – for example counting the trees left in the estates, or recording coffee yields; (2) observing the social interactions and documenting the narratives developped by the players; and (3) gathering direct feedback from the participants, during the debriefing and through the use of a questionnaire designed to better understand the strategies of the players.

A full description of the model is provided in the Methods section.

Scenario testing

Previous research [16, 39] had identified tree tenure rights as critical to the decisions of coffee farmers. We used our boundary object to explore the potential environmental and livelihood impacts of a policy change contemplated by decision makers and stakeholders. Two scenarios were tested, each using the same model but with a slightly different set of rules regarding the possibilities of coffee farmers to cut, transport and sell Jungle Wood to the Timber Merchant. The first scenario (S1) represents the situation as it currently is in the field: Coffee Farmers are free to cut and sell the Silver Oaks in their estate, but have to request a specific permit from the Forest Department to sell their Jungle Wood (native trees). The research assistant playing the Forest Department official during gaming sessions behaves in such a way that securing this permit is difficult and time consuming, mimicking reality. The second scenario (S2) represents the situations as advocated by representatives of the coffee farmers' associations: no restrictions on the selling of Jungle Wood or Silver Oak from their Estate. In both cases, at the request of the stakeholders involved in the game design, we introduced a coffee market crash on Turn 4, mimicking recent events in the global coffee market. The definition of the scenarios was agreed upon during a specific workshop involving coffee farmers, academics and policy makers engaged in the CAFNET project that funded this research (see Acknowledgments).

In S1, there are thus two channels to sell Jungle Wood. Players can sell their Jungle Wood logs to the Timber Merchant and receive the full value of the timber through the proper procurement of a valid Timber Selling Permit. This requires filling in forms, obtaining stamps and signatures from several members of the research team posing as administrative clerks, including the Forest Department official, who all have to deal with the simultaneous demands of all prospective timber sellers, under a strict time constraint. This process is difficult, time consuming and frustrating, according to the players themselves. At the request of the stakeholders involved in the game design, as the game progresses, players could also try to secure a direct agreement with the Timber Merchant who would do the administrative paperwork on their behalf, at the cost of a fraction of the timber price. In S2, there is no longer need for the Timber Selling Permits and the players can bring their Jungle Wood logs directly to the Timber Merchant and receive the full payment as per the market price.

We organised 8 sessions, each time playing the first scenario in the morning and the second scenario with the same players in the afternoon; 57 players in total and numbers varying between sessions (min 5, max 8). Both scenarios began with the same initial conditions, described in the Methods section. We measured and recorded the following indicators during the game sessions, which also served to support the discussion with the players during the debriefing: (1) the income of the players, (2) the number of trees sold in the market, (3) the number, (4) age class, and (5) species of the trees left in their Estate. The cumulative outputs of the game sessions suggest the potential impacts of the policy change in terms of livelihood, monitored through the income of the players, the economy, represented by the supply of logs to the Timber Merchant, the environment, represented by the changes of the composition of the canopy cover of the Estates (values after ± are Standard Deviations).

Impact on livelihoods

We recorded the total income of the players – adding the revenues from the sale of coffee, pepper, and timber (Fig. 5). The total income was significantly different between the scenarios ($p=0.02$) with players having a 20 CINR (±4.3, LLR= 22.21, P = 0.001) higher income per round in S2. The difference came from the increased revenue from timber (LLR =125.61, $p<0.01$), as there was no significant difference between the revenue from coffee (LRT = 1.78, $p=0.194$) or from pepper (LRT=3.44, P=0.065). Coffee

Farmers in the game were better off when the restrictions on the sale of Jungle Wood were lifted. The downward slope of the income curves reflects the fact that the game had a coffee market crash designed to happen in round 4, for both scenarios. It is of no relevance to the comparison to the two policy scenarios.

Figure 5: Income and revenue of the players from coffee, pepper and timber. Income in CINR, a fake monetary unit created for the purpose of the game. The market price for Coffee in round 4 decreased because of the scripted market crash, reducing the income of all players. For all subfigures, the line represents the predicted mean (Scenario 1 Black, Scenario 2 Gray) and the shaded band indicates the standard deviation.

Impact on the timber supply chain

We monitored the amounts of logs sold to the Timber Merchant in both scenarios (Fig. 6). In S1, players sold 234 logs in total, 76% of them Silver Oak. The two channels to sell Jungle Wood, with permit and through direct agreement, contributed 9 and 15% of the logs sold. In S2, the number of logs brought to the market has more than doubled – 517 logs in total, and 41% of them Jungle Wood

Figure 6: Type of timber sold on the market. Cumulative timber sales in scenario 1 (left) and scenario 2 (right). The logs traded in scenario 1 are either mature and saplings of Silver Oak (SO), or mature Jungle Wood sold with a Timber Transport and Sale Certificate (JW Mature TTSC) or through a direct arrangement (JW Mature Direct). In scenario 2 no TTSC was required for selling jungle wood (JW). The size of the pie charts reflect the amounts of timber on the market.

Impact on tree cover

The evolution of the tree cover of the Estates in the game was the result of the interaction between the ecological processes represented in the rules of the game and the management decisions of the Coffee Farmers. Tree cover could be tracked with three indicators: (1) tree density (number of trees on the boards), (2) stand structure (proportion of seedlings, saplings and mature trees) and (3) stand composition (proportion of Jungle Wood and Silver Oak).

The average number of trees (saplings and mature trees) per estate was significantly greater under scenario 1 (7.63 ± 0.13 trees) than under scenario 2 (6.22 ± 0.14 trees; LLR = 91.02, P = 0.001). The average density of Jungle Wood trees was also greater in scenario 1 (5.55 ± 0.38) than scenario 2 (3.66 ± 0.38; LLR = 143.45, P = 0.001). In contrast, the density of Silver Oak trees was slightly, but significantly, greater in scenario 2 (2.56 ± 0.35) than scenario 1 (2.09 ± 0.34; LLR = 14.14, P=0.001). In both scenarios the density of Silver Oak showed an upward trend as the rounds progressed, while the density of Jungle Wood trees remained stable or decreased (Fig. 7).

Figure 7: Impact of policy scenarios on the tree cover. Evolution per round of the total number of trees, of the number of Silver Oak, and the number of Jungle Wood trees at the end of each round on the game board of the players in the two scenarios. Scenario 1 (left) the farmer does not possess the rights to harvest jungle wood and needs to obtain a certificate to cut them, while in scenario 2 (right) no such restrictions are present. For Silver Oak trade there are no restrictions in both scenarios. The initial conditions of the game board consisted of six jungle wood trees, two Silver Oaks and two jungle wood seedlings. For all subfigures the line represents the predicted mean and the band indicates the standard deviation.

The stand structure shaped by the players in their Estates also changed with the scenarios (Fig. 8). In each scenario, the structure seems stable after an initial adjustment. It seems that players establish a stable rotation, harvesting only a fraction of their mature trees thus keeping a constant canopy. However, this “stable state” is very different between scenarios. The proportion of mature trees is significantly lower in Scenario 2 than Scenario 1 (LLR = 231.28, p = 0.001).

