Integrated or monofunctional landscapes? Agent-based modelling for evaluating the socioeconomic implications of land use interventions

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Preface

The following material from the research conducted for this thesis has been presented:

- Chapter 4, 5, 6:

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- A summary of findings:

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  Serban A., 2017. *Predictive methods in environmental conservation*. International Conference on Conservation Biology, Cartagena, Colombia.

  Serban A., 2017. *Critically assessing the socioeconomic and environmental sustainability of land use interventions*. International Conference on Conservation Biology, Cartagena, Colombia.

Declaration

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the Preface and specified in the text.

It is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. I further state that no substantial part of my dissertation has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University of similar institution except as declared in the Preface and specified in the text.

This thesis does not exceed the regulation length of 80,000 words, excluding the table of contents, photographs, diagrams, figure captions, appendices, bibliography and acknowledgements.

Anca Serban
2017

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Summary

The effectiveness of land sharing and land sparing (LS/LS) approaches to conservation in the face of rising agricultural demands has been widely debated. While numerous studies have investigated the LS/LS framework from an ecological lens (yield-biodiversity relationship) the relevance of the framework to real life depends on broader considerations. Some of the key caveats include: i) limited knowledge regarding the feasibility of interventions given diverse stakeholders' interests, ii) the social acceptability (uptake) of these contrasting strategies to direct land users, and iii) limited knowledge regarding their impacts on individuals' livelihoods and food security. Without considering these social science dimensions proponents of the framework risk an incomplete picture that is not grounded in local realities and can paradoxically force into opposition the very conservation and development interests they seek to reconcile. Using a Companion Modelling approach, which comprises the development of a role-playing game (RPG) and an agent-based model (ABM), this thesis addressed these caveats. The research was based in the Nilgiris of Western Ghats India, a tropical agricultural system at the forest frontier.

The main findings show that through engaging local stakeholders in a participatory process, plausible land use strategies that align with their objectives could be identified. Stakeholders proposed three land use interventions. Two of them resemble a form of land sparing ('monofunctional' landscapes) on the farms: sparing land for Wildflower Meadows or Tree Plantations while increasing yield on the remaining land. The third intervention asks farmers to accept yield penalties for Intercropping more trees on their farms, a form of land sharing ('integrated' landscapes).

In terms of decision-making regarding the adoption of these three interventions by direct land users, the study reveals several findings. Firstly there are three main types of motivations that influence farmers' decision to adopt interventions, in order of importance: monetary benefits, pro-environmental motivations and social norms. Secondly, land use, the type of management preferred on the farm and whether land users accept trees on the farm or not are factors that influence what type of interventions is socially acceptable on individual farms. These factors have been detected in the in-depth household survey and also validated by the RPG. When assessing the adoption of the three interventions, *ex ante* their implementation, using an ABM, there are some important differences observed between the interventions. Wildflower Meadows is the intervention adopted by the largest number of households, whereas Intercropping is adopted across the largest area of land. Forest Plantations is significantly more unpopular then the other two interventions.

The third line of investigation, about the outcomes of adoption, has important policy implications. Adding a socioeconomic dimension to the ecological one adds a level of complexity and creates a less straightforward choice between the LS/LS strategies. None of the three interventions can provide optimal outcomes for production, aspects of biodiversity conservation, livelihoods and food security. Each intervention has indicators that score better compared to the other two interventions.

The findings demonstrate that the ecological focus of the LS/LS framework is insufficient to deal with real world complexities and lends itself to overly simplistic policy prescriptions. More meaningful policies could be achieved when bridging natural and social sciences to better understand the merits and limitations of the LS/LS approaches.

Acronyms

ABM(s)…………………………	Agent-based model(s) or agent-based modelling
ComMod……………………..	Companion Modelling
FCS……………………………	Food Consumption Score
HDI……………………………	Human Development Index
INR……………………………	Indian Rupee
LS/LS…………………………	Land sharing and land sparing
LULC…………………………	Land use and land cover
NBR…………………………..	Nilgiris Biosphere Reserve
PDS……………………………	Public Distribution System
PLUSES………………………	Policy Land Use Socio-Economic Simulator
RPG(s)…………………………	Role-playing game(s)
SC(s)…………………………..	Scheduled Castes
SHG(s)…………………………	Self-help group(s)
SL……………………………..	Sustainable Livelihoods Framework
ST(s)…………………………..	Scheduled Tribes
UPASI…………………………	United Planters' Association of Southern India
WG……………………………	Working Group of the relevant stakeholders

PART I

Chapter 1

Integrated or monofunctional landscapes? Unpacking the food-biodiversity nexus

1.1 Feeding a hungry world

The global human population is projected to reach 9.8 billion by 2050 (UN, 2017) and already 795 million people are estimated to be chronically hungry (FAO et al., 2015). In absolute terms, the highest burden of hunger is experienced in Southern Asia, followed by Sub-Saharan Africa. Most areas of the world have seen improvements, but regions such as Central Africa and Western Asia are moving away from the hunger targets, with a higher proportion of undernourished in the population now than in 1990–92 (FAO et al., 2015). While it has been argued that there is sufficient food globally for everyone to lead healthy and active lives (Alexandratos, 1999, Alexandratos, 2009), widespread inequality means the current world's food system is not adequately equipped to ensure equitable distribution for everyone (Conway, 2012, FAO et al., 2015).

Food security is described by the FAO (1996) as 'when everyone has physical and economic access to sufficient, safe and nutritious food' (FAO, 1996). Although this definition has been contested it still remains the most commonly used (Jones et al., 2013). Achieving global food security, within the context of a burgeoning global population requires 'major transformations' of the planet's food systems on multiple fronts (FAO, 2017a). Some of the key leverage points include: reducing inequality and poverty, addressing climate change, promoting dietary shifts, more efficient use of fertilisers and water, closing yield gaps, reducing food waste (particularly in developed countries) and ensuring a sustainable natural resource base or targeting food for direct consumption (Fedoroff et al., 2010, Gustavsson et al., 2011, Cordell and White, 2014, West et al., 2014, Alexander et al., 2017, Bennett, 2017, FAO, 2017, Fischer et al., 2017a, Myers et al., 2017). For example, estimates indicate that by reducing food waste in the United Sates of America, India and China an additional 413 million people per year could be fed (West et al., 2014).

Global food demand is partially driven by changing diets in increasingly wealthy nations, largely feeding the wants of the wealthy, not the needs of the poor (Tilman et al., 2011, Fischer et al., 2017a). As a result, growing demand for food is often taken as unalterable. Whilst changing existing production and consumption norms can reduce global food insecurity, meeting the dietary needs of everybody is unlikely without an increase in food production. Models indicate a need to increase food production by between 60 and 110% by 2050, largely in developing countries (Tilman et al., 2011, Valin et al., 2014, FAO, 2017a).

Of the estimated population that is not able to meet basic dietary needs approximately 80% live in rural areas and about half are smallholder farmers, commonly farming two hectares of land or less (FAO et al., 2015). These smallholders are currently the backbone of food production in the developing world. Managing approximately 500 million small farms they provide over 80% of the food consumed in large parts of the developing world, particularly Southern Asia and sub-Saharan Africa (IFAD-UNEP, 2013, Tscharntke et al., 2012, Graeub et al., 2016). There are multiple barriers that prevent these farms from achieving increases in production, including; competing land demands, climate change threats, water scarcity, land tenure rights, soil degradation, limited access to credit and capital for investment, unfair competition and restricted access to markets, extension services and inputs (Lee and Barrett, 2001, World Bank, 2008, FAO, 2017a).