Figure 8: Impact of policy scenarios on the canopy structure. The bars represent the age structure of the canopy – seedlings, saplings, mature trees, in proportion of the total number of trees standing. The proportion of mature trees in the gamescape diminishes significantly (S1: 0.54; S2:0.29; z=7.9; p<0.0001) as they are replaced by seedlings and saplings

The proportion of *Silver oak* in the game increased significantly between the two scenarios (Fig. 9). In the second scenario, the proportion exceeded 50% of the trees present in the game, against 30% in the first scenario (see also Fig. 7 centre). When players no longer have restrictions on the cutting and selling of Jungle Wood, they increase the pace of transition towards a simplified, *Silver oak* dominated canopy cover in their coffee estates.

Figure 9: Impact of policy scenarios on the canopy composition: Evolution of the proportion of Silver Oak (*Grevillea robusta*) and Jungle Wood trees (saplings and mature) in the gamescape, over the four rounds of both scenarios. The bars represent the proportion of Jungle Wood (brown) and *Silver oak* (green), as a percentage of the total number of trees standing in the gamescape. The proportion of Jungle Wood in the gamescape diminishes significantly in Scenario2 ($p < 0.0001$), as Players replace it with Silver oak.

Discussion

Dealing with complexity

The coffee agroforestry landscape of Kodagu is the result of the complex interactions between (i) ecological processes – the link between shade and productivity, the differential tree growth between *Silver oak* and most other tree species found in the coffee agroforestry landscape of Kodagu – (ii) the coffee farmers' needs and aspirations – improving their livelihood and balancing risks – and (iii) the norms and institutions regulating the access of the latter to the former – timber regulations, markets, informal arrangements. Given this complexity, the multiple feedback loops in the system and the capacities of the stakeholders to revise their strategies based on new information, anticipating the impacts of a policy change using only one's cognitive capacities and a mental model is challenging at best, and certainly overwhelming. Our participatory modelling approach thus has the potential to pave the way for an explicit integration of humans' bounded rationality and behavioural plasticity in models of landscape change, with due recognition to the subjectivity of model construction and the limits of their application.

As with all other model components, policy of land ownership in Kodagu is far more complex than depicted in the role-playing game. With 37 possible land tenures [51], the ownership of the native trees depends on whether the land is redeemed or not. To avoid getting lost in complexity, together with the stakeholders involved in the design process, we reduced it to two fundamental scenarios, scenario 1 (No Policy Change) with restrictions in cutting and selling jungle wood, and scenario 2 (Restitution of Rights) without restrictions.

The results of the gaming session suggest that farmers would be better off were they to receive full rights over the jungle wood in their estates. Having access to an additional resource in their land, they are likely to increase their income, and benefit from an additional easily accessible safety net in case of market fluctuations of their main crop, coffee. To a large extent, pepper already plays this role, and the synergies between pepper cultivation and the plantation of *Silver oak*, regularly mentioned by farmers as a "good stand for pepper", strengthen this point. As seen in our sessions, the investment of players in pepper cultivation is regular and sustained.

This improvement of livelihood would likely stem from an increase of the flow of timber leaving the agroforestry system. In the game sessions, the amount of timber exported by the farmers more than doubled, and the increase overwhelmingly came from the Jungle Wood logs felled in the estates.

While players maintain tree cover under scenario 2, the trees in their estate are younger. The rotation time is shortened as a result of the changing management strategies of the players. This faster turn-over, were it to happen in the real system, would translate into a reduction of the basal area of the plantations, and a consequential release of carbon stored above ground, with implications for the GHG emissions of the system.

Finally, we observed that when given rights, players decide to hasten, rather than reverse, the conversion of the canopy cover from Jungle Wood to *Silver oak.* Players respond to the policy scenario by replacing the original cover with one made of a single fast-growing species. This strategy, contrary to what was expected based on the narratives developed by defendants of the farmers' rights, surprised the research team. With the provision of a possible rebound effect on the very first turn, where farmers would quickly realise the benefits of the new policy change (cutting Jungle Wood) before the window of opportunity closed, the behaviour we had come to expect was one of farmers deciding to retain in the system a resource – Jungle Wood - they could now fully benefit from. This should have translated into a stabilisation and/or decrease of the proportion of *Silver oak* in the last rounds of scenario 2.

Based on our results and on the subsequent discussions with the players, we have now come to expect the opposite. Simply put, the fast rotation of *Silver oak* trumps the market premium for high quality native trees, the stated ecosystem services farmers attribute to the original canopy cover, or even a hypothetical existence value of the native trees – all of these arguments having been raised in interviews or during the game sessions.

In addition, our model did not include tree mortality, and as a result, the only Jungle Wood trees removed from the game where the result of a conscious decision by players. We expect the transition to *Silver oak* would have been even faster in the game had we included tree mortality, as players would probably have made use of the opportunity to replant *Grevillea*. Finally, if we consider that in reality natives trees are a mix of many different species, many of them soft woods without market value, the trend we observe in the game is even more conservative.

Our work allows unravelling the different elements weighted by coffee farmers when making decisions about coffee farming, which goes beyond shade management and timber cutting. The results we describe in the “gamescape” do not aim at predicting real policy outcomes, but highlight the forces driving the system, and serve as basis for informed discussions. The game and the conceptual model, acting as boundary objects, enable stakeholders to grasp and manipulate the complexity of the system. The model lets us explore, in a safe and friendly arena, the likely impacts of a policy change– which in the real world has been hotly debated for more than ten years, and which cumulates in a constant and seemingly intractable wicked problem inflicted by conflicts – the restitution of coffee Farmers’ rights to cut and sell Jungle Wood trees in their Estates.

Model calibration, complexity and timescale

The purpose of the role-playing game is not to create real world predictions; the behaviour in the game is nothing more than “behaviour in the game” [52]; the exact values of the model parameters are meaningless. Our model trades precision for realism and generality [53]. The dynamics resulting from the game sessions “feel real” to the participants, the chain of thought of players – all coffee farmers in real life - devising their strategies are similar to those of the farmers in the field, and the elements they consider are part of the model too. The starting conditions mimic the current situation in the field. The game presents players with a system where *Silver oak* represents 20% of the trees in the landscape. Other initial conditions could steer the system in other directions, but this would need to be tested and validated. The game parameters are designed in a way that confronts the players with the problem in the time allotted for a game sessions – a couple of hours. This constrained calibration encourages players to speak up and therefore facilitates the dialogue between stakeholders, scientists and officials.

Lessons learnt

Players’ actions in the role-playing game suggest that a policy giving more autonomy to farmers in managing Jungle Wood would result in the fast replacement of Jungle Wood with *Silver oak*, accompanied by an increased income from the sale of timber, a loss of biodiversity and possibly carbon storage. Players planted more *Silver oak* in the second scenario, a behaviour in line with the Forest Department’s claim that the liberalisation of the timber market will push farmers to intensify. The percentage of shade seems however untouched by this policy change.

Landscape dynamics result from the interactions between physical, biological and social processes. We present here an approach that allows stakeholders to understand the drivers of landscape change and explore potential responses. The approach rests on three components. First, an explicit conceptual model that highlights the system boundaries participants agree upon. It is descriptive, and not normative. Second a game that acts as boundary object and lets the participants grasp driving forces and explore system behaviour from within. Finally, the definition of scenarios for players to explore the impacts of management interventions. The conceptual model is useful to allow participants to stay focused on the topic to explore. It build consensus on how the system works. Alone however is not sufficient. The impacts of emergent phenomena and counter intuitive feedback loops cannot be easily predicted from the conceptual model itself. The game, offering participants to enter the system and be a part of it, gives them increased understanding, even if there is no new data formally introduced. This is an element that requires further research, as we are unable yet to measure the epiphany learning participants report [54]. Finally, scenario testing lets participants explore the resilience of the system. Sessions with identical starting points but divergent outcomes suggest stakeholders have a scope to steer the system in different directions. If game sessions under a specific scenario always reach the same end-point, the system is probably in a lock-in, and stakeholders are probably powerless to change course and must rely on adapting their strategies instead.

In this process, trust in the model, ownership as participants feel they have contributed to the common description of the world, and momentum to build understanding from one session to the other are especially relevant to allow emergence and innovation. Without model elicitation, participants will not trust the model. Without playing the game, participants will not experience the process and draw the insights. Without the exploration of all possible strategies, decisions made will not be robust to surprises [26]. Each of the three processes is a necessary step, but not sufficient. Combining the three makes a powerful combination to help stakeholders address the complexities of landscape management.

Games can be used to address conflicts in conservation [55], and the constructivist approach to their use we present here empowers participants. The question then is how outsiders will respond. The process we present will not modify the power structures in place, unless linked to local leadership and legitimacy [56].

Our game revealed system components and processes that had been identified in none of the policy narratives of the concerned parties. These represented hidden pitfalls that would have plunged the system in a non-desired state had the current policy change been implemented as initially designed. We were however unsuccessful in transferring these lessons to the policy process, in part because we did not ensure lasting engagement in the field, in part because the findings undermined the initial position of our main partners, the coffee farmers themselves.

Materials and methods

Companion modelling

The model and the game were developed through the approach called Companion Modelling (ComMod) [57]. ComMod is an interactive process where stakeholders, supported by the ComMod practitionners, develop models and simulations to be used as mediating tools in the support of problem framing, collective learning, dialogue, and collective decision-making [58]. A ComMod process undergoes multiple iterations, where the problems, models, and underlying understanding of the process at play are progressively refined and if necessary redefined – end-user interests drive the modeling and simulation activities

The ComMod process in Kodagu was initiated in 2009, as a sub-component of the Connecting, Enhancing And Sustaining Environmental Services And Market Values Of Coffee Agroforestry In Central America, East Africa And India (CAFNET) project, that lasted from 2007 to 2010.

The initial phase took place between March and August 2009, with 68 interviews, participant observation (5 months of presence in the field by one of the authors), 3 group discussions and modelling workshops) and 5 game sessions organised, totalling 72 stakeholders, essentially coffee farmers but also academics, timber merchants and representatives of the Forest Department [59]. This led to the design of the conceptual model and the validation of the first game prototype. The two scenarios where defined in a workshop of the CAFNET project involving academics, representatives of the Central Coffee Board, officials from the Karnataka Forest Department and coffee farmers. The game was then brought back to the field for eight exploratory game sessions involving 57 players organised between November 2010 and May 2011.

Model, game rules and sessions

The conceptual model is the first output of the ComMod process, and as such is presented in the Results section. Each of the interactions detailed in Fig. 2 is defined and detailed in the model description, together with the processes A model based on the best available knowledge of the processes involved in coffee management was constructed.

The RPG was played with 57 farmers, distributed in eight playing sessions and each player playing two scenarios. The playground is a board representing the coffee Estate with 10 holes filled initially (at round 0 of the game) with toy models of six Jungle Wood trees, two *Silver oak* trees and two JW seedlings. The players need to manage their estate by:

- cutting and pruning trees
- obtaining and planting SO seedlings and pepper
- buying and installing irrigation
- selling coffee, pepper and timber
- interacting with players and officials
- paying their living costs

There are several offices set up in the game room, where players can obtain information and talk to the officers. In the Official Clerk’s Office, the market prices of coffee, pepper and irrigation are displayed. The prices of wood are displayed in the Timber Merchant Office, and forms for obtaining Timber Transport Cutting and Sales (TTCS) certificates for selling JW are available from the Forest Office. The Coffee Board shows graphs of the dependency of coffee and pepper productivity on shade and irrigation. SO seedlings and pepper vines (one per tree) can be bought at the nursery, while JW seedlings appear naturally in the estate.

The first scenario, played in the morning, resembles the current state of policy where a certificate is needed to transport and sell JW, while no restrictions apply to SO. Players have the alternative option of asking the Timber Merchant to deal with the formalities. If the Timber Merchant accepts, they will get a lower price from the direct sale . During the fourth round of the first scenario, a coffee market crash is announced by the game master at the start of the round. The price for coffee bags will drop from 6 to 2 CINC for this turn only. Scenario 2 is played in the afternoon, with JW no longer being protected. A market failure is simulated in round 4, as in scenario 1.

Trees can be cut, by removing the toy model from its hole in the Estate. A tree that is cut during the game by a player cannot be replanted. Instead, a new seedling will need to appear (JW) or be planted (JW). A tree can also be pruned by removing the crown and leaving the stem in place. From round to round, the trees grow and the crown reestablishes. All seedlings are replaced with saplings at various rates depending on the species: SO saplings become mature trees after one round, while JW saplings need two rounds to become mature. Crowns regrow every round. At the end of every round farmers collect their crop yields, which vary depending on their management decisions and a random factor.

The shade-yield relation [50] was taken as basis for the model's dynamics. The parameters were fitted to simulate outcomes judged plausible by the participants and adjusted through multiple testing rounds. Shade is calculated for every estate with every sapling and mature tree with crown adding 10% of shade to the estate. The following formulas were used to calculate the yields:

Coffee yield (in bags):

$$Y_C = \alpha S^2 + \beta S + \delta + \varepsilon(S) \qquad (1)$$

Where Y_C is the coffee Yield (in bags), S is the shade value of the estate (from 0 to 1), and α,β,δ a set of parameters that change with the presence of irrigation.

	Without Irrigation	With irrigation
α	-45	-35
β	40	20
δ	10	20

ε(S) is a random factor that depends on Shade, to represent the dampening effect shade has on yield fluctuations [50].

$$\varepsilon(S) = 10K(1 - S) \qquad (2)$$

With K following a normal distribution. Values were rounded to the integer and given a minimum value of 5 bags to allow unlucky players to remain in the game.