1.2 A complicated relationship: agriculture and biodiversity

In the past, increases in global food production have resulted from an expansion in the area of arable land, a pressure that was partially alleviated with the advancement of technologies that allowed for intensification, leading to what came to be known as the Green Revolution (WCED, 1987, Borlaug, 2007). Many countries are now seeing a slowing down of farmland expansion. In others, yet to undergo an agricultural revolution, such as many African states, the conversion of natural habitat to agriculture is expected to continue (Pretty, 2008, Fedoroff et al., 2010, McLaughlin, 2011, Hertel et al., 2014). Impacts on biodiversity have been most noticeable in the tropics where over 55% of the land opened for agriculture between 1980 and 2000 came at the expanse of intact, tropical forests (Geist and Lambin, 2002, Gibbs et al., 2010). Such forests only cover approximately 5% of the global land surface yet they contain over 50% of the world's biodiversity. Tropical forests also represent a vital food security and livelihoods resource to many people (Wilkie et al., 2011, Vira et al., 2015, FAO et al., 2016).

Increasing productivity can in theory relieve the pressure on land requirements, however short-term improvements in productivity can create different forms of ecological stress, with extensive evidence linking conventional intensification with biodiversity loss (Foster et al., 1999, Lambin and Meyfroidt, 2011, Adams, 2012, Ceddia et al., 2014, Venter et al., 2016). Thus, achieving 'win-win' policy solutions is challenging given the multifaceted relationship between biodiversity and agriculture (Dudley and Alexander, 2017).

Biodiversity maintains global level ecological services in addition to a number of much more localized services of specific relevance to agricultural production, including: the operation of hydrological cycles, the recycling of nutrients, the conservation and regeneration of soils, and the pollination of crops (MEA, 2005, Turner et al., 2007). These ecosystem services influence the productivity of an agricultural system and its capacity to maintain production over a range of environmental conditions. Such services occur at the on and off farm scale. For example watershed protection offers a range of services from surface runoff regulation to erosion control and localized climatic effects (Daily, 1997). Biodiversity therefore plays a key function in the sustainability of agriculture through its role in maintaining the provision of vital services (Perrings et al., 2006, Glamann et al., 2017). It has also been argued that food is biodiversity, so biodiversity comes through both as a final good and as a supporting service, thus often creating confusion as to how biodiversity and ecosystem services fit together (Mace et al., 2012).

Whilst of substantial importance, biodiversity is often undervalued (MEA, 2005), a factor which drives its rapid loss (Daily et al., 2009, Dudley and Alexander, 2017). The global Living Planet Index, a measure of the state of the world's biological diversity based on the population trends of terrestrial, freshwater and marine vertebrate species, declined by almost 30 per cent between 1970 and 2008 (WWF, 2012). The global tropical index, a measure of biodiversity in the tropics, declined by 60 per cent during the same period, with agriculture playing a major role in this outcome (WWF, 2012, Laurance et al., 2014).

There are many ways in which agriculture impacts biodiversity. The conversion of land to agriculture can fragment or isolate habitats, changing connectivity patterns (Fischer and Lindenmayer, 2007, Dudley and Alexander, 2017). Many rare, endemic, or specialized species, especially those that require large expanses of wild habitats to survive, cannot persist in such fragmented landscapes and subsequent trophic cascades and other ecosystem-wide effects can lead to rapid species loss (Price et al., 1999, Gibson et al., 2013). For other species, agricultural systems can represent suitable habitat and high-quality agroecosystems have been shown to be important for the movement of forest organisms among patches of natural vegetation (Ricketts, 2004, Perfecto and Vandermeer, 2008, Franklin and Lindenmayer, 2009, Mendenhall et al., 2014).

Agriculture can also be the source of changes to hydrological and biogeochemical cycles leading to nutrient runoff, sedimentation of waterways and/or soil leaching causing changes in species compositions in more distant locations (Tilman et al., 2001, Power, 2010). At a more localized level, facilitating an optimum growing environment for a single target crop often requires altering in situ biodiversity such as simplifying ecosystems by reducing competition with other species or substituting the roles of functional biodiversity and natural system dynamics with chemical and mechanical inputs (Jackson et al., 2005, Omer et al., 2007). The alteration of ecological systems may result in a cascade of extinctions and co-extinctions along the trophic chain (Cowlishaw, 1999).

The impacts of agriculture can feed back to have negative impacts on agricultural systems themselves (MEA, 2005, Norris, 2008, Chaudhary et al., 2015, Chaudhary et al., 2016). The ‘optimization’ of agriculture has been shown to cause declines in crop genetic diversity, the number of natural pest predators and soil biota with associated negative impacts on soil fertility, pollination, and the resilience of production (Perrings et al., 2006, Chiron et al., 2014, Dudley and Alexander, 2017).

The complexity of the interdependencies between biodiversity and agriculture remains poorly understood. On-going ambiguity often leads to divisive, sometimes antagonistic research and policy stances (Jackson et al., 2005, Mace et al., 2012, Mertz and Mertens, 2017). A lot of this controversy is about how best to reconcile trade-offs between agriculture and biodiversity conservation. The land sharing-land sparing (LS/LS) framework is one of the most contentious examples within the current literature. It has attracted a lot of attention and engaged researchers in a heated debate that has now unfolded over more than a decade without leading to a clear conservation consensus.

1.3 The land sharing-land sparing framework

Green et al. (2005) introduced a debate on the advantages and disadvantages, for conservation, of wildlife-friendly farming in relation to a land sparing strategy. This was soon reframed as 'land sparing versus land sharing', or the LS/LS framework. The debate looks at whether high yield agriculture on a small land foot print (land sparing) or low-yielding, wildlife-friendly farming on a larger foot print (land sharing) will promote better outcomes for local and global biodiversity. Thus, the central element of the debate concerns how biodiversity reacts to increasing agricultural pressure (or yield). If the biodiversity/yield response follows a convex negative curve (Figure 1.1.1) it means that the loss of either unfarmed or very extensively managed habitats is the most detrimental to biodiversity. In this case the preferred strategy is taken to be 'land sparing', in which intensive farming in some areas is coupled with land 'spared' for nature conservation elsewhere.

In contrast, if the biodiversity/yield response follows a concave curve, meaning that biodiversity declines slowly as intensity starts to increase, but becomes severely impacted at high-intensity levels, the 'land sharing' strategy is taken to be the most efficient (Figure 1.1.1). The land would be farmed with moderate farming intensity, reconciling both agricultural production performance and biodiversity conservation criteria.

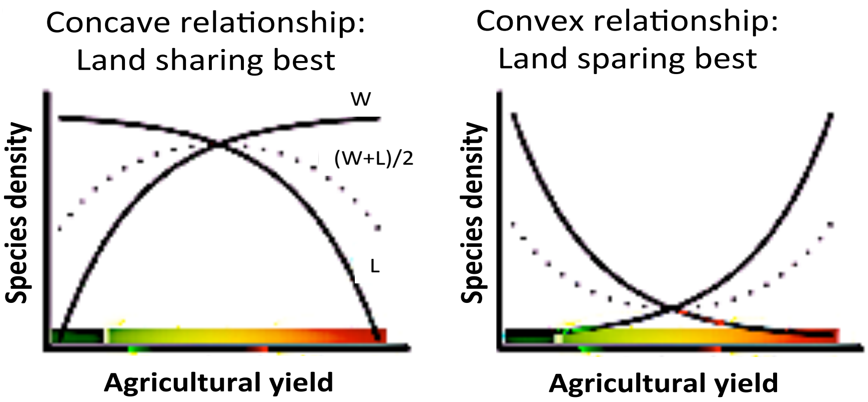


Figure 1.1.1 Land sparing and sharing model applied to tropical and temperate ecosystems adapted from Salles et al. (2017) as originally formalized by Green et al. (2005) and further applied by Phalan et al. (2011b)

The colour gradient shows the unexploited land uses (in dark green) all the way to the highest level of agricultural intensity (in dark red). For those species whose density increases with land conversion, so-called 'winners' (W), sharing is the best strategy. For species whose density always decreases when land is converted to agriculture, so-called 'losers' (L), sparing is the best strategy to ensure sufficient existing habitat. The sum between loser and winner [(W+ L)/2, dotted lines] is not constant along the intensity gradient. If the sum is concave then land sharing is the best strategy, if the sum is convex, than land sparing is best.