Pepper yield (in bags):

$$Y_P = V_{Sh} + 0.6V_{FS} \qquad (3)$$

Where Y_P is the pepper yield (in bags), V_{Sh} (Shade) the number of pepper vines growing on trees with canopies and V_{FS} (Full Sun) the number of pepper vines growing on pruned stems. The value is rounded to the closest integer.

If players do not sell their harvest, it is lost. There is no storage capacity. Farmer can interact with each other to sell and buy goods. The Forest Office can control players "transporting" (walking around with) or cutting trees to ensure that they have a certificate, and can otherwise fine them.

Additional costs and values

Item	Cost (in CINC)
Irrigation (per round)	10
Pepper vine	1
Silver oak seedling	1
Simple House (per round)	80
Medium House (per round)	140
Large House (per round)	220

Item	Value (in CINC)
Jungle Wood sapling	0
Jungle Wood mature	16
Silver oak sapling	3
Silver oak Mature	10

Coffee bag (normal price)	6
Coffee bag (crash price)	2
Pepper bag	2

The following values are recorded every round for each player's estate in an Excel sheet: (i) percent shaded, (ii) irrigation, (iii) number of pepper vines (sun/shade), iv) market gains (coffee & pepper bags, SO saplings, SO mature, JW mature TTSC, JW mature direct and price), (v) size of house (simple/medium/large), (vi) expenses (pepper & SO seedlings bought, fines, misc. costs), and (vii) tree abundance (SO/JW, seedling, pruned sapling, crowned sapling, pruned mature, crowned mature). These data are then used to calculate players' income depending on market prices.

Statistical analysis

We used mixed-effects models to examine the relationships between scenarios and turns and the various responses of interest. Models of total income, revenues from coffee, timber and pepper assumed Gaussian error distributions. The proportions of tree locations occupied by any trees (total cover) and saplings and mature trees of jungle wood or silver oak were modelled using Generalized mixed-effects models assuming binominal error distributions [60, 61]. All models included scenario and round and their interaction as fixed-effects and variation among sessions and players was accounted for by adding them as random effects with intercepts for players and sessions drawn from normal distributions. The full binomial models were examined for overdispersion. We assessed the statistical significance of each term by computing the log-likelihood ratio (LLR) of models with and without the term of interest. Tests of the main effects of scenario and round were assessed after removing their interaction. Statistical significance of differences between models was assessed by comparing the observed LLR to a null distribution, created using a parametric bootstrap. The null model (the model without the term of interest) was used to simulate the response data 999 times. Both the null model and the model with the term of interest were fitted to these simulated response data and the LLR between calculated. The proportion of simulated LLR values that were greater than the observed LLR value was used as a test of the null hypothesis (that the term of interest was not important). Analyses were carried out with R 3.3.0, using the packages lme4 v1.1-12 and pbkrtest v0.4-6.

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Figure legends

Figure 1: Kodagu Landscape : mosaic of terraced rice fields in the lowlands dotted with water tanks used to irrigate the coffee and coffee plantations on the slopes, with a great variety of tree cover,. Google Earth Map. Position 12°10'10.97"N 75°46'13.42"E

Figure 2: Conceptual Model of the Kodagu Role Playing Game – The system components are either Resources (round squares) or Actors (ovals). Resources are spatial units (blue), physical elements (violet), sets of norms (pink) or natural elements (green). The Actors are either autonomous (yellow) or scripted (orange), meaning that in our model, their behaviour is restricted. In practice, orange actors were played by members of the research team. Actors and Resources are connected by one or two-sided arrows that represent the main interactions between them. Each arrow can be understood as a verb linking two components to create a sentence. For example, a *Coffee Farmers* plants a *Silver Oak.* For the sake of clarity, we have omitted the interactions between *Coffee Farmer* and *Jungle Wood*, identical to the ones between *Coffee Farmer* and *Silver Oak.*

Figure 3: Creating a toy model. In order to allow stakeholders to understand, manipulate and explore the behaviour of the conceptual model, we transformed it into a physical toy model. All the Resources identified in the conceptual model were represented. The Actors became players of the game, and the Interactions were detailed as the rules of the game. In addition to the resources listed in Fig. 2, we used fake bank notes to act as currency and allow for economic transactions during the game sessions.

Figure 4: Playing the game. The combination of the board, the tokens, the players, the research team impersonating the scripted actors, the set of rules that define the steps and the outcomes of the actions taken, and the room where the game is played constitute a incarnation of the conceptual model, allowing the participants to manipulate and explore the behaviour of the model and the researchers to record the outcomes and generate discussions.

Figure 5: Income and revenue of the players from coffee, pepper and timber. Income in CINR, a fake monetary unit created for the purpose of the game. The market price for Coffee in round 4 decreased because of the scripted market crash, reducing the income of all players. For all subfigures, the line represents the predicted mean (Scenario 1 Black, Scenario 2 Gray) and the shaded band indicates the standard deviation.

Figure 6: Type of timber sold on the market. Cumulative timber sales in scenario 1 (left) and scenario 2 (right). The logs traded in scenario 1 are either mature and saplings of Silver Oak (SO), or mature Jungle Wood sold with

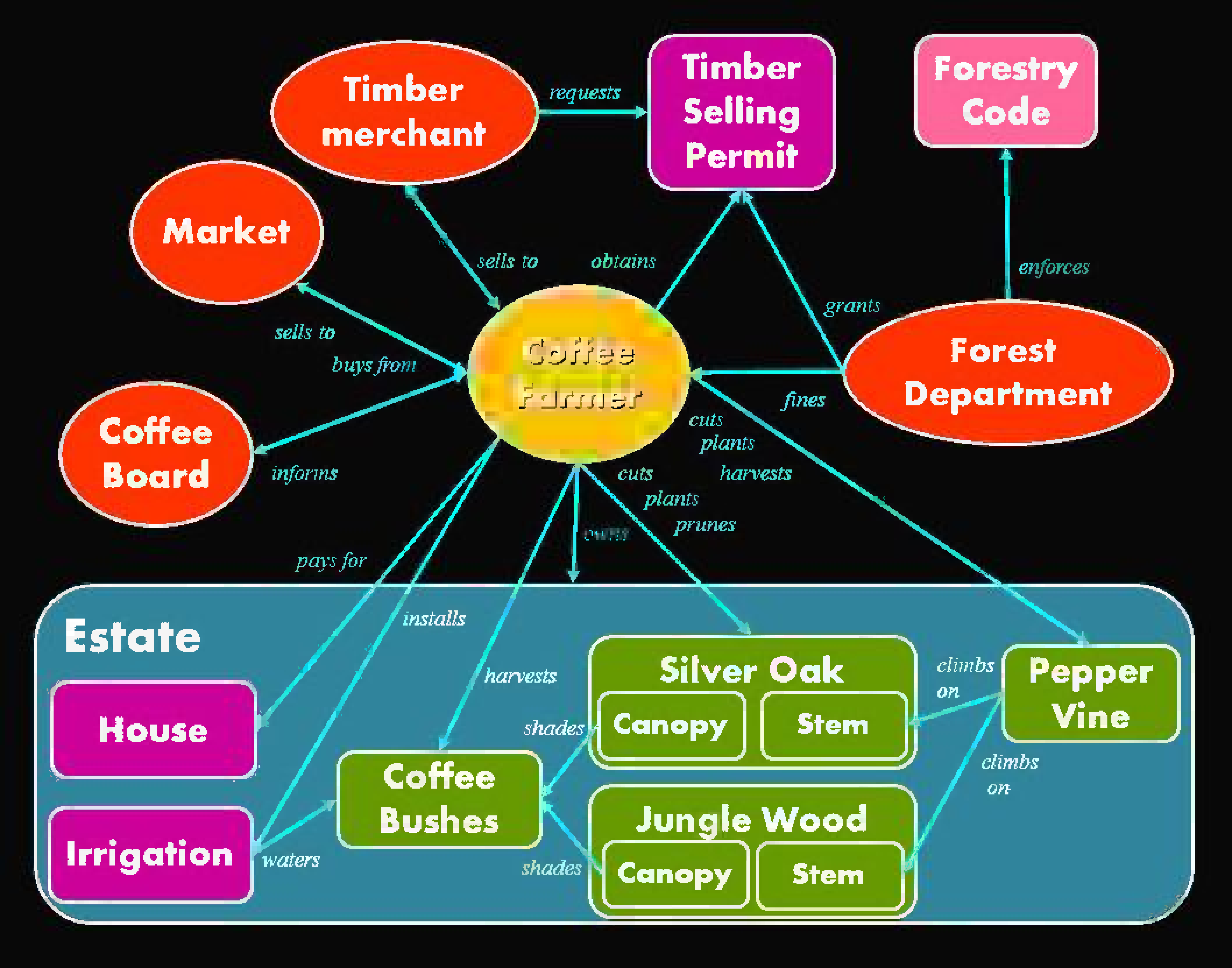
a Timber Transport and Sale Certificate (JW Mature TTSC) or through a direct arrangement (JW Mature Direct). In scenario 2 no TTSC was required for selling jungle wood (JW). The size of the pie charts reflect the amounts of timber on the market.

Figure 7: Impact of policy scenarios on the tree cover. Evolution per round of the total number of trees, of the number of Silver Oak, and the number of Jungle Wood trees at the end of each round on the game board of the players in the two scenarios. Scenario 1 (left) the farmer does not possess the rights to harvest jungle wood and needs to obtain a certificate to cut them, while in scenario 2 (right) no such restrictions are present. For Silver Oak trade there are no restrictions in both scenarios. The initial conditions of the game board consisted of six jungle wood trees, two Silver Oaks and two jungle wood seedlings. For all subfigures the line represents the predicted mean and the band indicates the standard deviation.

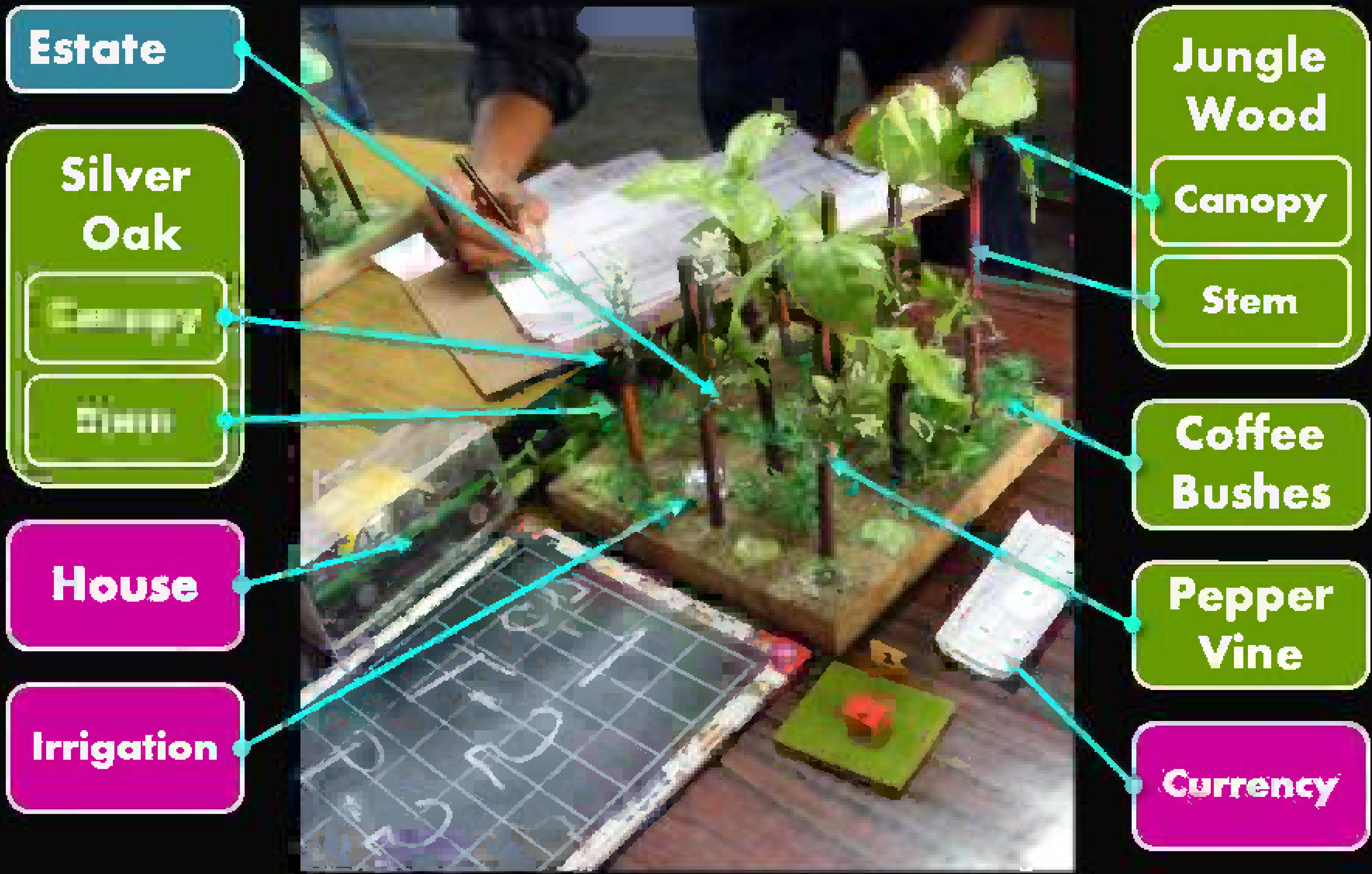
Figure 8: Impact of policy scenarios on the canopy structure. The bars represent the age structure of the canopy – seedlings, saplings, mature trees, in proportion of the total number of trees standing. The proportion of mature trees in the gamescape diminishes significantly (S1: 0.54; S2:0.29; z=7.9; p<0.0001) as they are replaced by seedlings and saplings