The debate around agriculture and biodiversity trade-offs has a long history in the literature (see Salles et al., 2017) and the new conceptual framework presented by Green et al. (2005) led, initially, to a modest increase in the number of publications (Figure 1.2). This was followed by a rapid increase with the publication of the Phalan et al. (2011a) study which presented evidence and arguments in favour of land sparing and ignited global debate (Figure 1.2).

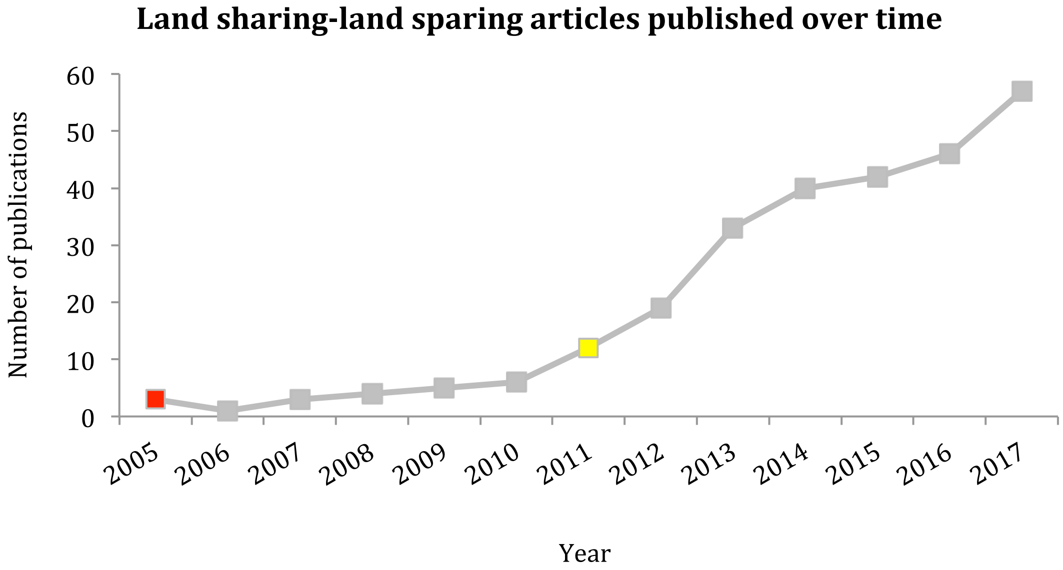


Figure 1.2 Land sharing-land sparing articles published over time. In red is the year when the framework was conceptualized by Green et al. (2005) and in yellow the year of Phalan et al. (2011a), one of the most quoted articles of the debate. *Source: Scopus (keyword search "land sharing" OR "land sparing", 14th of December 2017)*

Since 2005 empirical studies comparing LS/LS strategies have looked at a variety of response variables, including wildlife population density, species abundance and richness at local and regional level and species turnover. These studies have been carried out across a range of taxonomic groups including birds, insects, trees, plants, primates and big cats, sampled across different biomes, continents, spatial scales and farming systems, including those spanning thousands of years of cultivation (Ranganathan et al., 2008, Clough et al., 2011, Chandler et al., 2013, Gilroy et al., 2014, Edwards et al., 2014, von Wehrden et al., 2014, Vongvisouk et al., 2016, Jiang et al., 2017, Jóhannesdóttir et al., 2017, Rahman et al., 2017, Thaler, 2017). The debate has also transitioned from a pure agriculture and biodiversity focus to incorporate other land uses including forestry, housing, aquatic ecosystems and seascapes (Edwards et al., 2014, White and Costello, 2014, Collas et al., 2017, Koning et al., 2017). This thesis refers primarily to the original trade-off between terrestrial agriculture and biodiversity conservation. The viewpoints presented in the published literature so far have been quite divisive and almost entirely based on ecological evidence, meaning the debate lacks social

dimensions. Groups have advocated for one strategy over the other, or for the use of both strategies (Kremen, 2015). Others have called for the creation of entirely new theoretical frameworks (Kremen, 2015, Mertz and Mertens, 2017).
The next section presents a short history of the evolution of the debate to date (*Section 1.3.1*) and some of the controversies related to the scale and terminology of LS/LS (*Section 1.3.2*), before moving to the limitations of the framework (*Section 1.4*).

1.3.1 A brief history of the LS/LS debate based on ecological evidence

Monofunctional landscapes-the case for and against land sparing

In a review of the studies comparing LS/LS, Kremen, (2015) considers measuring individual species densities along an intensification gradient to be the best practice for the ecological evaluation of the two strategies. Individual species densities are preferable to aggregate measures, such as species richness or species diversity, as they can mask underlying patterns, particularly for disturbance-sensitive species of greater conservation concern (Phalan et al., 2011a, Balmford et al., 2015). Studies utilizing this research design (Hodgson et al., 2010, Phalan et al., 2011a, Phalan et al., 2011b, Hulme et al., 2013, Edwards et al., 2014, Williams et al., 2017) have generally concluded that, since the majority of species in the world can't survive in farming systems of even the lowest management intensity, land sparing is the best strategy, at least in theory, for conserving the most biodiversity.

To various degrees intensification has been shown to spare conservation land (Ramankutty and Rhemtulla, 2012, Stevenson et al., 2013, Hertel et al., 2014). The *Borlaug hypothesis* states that intensified agriculture cuts deforestation as it concentrates production on a limited area of land, removing the need to convert additional land to agriculture to achieve the same level of production (Waggoner, 1996, Ausubel et al., 2013). It emanates from the proposed win-win solutions of the Green Revolution, which is claimed to have spared several hundred million hectares of land from agricultural conversion as a result of intensification (Borlaug, 2007).

Land sparing strategies envision that biodiversity conservation should occur primarily in protected areas by spatially segregating conservation and production functions. In the extreme vision the world would be separated into 'monofunctional' entities – one optimized for agricultural production and one for biodiversity conservation (Fischer et al., 2017b). From a conservation point of view, undisturbed areas of habitat are considered to be more effective at protecting biodiversity than conserving only elements of nature by integration on farms (Grau et al., 2013). Other benefits of protected areas include: extinction prevention, maintaining ecological services and protection against human impacts such as land clearing (Terborgh, 1974, Bruner et al., 2001, Nagendra, 2008, Gibson et al., 2013, Cumming, 2016). From an aesthetic view, increasing farm yields under land sparing would probably diminish people's enjoyment of farmscapes but may offer greater prospects of experiencing vast and diverse natural habitats (Balmford et al., 2015).

Despite evidence that land sparing has value as a tool for conserving biodiversity (Cohn et al., 2014) studies have also explored the unintended consequences of pursuing this strategy. Market forces, land claims and economic development continue to stimulate land expansion even in scenarios that promote high productivity agriculture (Angelsen and Kaimowitz, 2001, Ewers et al., 2009, Rudel et al., 2009, Lambin and Meyfroidt, 2011, Hertel et al., 2014, Busch and Ferretti-Gallon, 2017). It is therefore unlikely that intensification alone can lead to land sparing in the future.