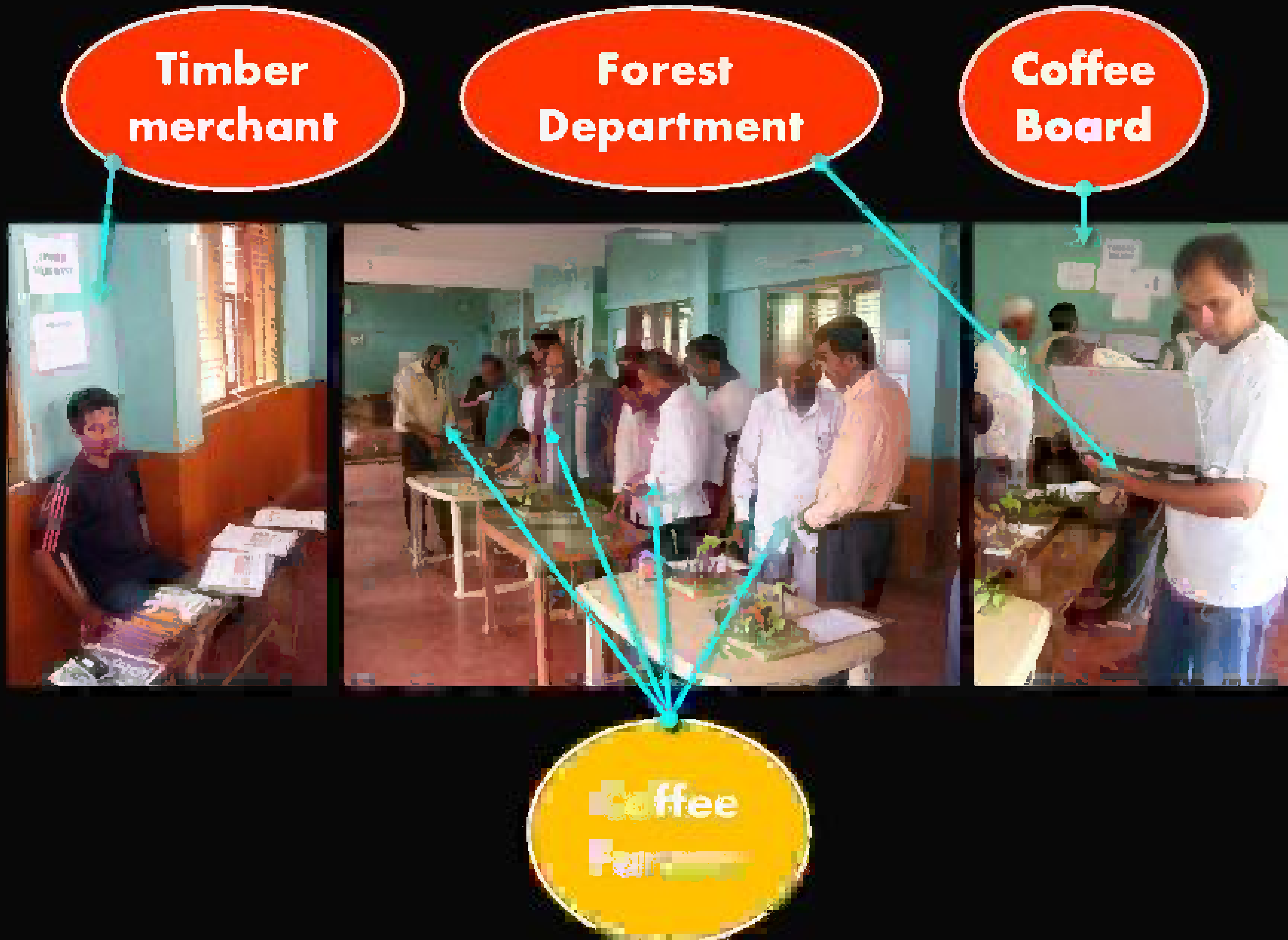
Figure 9: Impact of policy scenarios on the canopy composition: Evolution of the proportion of Silver Oak (*Grevillea robusta*) and Jungle Wood trees (saplings and mature) in the gamescape, over the four rounds of both scenarios. The bars represent the proportion of Jungle Wood (brown) and *Silver oak* (green), as a percentage of the total number of trees standing in the gamescape. The proportion of Jungle Wood in the gamescape diminishes significantly in Scenario2 ($p < 0.0001$), as Players replace it with *Silver oak*.