These issues have been shown to be particularly prevalent in so-called frontier areas such as the Brazilian Amazon, where intensification is associated with forest clearance rather than sparing (Barretto et al., 2013). This confirms the *Jevon's paradox* or *rebound effect* by which higher yields and associated higher profits increases motivations for further land clearance (Chandler et al., 2013, Ceddia et al., 2014). In Peru, it was estimated that high-yielding farms require 64% less total land to produce the same amount of product, but they would convert 58% more old-growth forest than smallholders (Gutiérrez-Vélez et al., 2011). Such trends often occur when high-yielding agriculture, particularly of cash crops with rapidly expanding global markets such as soy or oil palm, expand into primary forests rather than already cleared lands (Grau et al., 2008, Gutiérrez-Vélez et al., 2011, Meyfroidt et al., 2014 Nepstad et al., 2014). It has been predicted that a prospective Green Revolution in Africa could potentially lead to similar outcomes (Hertel et al., 2014). The Global Land Outlook of the UN Convention to Combat Desertification has concluded that intensification has failed to solve the biodiversity crisis and has often accentuated it further, undermining the sustainability of large areas of land (Dudley and Alexander, 2017). Another criticism of the land sparing approach is that concentrating efforts to conserve nature in protected areas can result in a series of unwanted outcomes including poor governance and ineffective protection, species loss and degradation of natural habitats, isolation of biodiversity, unrepresentative ecosystem diversity and conflicts with wildlife (Hannah et al., 2007, Craigie et al., 2010, Stevens, 2014, Cumming, 2016, Johansson et al., 2016).

Integrated landscapes-the case for and against land sharing

Land sharing is a strategy that encourages wildlife-friendly farming through the promotion of crop growth alongside wild species within integrated landscapes (Green et al., 2005). It can range from swidden agriculture, to the retention of small patches of semi-natural habitat on-farm, to agroforestry systems (Kleijn and Sutherland, 2003, Schroth et al., 2004, Scales and Marsden, 2008, Scherr and McNeely, 2008, Anand et al., 2010, Karanth et al., 2016). Land sharing proposes multi-functional agricultural landscapes or mosaics that include a combination of buffer zones, corridors and stepping stones in which agricultural land provides resources to species and enables their migration between natural habitats (Perfecto and Vandermeer, 2008). It creates opportunity for agricultural systems to benefit from ecological processes, by utilising ecosystem services to partially achieve functions otherwise fulfilled by chemical inputs, a field known as agro-ecology (Altieri, 1999). By focusing on the specific agricultural practices utilized, some researchers consider that practices and systems such as agroforestry, conservation biological control and conservation agriculture could outproduce conventional systems, or be equally productive or profitable (Clough et al., 2011, Tscharntke et al., 2012, Kremen, 2015). The benefits and importance of such systems are found in both temperate climates (Paracchini et al., 2008, Johansson et al., 2016) and tropical landscapes (Ranganathan et al., 2008, Anand et al., 2010, Ranganathan et al., 2010, Garcia et al., 2010, Robbins et al., 2015, Karanth et al., 2016, Cordeiro et al., 2017).

Agroforestry is of particular importance, given that an estimated 90% of tropical forests exist in human-modified landscapes outside of protected areas and about 43% of terrestrial species are connected to landscapes that are being or have been used for agricultural purposes (Ferrier et al., 2004, Bhagwat et al., 2008, Barthel et al., 2013). Moreover, there is evidence that when low-intensity mosaic landscapes are present alongside old-growth forests, they exhibit biodiversity as high as purely land sparing strategies (Ranganathan et al., 2008, Rerkasem et al., 2009, Berry et al., 2010). If intensification or abandonment of agro-ecological management practices occurs in such landscapes it may lead to an increase in invasive species richness (Cordeiro et al., 2017) and cause cascading effects on surrounding biodiversity (Clough et al., 2011).

Land sharing may also be more desirable in developing countries where smallholder farmers utilize neither high levels of agro-inputs nor environmentally friendly practices. Examples show that wildlife-friendly farming practices can considerably increase yields, in some cases up to 200%, without the environmental and economic costs associated with conventional monocultures (Altieri, 2002, Chappell and LaValle, 2011).

Land sharing envisions that biodiversity conservation strategies should extend beyond nature reserves (Chappell and LaValle, 2011). This is of particular importance in areas where setting aside the amount of land needed to conserve the habitat requirements of even relatively small species can be unrealistic (Perfecto and Vandermeer, 2010), or where the positive effects of expanding protected areas are counteracted by the negative outcomes of activities such as illegal logging and harvesting, encroachment and clearing (Bruner et al., 2001, Cumming, 2016, Busch and Ferretti-Gallon, 2017).

Despite evidence of its benefits land sharing has also been criticised. There are two main criticisms of the strategy. Firstly, environmental-friendly landscapes often provide a poor substitute habitat. This can lead to biotic homogenisation, replacing local endemics and sensitive species with generalist or common species (Edwards et al., 2010, Phalan et al., 2011a). Those species that can occur in the matrix may still require areas of native habitat above a given size at one point in their lifecycle to ensure their survival on long term (Homan et al., 2004, Savilaakso et al., 2009). Secondly land sharing landscapes often produce lower yields and therefore require more land to produce a given amount of food, potentially stimulating the conversion of land to agriculture elsewhere to meet demand (Kleijn and Sutherland, 2003, Jackson et al., 2007, Phalan et al., 2011a, Tittonell and Giller, 2013).

1.3.2 Debates over terminology and scale

It is important to reflect on the ‘sharing’ and ‘sparing’ terminology because it has often been used imprecisely or in contradiction, in many cases creating confusion (Fischer et al., 2014). For example, the term ‘land sparing’ is often used to imply nature conservation, but land sparing is not the same as nature sparing (Kremen, 2015). Nature conservation as a result of yield intensification (land-sparing process) may occur under certain circumstances while associated nature sparing commonly requires a form of enactment such as environmental policies or formal declaration of protected areas (Matson and Vitousek, 2006, Lambin and Meyfroidt, 2011, Ceddia et al., 2014).

Wildlife-friendly farming also comes with confusing characterizations. For some authors (e.g. Phalan et al., 2011b, Williams et al., 2017) the level of wildlife-friendliness is established based on yield levels, where low-yielding agriculture is assumed to be more wildlife friendly. Other authors (e.g. Donald, 2004, Khan et al., 2011) use the type of farming practices (how biodiversity-friendly a practice is) as a proxy. It has been suggested that confusion can be dealt with if the LS/LS continuum were defined by the specific combination of agricultural practices (which is likely to dictate both the yields and wildlife friendliness), rather than yields alone (Kremen, 2015).

Another ambiguous aspect is the scale at which the two strategies are distinguished from one another. In the land sparing strategy, areas of natural habitat should be contiguous and sufficiently large to support viable populations, e.g. what constitutes enough land spared for a beetle may not be enough to provide food and nesting habitats for a bird (Phalan et al., 2011b). Therefore, grassy strips, hedges and forest patches could be considered as land sparing at a field or farm scale, but at landscape scale they resemble land sharing. For the conservation of most farmland species, such as birds or pollinators, the landscape level, another loose concept, is considered to be the relevant scale (Phalan et al., 2011b). In an effort to reduce ambiguity Balmford et al. (2015) proposed for the 'landscape' to be defined by the scale at which major land-use decisions are made, typically that of landholdings through to regions.

Nevertheless, scale becomes a plastic concept if we look from a different angle. Land spared as a result of intensification could result in nature being spared at any scale or configuration, including small, dispersed fragments, thus creating landscapes that would typically be identified with land sharing (Edwards et al., 2010, Hodgson et al., 2010, Chandler et al., 2013). These debates remain unresolved and important areas of contestation.

1.4 Limitations of the framework and the focus of this research

The LS/LS debate is essentially a new way to deal with an old issue, the relationship between biodiversity conservation and agriculture. Is it more effective to focus conservation efforts on biodiverse-rich areas, or to concentrate on preserving ecological systems and dynamics ubiquitously? Similarly to how the notion of ecosystem services provided a new framework for thinking about the reliance of human societies on ecological processes and ecosystem functions, the LS/LS debate has generated a space for the examination of future potential trade-offs and synergies between agricultural and conservation policies (Salles et al., 2017). Yet, in doing so, the biodiversity/yield curves (though insightful from an ecological standpoint) offer no insights into the socioeconomic facets and context specific factors that are important for developing effective interventions (Fischer et al., 2014, Bennett, 2017).

A failure to take a more interdisciplinary approach to evaluating the relative merits of LS/LS has many implications. Additional factors that have been identified as influencing the choice between the two strategies are numerous and include: land-use patterns (Henderson et al., 2012), interactions between land-uses and species (Butsic et al., 2012, Mendenhall et al., 2014), inclusion of uncertainty (Johnson et al., 2012), and spatial and temporal heterogeneity (Piha et al., 2007, Mahood et al., 2012, Maskell et al., 2013, von Wehrden et al., 2014, Macchi et al., 2016). For example, in a review of literature von Wehrden et al. (2014) found that studies spanning the historical agricultural areas of Europe, Asia and the Americas have shown that agricultural landscapes established centuries ago continue to influence current land use schemes, species diversity and local species pools, ultimately influencing the choice between what constitutes the appropriate land management locally (Wehrden et al., 2014).

Whether land sharing or land sparing is more desirable will also be affected by market factors like labour wages, input and commodity prices, remoteness or distance to markets and land tenure (Adams, 2012, Baudron & Giller, 2014). For example, land sparing is thought to be ineffectual in areas of communal land ownership or where systems of land tenure are insecure and is usually suited for larger commercial farms where secure land tenure systems could facilitate investment in intensification (Adams, 2012, Baudron and Giller, 2014). Conversely, land sharing has been linked to smallholder farms that rely less on technologies for intensification and more on agro-ecological practices (Baudron and Giller, 2014). Access to these services paired with land scarcity or availability will indicate the most appropriate strategy of the two (Noltze et al., 2013).

Determining meaningful land use policy also requires the consideration of socioeconomic aspects and the preferences of individuals or institutions. The impacts of different farming systems on livelihoods and the inequality implications of proposed land use strategies are likely to have strong regional impacts on the suitability of LS/LS initiatives (Perfecto and Vandermeer, 2008, Balmford et al., 2015, Law and Wilson, 2015, Kremen, 2015). There are also concerns that the LS/LS framework is not equipped to deal with aspects of food security and focuses entirely on food production (Tscharntke et al., 2012, Fischer et al., 2014). As discussed in *Section 1.1* food production is only a means to an end while the implied societal goal is to ensure food security. Policy feasibility will also be highly dependent on stakeholders diverse interests, the governance systems, how well the policies are adapted to local institutions, the capacity of the institutions to support implemented policies, and most importantly it will depend on the uptake and social preferences of these policies to direct land users (Angelsen and Kaimowitz, 2001, Barraquand and Martinet, 2011, Brady et al., 2012, Ceddia et al., 2014).

This plethora of limitations of the LS/LS framework has led some authors to caution against uncritical applications of the framework, arguing that such polarized debates are not constructive (Tscharntke et al., 2012, Fischer et al., 2014, Kremen, 2015). Authors increasingly consider the debate stalled and plea for a middle ground, a re-iteration of the framework, a more inclusive one or ultimately a completely new framework equipped to deliver under the Sustainable Development Goals (UN, 2015) and local realities (Table 1.1).

Table 1.1 Studies that have proposed changes to the current LS/LS framework or new alternative frameworks**.**

Study	**New alternatives or expanding the LS/LS framework**
Kremen, 2015	The study concluded that the dichotomy of the sharing-sparing framework limits the realm of future possibilities to two, largely undesirable, options for conservation and as a result the framework should be abandoned. Alternative such as agro-ecology are better adapted to answer **food security** problems.
Law and Wilson, 2015	Provide foundational evidence that **context** warrants explicit inclusion in assessments of agricultural and environmental policy.
Dressler et al., 2016	Provide evidence that **'livelihood bricolage'** (livelihood portfolios based on the economic and socio-cultural considerations of place) is an important component of the sharing-sparing decision-making.
Bennett, 2017	Calls to expand the framework to include **human wellbeing** and **ecosystem services**.
Mertz and Mertens, 2017	Calls to expand the framework to include **economic aspects**.
Walter et al., 2017	**'Smart farming'** a better framework that offers a path towards sustainable agriculture by diversification of technologies, crop and livestock production systems, and networks across all actors of the agri-food sector.
Mockshell and Kamanda, 2017	The study asks if "**blended sustainability**", a form of sustainable agricultural intensification and agro-ecological intensification has the potential to solve the sharing-sparing dispute by aligning the interests of different **stakeholders**, including private sector actors, international donors, NGOs, civil society actors and conservation scientists.
Donaldson et al., 2017	Introduces a landscape scale conservation framework that can help the decision between a sharing and a sparing landscape.
Fischer et al., 2017a *Fischer et al., 2017b,* *Dudley and Alexander, 2017*	Probably the most overarching framework proposed is moving towards a **multifunctional landscape** vision in which multifunctionality is not only seen as an issue of which ecosystem services are being generated, but also one of who receives and benefits from these services. The promoters argue that typically, in these landscapes, a broader range of beneficiaries has access to a more varied set of ecosystem services. Besides, the ecosystem services benefits are generally experienced more locally, and local people are more likely to be in control of landscape management. Hence, it is important to distance research from "monofunctionol" landscape vision of the sparing strategy which reinforces a growing disconnect between people, ecosystem services, and the landscapes where these services are produced. First evidence that engaged with this framework suggests that by understanding a landscape as a multifunctional entity, optimum yield-biodiversity outcomes result from adoption of mixed sharing-sparing policies (Law et al., 2017).

The architects of the framework have responded that while the sparing-sharing debate remains controversial, the framework should not be abandoned since it has provided a valuable structure that forces researchers to be explicit about their objectives in evaluating alternative approaches to food production (Balmford et al., 2015). But if the framework is to influence policy then these limitations need to be addressed.

This study seeks to contribute to addressing these limitations of the LS/LS framework by assessing, in a case study landscape, the feasibility of proposed interventions given stakeholders' interests, the uptake of the interventions by direct landowners and their socioeconomic and environmental implications, beyond a simple biodiversity/yield analysis. The following sections explain these topics in more detail.

1.4.1 Land sharing-land sparing interventions and the importance of including stakeholders in the elaboration of effective policies

The debate around the LS/LS framework aims to better recognize, evaluate and value existing situations, but more essentially to formulate successful policies that align biodiversity conservation and food production. LS/LS are possible land use scenarios, but they are unlikely to be achieved without some form of policy intervention.

Advocates of land sparing have proposed four categories of 'active' land sparing mechanisms (Figure 1.3) that could link yield increases with habitat protection or restoration: i) land use zoning, ii) economic instruments, such as payments, land taxes, and subsidies, iii) spatially strategic deployment of technology, infrastructure, or agronomic knowledge and iv) standards and certification (proposed by Balmford et al., 2015, and reinforced and expanded on by Phalan et al., 2016).

Evidence for the use of scientific results as a basis for developing land use policies is limited (e.g. Wentworth, 2012). Although many studies reference policies, there is insufficient information on how specific land use policies have been developed and whether they are part of conscious decisions to promote strategies (Mertz and Mertens, 2017). Evidence so far suggests it is more likely that current interventions that can be categorised as LS/LS have not transpired as a direct result of policy recommendations from this literature (Mertz and Mertens, 2017). However the forms of land sparing mechanisms that have occurred around the world do resemble the categories presented in Figure 1.3.