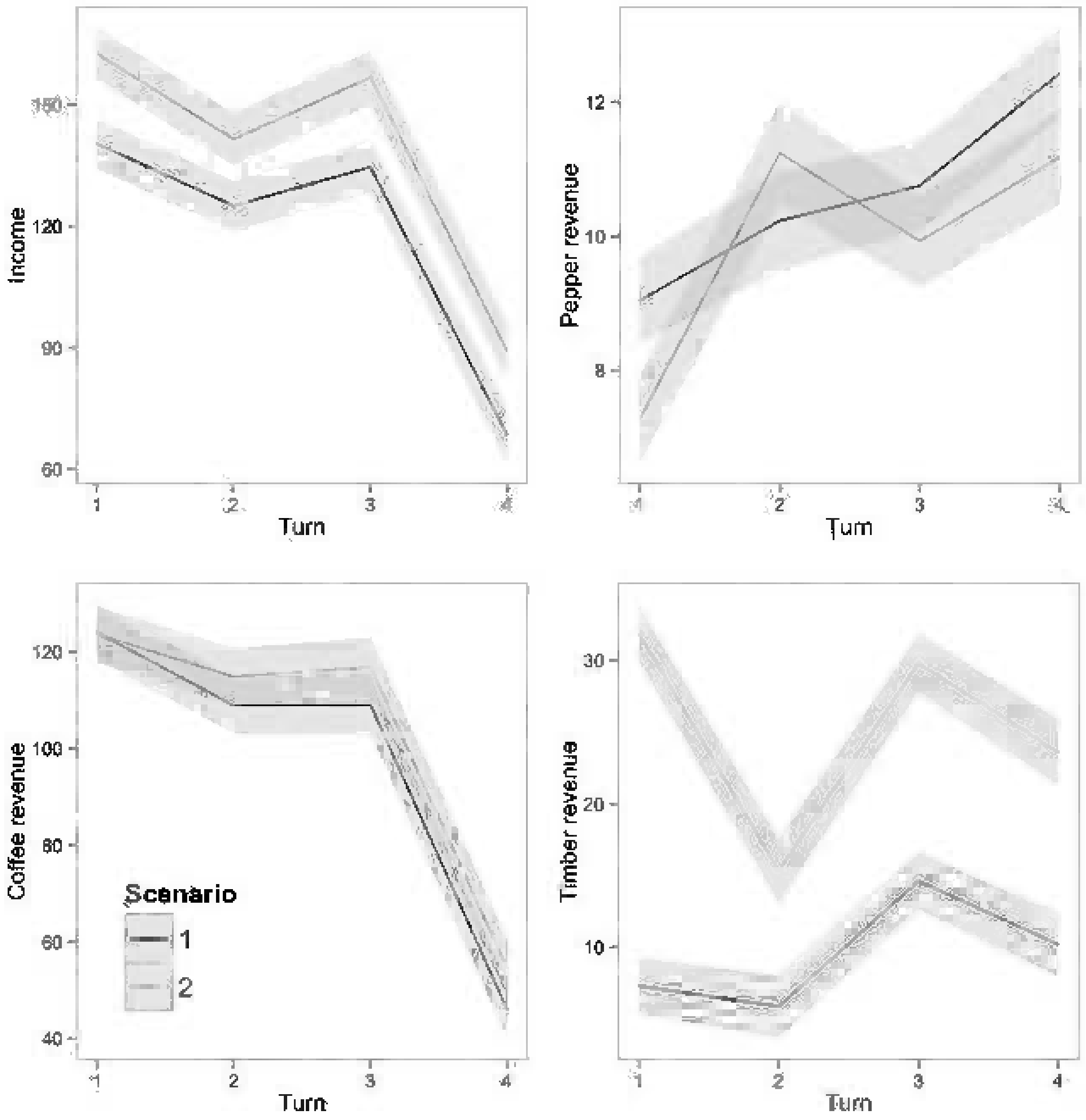

Rice paddies
Coffee Agroforestry
Water tank
Google earth



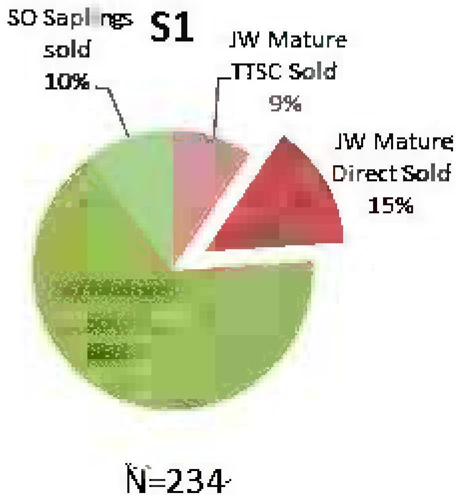
Timber merchant
requests
Timber Selling Permit
Forestry Code
Market
sells to
obtains
grants
enforces
sells to
buys from
Coffee Farmer
Forest Department
fines
Coffee Board
informs
cuts
plants
harvests
cuts
plants
prunes
pays for
installs
harvests
Estate
House
Silver Oak
Canopy
Stem
climbs on
Pepper Vine
shades
Coffee Bushes
climbs on
Jungle Wood
Canopy
Stem
Irrigation
waters
shades

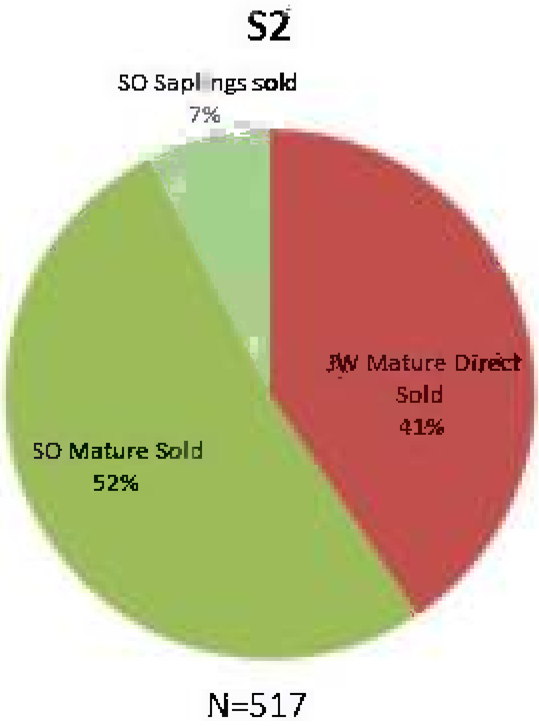

Estate
Silver Oak
House
Irrigation
Jungle Wood
Canopy
Stem
Coffee Bushes
Pepper Vine
Currency