	1. Land-use zoning	2. Economic incentives	3. Strategic deployment of technology, infrastructure and knowledge	4. Standards and certification
How it could spare (or restore) habitat	Zoning land as off-limits to conversion	Payments for habitat protection, taxes disincentivizing conversion	Concentrates capital away from habitat, and as a condition of support (if reversible)	Requiring habitat protection as criterion of standard
How it could increase yields	Land scarcity incentivizing Boserupian innovation	Land scarcity incentivizing innovation, subsidies enabling investment	Providing inputs, lowering costs, reducing post-harvest losses in established farmlands	Technical advice, market access and increased profits enabling investment
How link between sparing and high yields could be strengthened	Combining with 2 or 3	Rewarding farmers who both increase yields and protect habitat	Combining with 1 or 2 to strengthen protection of areas to be spared	Strengthening criteria requiring habitat protection and high yields
Key risks	Leakage, over-generous agricultural zones, unfair distribution	Poor contract design, poor targeting, inadequate scale, unfair distribution	Poor targeting, unfair distribution, stimulating demand	Selection bias, poor targeting, insufficient monitoring, inadequate scale
Scale at which land likely to be spared	Region, landscape, (landholding)	Landholding, (landscape)	Region, landscape, landholding	Landholding, (landscape)
Principal proponents	Governments	Governments, NGOs	Governments, NGOs, extension programs,	Standards bodies, buyers, producers

Figure 1.3 Potential mechanisms for linking yield growth to land sparing. *Source: Phalan et al., 2016*

Cells are colored in relation to the degree to which each mechanism is understood to spare habitat or increase yields. Green indicates there is good evidence, and yellow indicates mixed evidence, or a plausible but untested effect. The scale at which each mechanism is most likely to spare land is indicated. Other possible scales are presented in parentheses. Examples of the likely principal proponents of each sort of mechanism are provided (the proportion of the cell shaded gray indicates the expected relative importance of governments in implementing each sort of mechanism).

Under *land use zoning* for example, a combination of pro intensification and anti deforestation measures, using deforestation bans through national legislation, has been developed in response to international and national pressure to stop deforestation in Brazil and Costa Rica (Schroth et al., 2011, Fagan et al., 2013, Meyfroidt et al., 2014, Cialdella et al., 2015, Jadin et al., 2016). In Vietnam and Indonesia land zoning policies aim to separate areas into protection forest and production forest where agriculture appears to be tolerated (Meyfroidt et al., 2014, Law and Wilson, 2015).

Examples of *economic instruments* mechanisms used to promote land sparing are among the most common. Under international agreements such as the Convention to Combat Climate Change, REDD+ programs are incentivising farmers to reduce shifting cultivation and cattle ranching through intensification in Brazil (Eloy et al., 2012) and in a similar fashion the programme is promoting land sparing strategies in Argentina, DR Congo and Laos (Phelps et al., 2013, Macchi et al., 2016, Vongvisouk et al., 2016). Furthermore, in Brazil, the Forest Code allows flexibility in how landowners meet the required percentage of legally reserved

forests on their lands. Those that decide to deforest 100% of their land can purchase the rights from other landowners that have maintained forests in excess of the legal requirement (Soares-Filho et al., 2014).
In Indonesia incentives are given for local government to allocate large-scale oil palm and in Ghana they aim to encourage the transition from extensive low-yield cocoa to intensive high-yield cocoa (Gockowski et al., 2013, Lee et al., 2014). In the Spiti Valley, of Himalayan India, for designating land set-asides for the recovery of snow leopard, prey herders receive payments and technical assistance to reduce livestock losses to snow leopards and to increase yields as well (Macdonald and Loveridge, 2010).
Under *spatially strategic deployment of technology, infrastructure, or agronomic knowledge*, a case study from Philippines represents a good example of how production was increased by the Philippine National Irrigation Administration when they brought irrigation to southern Palawan in the 1990s. This allowed many lowland rice farmers to produce a second crop per year within a single area, shifting deforestation pressures away from fragile, forested uplands (Shively et al., 2001, Shively and Pagiola, 2004). In the last category *standards and certification,* an example from Cambodia shows how farmers who enrol in the Ibis Rice scheme are permitted to sell their rice through the village committee to a marketing association, and receive a price premium as part of an agreement not to hunt key species of conservation concern and help protect the local forest (Clements et al., 2010). The programme has been driven by a conservation organisation.

Under the land sharing strategy no proposed categorisation of mechanisms' has been made, but the strategies are similarly diverse. For example, silvo-pastoral systems implemented by the government in Colombia help conserve forest fragments (Montoya-Molina et al., 2016). In Argentina governmental subsidies are used to promote extensive cattle ranging in economically poor areas (Grau et al., 2008) and in the same country land zoning regulations have a category for 'sustainable use' with low intensity (Macchi et al., 2016). General pressure from consumers at the global level also pushes land policy-making into seeking more sustainable land use practices such as agroforestry and organic agriculture and engaging in payments for ecosystem services. For example, in Mexico municipalities and NGOs promote multi-functionality of landscapes with organic palm and shade coffee (Speelman et al., 2014), whereas in Brazil the forest code requires setting-aside private land for sustainable use (Eloy et al., 2012). In India the implementation of the Forest Rights Act is trying to make up for the mistakes of the past and promote community conservation with sustainable resource use (including agriculture) in a decentralized way (Rai and Bawa, 2013). For Transylvanian's communities in Romania the cultural and historical context allowed for a multifunctional socio-ecological system to thrive over time (Loos et al., 2016). The European Union's (EU's) Biodiversity Strategy and Japan's National Strategy for Biological Diversity have traditionally recognized and promoted land sharing approaches by acknowledging the multifunctionality of the landscapes (Fischer et al., 2017b). In the case of EU substantial investment has been placed in agro-environmental subsides to promote land sharing.

Although LS/LS strategies manifest across different regions of the world, the promoters of the framework have made a call to coordinate actions at national and international level to promote LS/LS policies based on the ecological evidence to date. Though insightful, the biodiversity/yield curves offer no insights into the social acceptability of the policies that have been derived from this evidence. In doing so there is a risk of developing ineffective interventions that are not adapted to local contexts and can paradoxically force into opposition the very conservation and development interests they seek to reconcile for which they were designed (Fischer et al., 2014, Bennett, 2017).

What drives the strategy or strategies adopted by each country seems to be dictated by any one or a combination of factors. They range from commitments under international conventions, the agenda of NGOs, private donors, governments and agri-businesses, the local realities of development needs, access to capital, international market forces or historical and cultural contexts (Eloy et al., 2012, Wentworth, 2012, Meyfroidt et al., 2014, Cialdella et al., 2015, Loos et al., 2016, Vongvisouk et al., 2016, Fischer et al., 2017a, Mockshell and Kamanda, 2017, Salles et al., 2017). Thus, it is not surprising that the few studies to have looked into the social acceptability of the LS/LS policy recommendations have highlighted that the integration of local stakeholders' perspectives from an early stage is likely to be an important factor in determining the interventions success (Steffan-Dewenter et al., 2007, Kremen, 2015, Jóhannesdóttir et al., 2017, Mertz and Bruun, 2017). Though there is much to be explored around the engagement of stakeholders in conservation policy (Reed, 2008, Sterling et al., 2017), there is evidence showing that farmers who participate in developing conservation schemes experience an increase in their commitment and satisfaction (Emery and Franks, 2012). The co-design of conservation management with landowners and other stakeholders from an early stage can also reconcile potential conflicts and ensure more robust and long-lasting policies (Redpath et al., 2013, Bouamrane et al., 2016). These findings build on evidence from different disciplines, which emphasise the growing need for knowledge exchange between researchers and those who affect or are affected by decisions, commonly referred to as stakeholders, in order to enhance the quality, relevance and legitimacy of research and its success on the ground (Oreskes, 2004, Diedrich et al., 2011, Jolibert and Wesselink, 2012, Reed et al., 2009).

In the biodiversity conservation literature there has also been a growing realisation that stakeholder participation has a significant role to play in the development and delivery of biodiversity policy and practice (Jones-Walters and Çil, 201, Young et al., 2013, Young et al., 2014). Stakeholder engagement around the world has been successfully implemented as part of a wide range of environmental applications. In the USA, stakeholder engagement in watershed problems increased cooperation and improved polices and their effectiveness (Sabatier et al., 2005). In Australia, stakeholders' innovative approach to mutual farm visits, and the emphasis on the demonstration of best practice, has led to both an increased awareness of land degradation problems and the creation of grassroots information networks (Wilson, 2004). In Madagascar, stakeholder engagement has played a central role in conservation decision-making for Bezà Mahafaly Reserve for over 40 years leading to higher quality decisions that are better adapted to the local social-cultural and environmental contexts (Richard and Ratsirarson, 2013). Case studies from India, Bolivia and Mali proved that stakeholder engagement helped achieve a common understanding of the principles of sustainability for better policy formulation (Rist et al., 2007), while a review conducted on forests world-wide showed that stakeholder engagement led to better forest management (Carter and Gronow, 2005).

Stakeholder engagement has also been shown to: increase the likelihood that environmental decisions are perceived to be holistic and fair, enhance the rate of adoption and diffusion of interventions among target groups, reduce implementation costs, help set more realistic targets, understand the barriers to success as well as shift direction if interventions where believed to diverge from intended targets (Martin and Sherington, 1997, Konisky and Beierle, 2001, Richards et al., 2004, Irvin and Stansbury, 2004, Junker et al., 2007, Reed, 2008, National Audubon Society, 2011).

In cases where stakeholders were not included in the decision-making process the risk of proposing inadequate or sub-optimal solutions has been shown to increase (Reed, 2008, Sayer et al., 2013). For example in the context of the Kalahari, Botswana, it was found that the majority of strategies to reduce and adapt to land degradation reported in the literature were not suitable for use by local pastoralists. The adoption of these strategies without prior discussion of their suitability risked advancing policies that were likely to fail from the start due to a lack of engagement (Reed et al., 2007).

These studies highlight that the integration of landowner perspectives and other stakeholders is likely to be an important factor determining the success of LS/LS conservation policy. Thus stakeholder involvement, especially connecting individuals and institutions at multiple, hierarchical levels across sectors through participatory processes (Young et al., 2014), would greatly aid the formation of effective policy that could maximize their utility and better promote their uptake in a landscape (Kremen, 2015).

1.4.2 Why socioeconomic factors can shift the outcomes of the debate

Along with stakeholder engagement, socioeconomic factors also play an important role in determining the choice between the two strategies. Only a few studies under the LS/LS framework (e.g. Steffan-Dewenter et al., 2007, van Vliet et al., 2012, Lee et al., 2014) have quantified the socioeconomic and environmental outcomes of these strategies within a real-world agricultural landscape. This small pool of studies shows that when socioeconomic aspects are considered, the choice between the two strategies is less clear than in the outcomes of biodiversity density-yield studies. For example, by using spatially explicit data on various important attributes for oil palm expansion, Lee et al. (2014) developed a computer-based model to simulate different pathways of oil palm expansion in Sumatra, Indonesia. Considering the environmental and socioeconomic outcomes of pursuing oil palm expansion via a land-sparing, land-sharing, and a hybrid approach, the model revealed the best compromise between environmental and socioeconomic outcomes from oil palm expansion is the product of the latter strategy. In another example van Vliet et al. (2012) showed land sparing approaches tend to create higher income for local people, but result in higher risk and vulnerability compared to swidden agriculture. Similarly, evidence from Southeast Asia collected between 1950 and 2015 shows that transition from swidden to intensive cropping has increased overall household income, but these benefits came at significant costs such as reductions of customary practice, socioeconomic wellbeing, livelihood options, and staple yields (Dressler et al., 2017).

A Philippine case studies show how disrupting livelihoods in multi-functional landscapes with policies that focus on intensification spatially constrains livelihood security and conservation objectives (Dressler et al., 2016). It concluded that more equitable forest governance and better livelihood outcomes are observed under land sharing (Dressler et al., 2016). Furthermore, Steffan-Dewenter et al. (2007) collected socioeconomic data showing that although full sun cacao plantations provide greater yield and income, growers prefer relatively biodiversity-rich shade cacao agroforests, suggesting that certification schemes that ensure price premiums for wildlife-friendly cacao are likely to be popular and effective. On the contrary, in the subarctic landscape, Icelandic farmers are unlikely to specifically consider bird conservation in their management, even if financial compensation were available (Jóhannesdóttir et al., 2017). Despite acknowledging the importance of having rich birdlife on their land they intend to increase the area of cultivated land in the near future. Nevertheless, there seems to be willingness to consider sparing patches of land and/or maintaining existing pools within farms, an essential habitat feature for breeding waders.

These studies demonstrate that the ecological focus of the LS/LS framework is insufficient to deal with real world complexities and lends itself to overly simplistic policy prescriptions. The exclusion of socioeconomic factors from the debate could ultimately further harm biodiversity and will continue to lead agricultural scientists, development economists, and ecologists to talk past each other ineffectively. There is an urgent need to widen the lens with which we look at the problem and by including socioeconomic consideration and by engaging the stakeholders in a participatory process better land use policies could be crafted so that they avoid serving entrenched interests (Phelps et al., 2013) and could promote biodiversity conservation on the long term.

1.5 Objectives and research approach

There is increasing impetus to find ways to reconcile food production with biodiversity conservation. The LS/LS framework has emerged as one such approach (Green et al. 2005) and is receiving increasing attention. While numerous studies (e.g. Hulme et al., 2013, Williams et al., 2017) have investigated the relative merits of LS/LS through an ecological lens, I have argued that the relevance of the framework to real life depends on a much broader set of factors. The framework fails to consider the social acceptability of the land use interventions to stakeholders and direct land users or the socioeconomic implications of their advancement in a real-world landscape (Fischer et al., 2014). By proposing ready-made expert solutions without understanding the social ramifications of the two approaches proponents of the framework risk a partial picture that is not grounded in local realities and can have profound implications for the conservation of biodiversity on the long run (Phelps et al., 2013, Kremen, 2015, Bennett, 2017).

To address these caveats the research presented in this thesis moves beyond the ecological approach by adding a socioeconomic dimension to the LS/LS framework. Based on the preceding review of the literature, the thesis proposes to investigate three main socioeconomic and environmental aspects:

i) **What land use interventions are plausible in a landscape given diverse interests of stakeholders?**
ii) **What is the social acceptability (uptake) of the interventions to direct land users?**
iii) **What are the implications of land users' choices, not only on production and biodiversity but also on local food security and livelihoods?**

Finally, the thesis considers the implications of the results of these investigations for the applicability of the LS/LS framework in real life situations.

Answering these questions means crossing disciplinary boundaries and analysing the system under study as a complex structure that is governed both by social and ecological processes. In doing so this research focuses on three main aspects: engaging stakeholders in participatory processes to identify feasible land use interventions considering the local realities, understanding farmers motivations to enrol in land use interventions, and analysing the comparative merits and benefits (socioeconomic and environmental) of adopting LS/LS interventions. All this information provides new insights into LS/LS policy recommendations. The thesis has been structured in ten chapters; with the chapters that contribute to or answer the research questions organised in five parts (Diagram 1). Each part has a short introduction and in each chapter, the final section conveys its main messages.