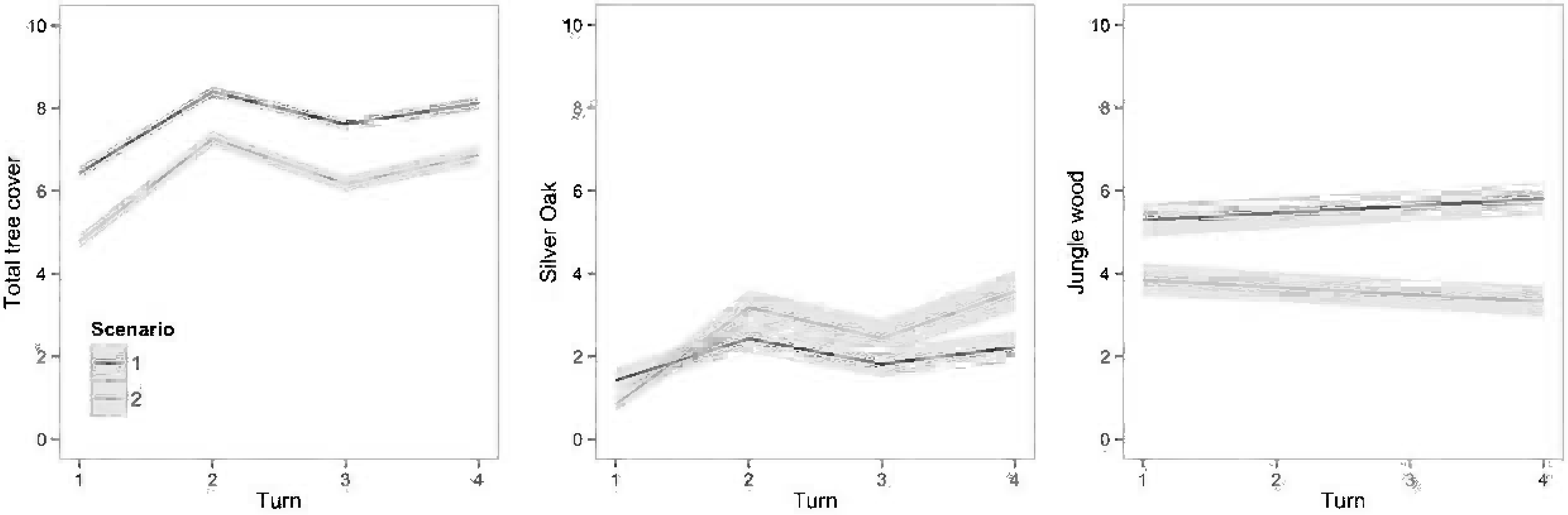

Timber merchant
Forest Department
Coffee Board



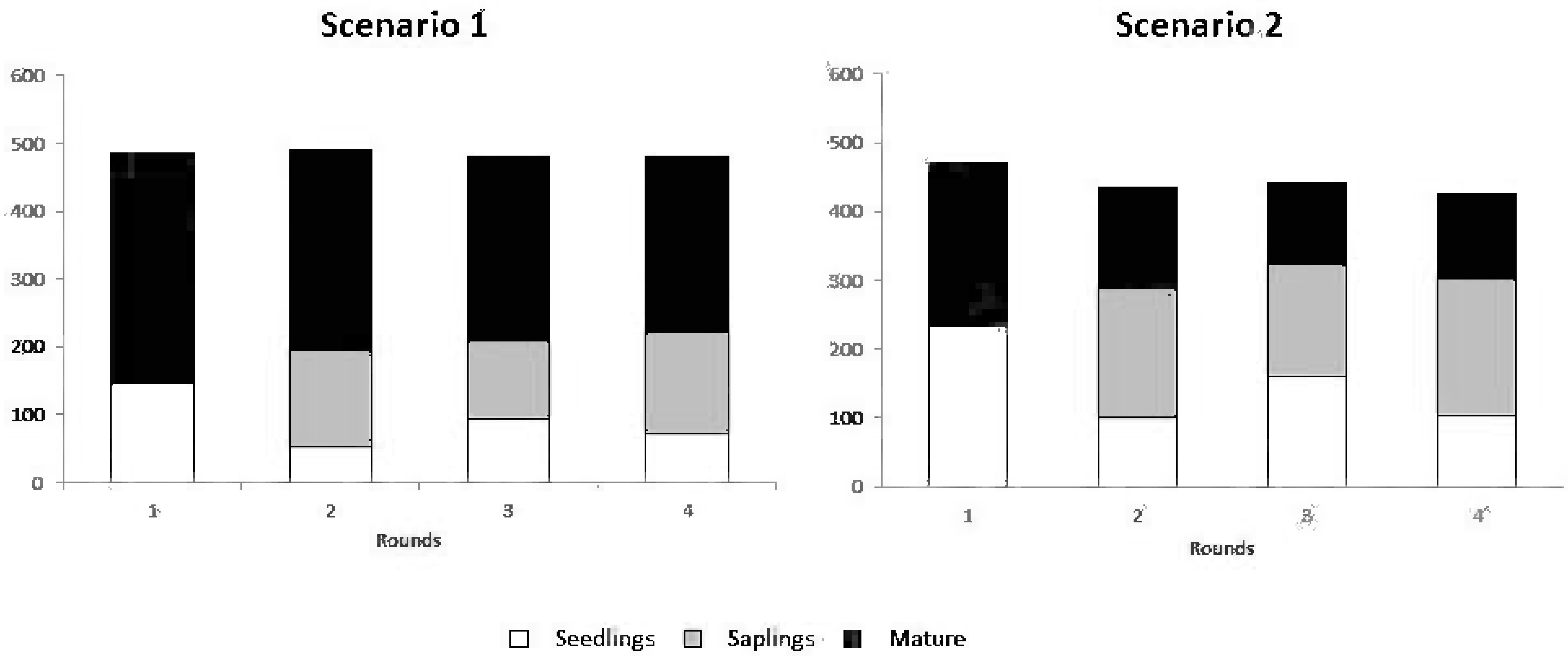
Income
Turn
Pepper revenue
Turn
Coffee revenue
Turn
Scenario
1
2
Timber revenue
Turn

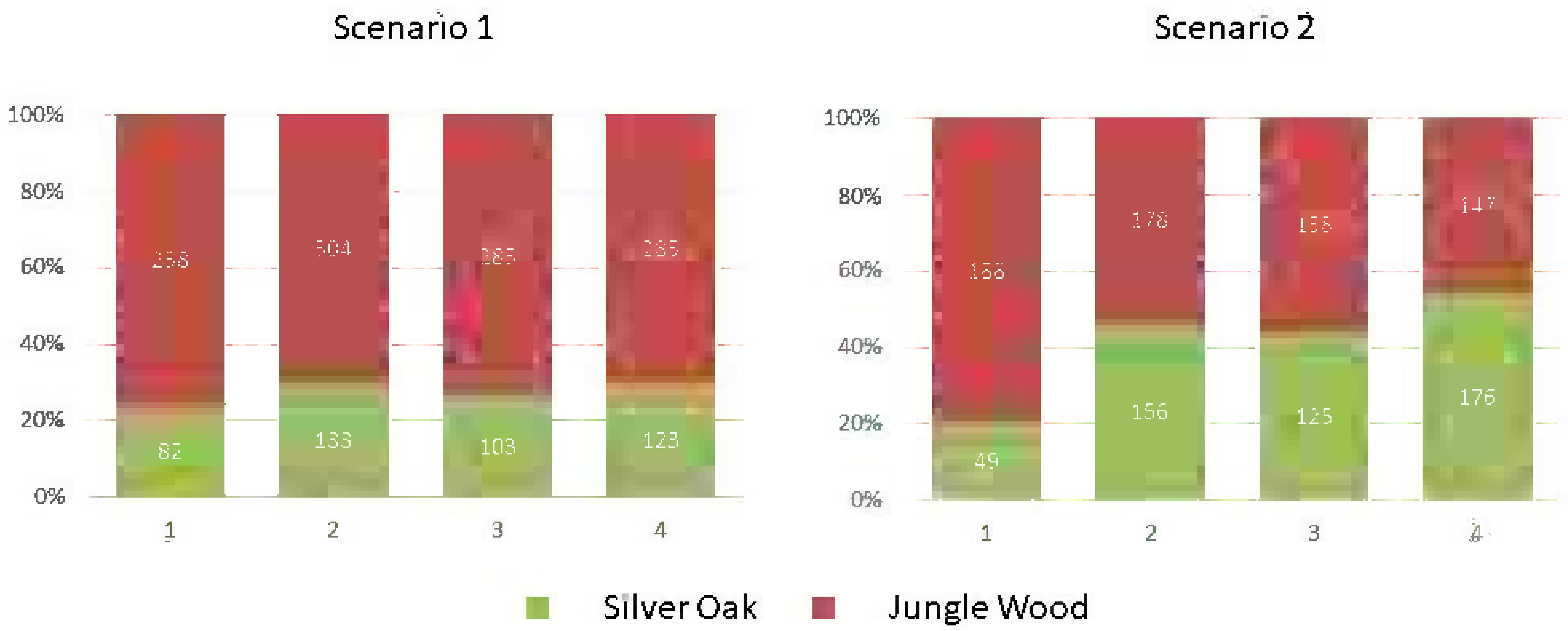

S1
SO Saplings sold 10%
JW Mature TTSC Sold 9%
JW Mature Direct Sold 15%
N=234


S2
SO Saplings sold 7%
JW Mature Direct Sold 41%
SO Mature Sold 52%
N=517



Total tree cover
Silver Oak
Jungle wood
Turn
Scenario
1
2
0
2
4
6
8
10
1
2
3
4


Scenario 1
600
500
400
300
200
100
0
1
2
3
4
Rounds
Scenario 2
600
500
400
300
200
100
0
1
2
3
4
Rounds
Seedlings
Saplings
Mature


Scenario 1
Scenario 2
100%
80%
60%
40%
20%
0%
82
133
103
123
49
178
156
125
176
1
2
3
4
Silver Oak
Jungle Wood