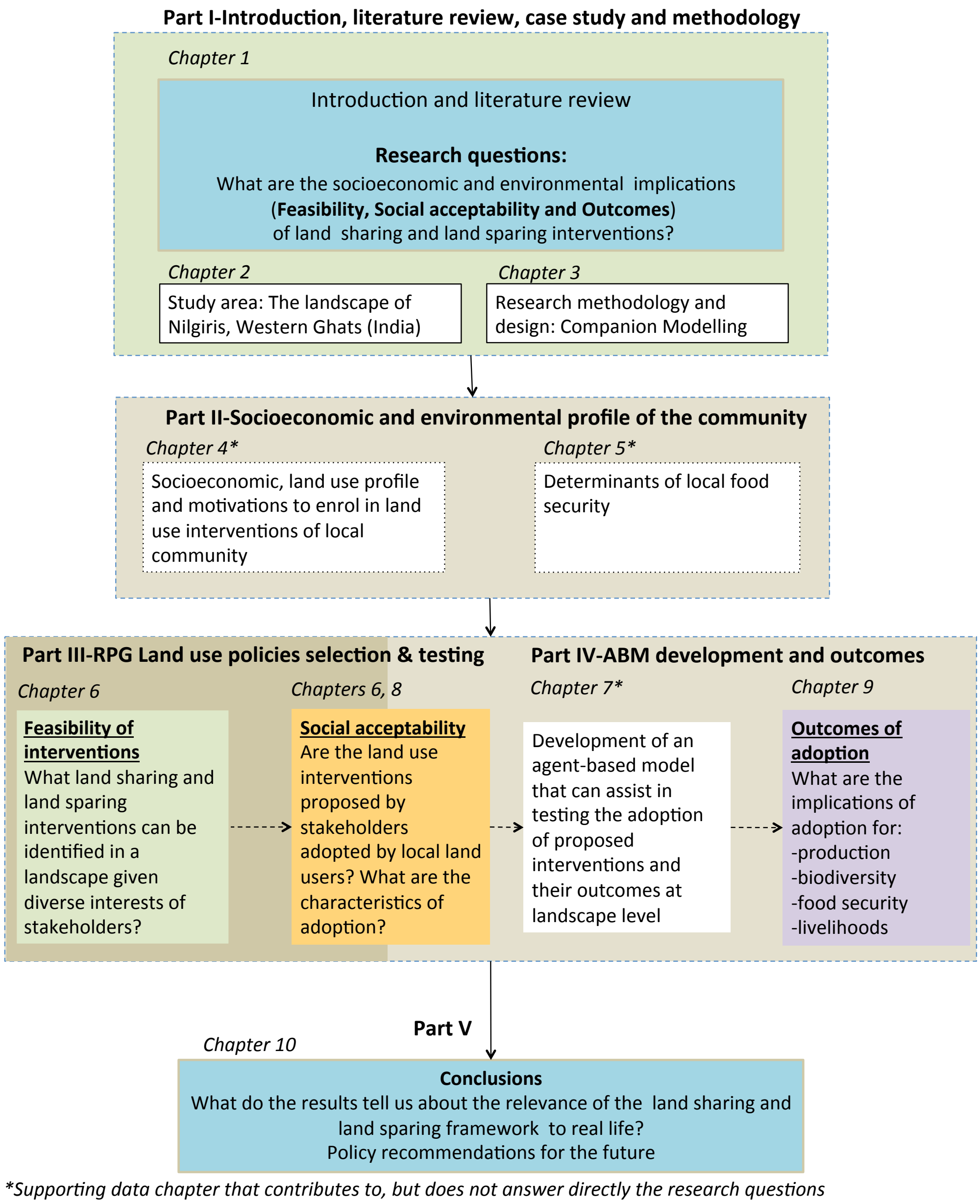


Diagram 1 Structure of the thesis

Engaging stakeholders in participatory processes to identify feasible interventions in a given landscape is challenging. Companion Modelling has emerged as an approach specifically designed to address these challenges. Its value for this study stems from its focus on facilitating dialogue between stakeholders, shared learning and collective decision-making in an adaptive and iterative way (**Part I, Chapter 3**). Using a combination of role-playing games and agent-based models with local stakeholders it enables a shared representation and validation of the land use and decision-making processes that occur in a system, that are otherwise difficult to observe or navigate.

In order to understand how land use decisions are shaped in landscapes that can accommodate both LS/LS strategies, Nilgiris, India was selected as a suitable fieldwork site. The area has a long history of subsistence and commercial agriculture with both intensification and expansion into one of the world's most biodiverse forests. The thesis explains the historical and economic drivers that shape the current landscape and livelihood decisions (**Part I**, **Chapter 2**) as long with a current socioeconomic, land use and food security profile of the study area in **Part II** (**Chapters 4 and 5**). Part II also includes information on farmers' motivations to enrol in land use interventions that have been collected using *what-if* scenarios. Part II uses both quantitative and qualitative data derived from an in-depth household survey and focus groups. The data are analysed using simple statistics or multivariate analysis. To establish what determines food security in the study area mixed effects models are also used.

The participatory processes used in engaging stakeholders in negotiating feasible land use policies for the reconciliation of agriculture and biodiversity conservation, and the outcomes of the processes in the form of concrete land use policies are presented in **Part III** (**Chapter 6**). Knowledge of the willingness and capacity of landowners to accept these strategies is of key value to the success of the policies. To understand the processes and motivations that govern land users decision-making related to land use and livelihoods decisions a role-playing game (**Chapter 6**) and an agent-based model were proposed (**Part IV, Chapter 7**). The agent-base model, referred to as PLUSES, allowed analysing *ex ante* the results of their hypothetical adoption (**Chapter 8**) and the implications of their adoption for local livelihoods, food security and environment (**Chapter 9**) over a 30-year period simulation.

Finally, **Part V** (Chapter 10) underlines how integrating a socioeconomic dimension to the LS/LS ecological debate contributed to understanding the applicability of the framework to real life situations.

The next chapter introduces the study site where the research has been conducted.

Chapter 2

Study area: The landscape of Nilgiris, Western Ghats (India)

This chapter describes key aspects of the Nilgiris district in Southern India's Western Ghats in which the field research for this thesis took place. The Nilgiris is a human-modified landscape that exhibits a high level of biodiversity and has a long history of agriculture. To understand the social acceptability of land use interventions, such as LS/LS, this chapter provides an account of the environmental and socioeconomic history affecting livelihoods, food security and the environment of the Nilgiris. The chapter also highlights key land use transitions in the regions' recent history. Understanding the key dynamics in this mixed-use environment and its recent history are instrumental for the empirical design developed in Chapter 3.

The chapter opens by justifying the selection of India as a suitable place to address the current research (*Section 2.1*) and reviewing the LS/LS strategies that have long been implemented in the country (*Section 2.2*). The chapter moves on to provide an overview of the relationship between agriculture and biodiversity in the Western Ghats (*Section 2.3*). The socioeconomic and environmental profile of a central part of the wider Western Ghats landscape, the Nilgiris are then considered (*Section 2.4*) and the chapter concludes with the current environmental threats in the area and the type of land use interventions found in the landscape (*Section 2.5*).

2.1 Introduction

The greatest biodiversity impacts from agricultural transformation will likely occur in areas of fast economic development that are characterized by a combination of high population densities, high biodiversity value and high rates of poverty and food insecurity (Jenkins et al., 2013, Phalan et al., 2013, Baudron and Giller, 2014, UN, 2017). India meets all of these characteristics. The country's human population density has almost tripled, from 154 to 445 people/km^2 between 1961 and 2016 (UN, 2017). India is now home to 1.3 billion people, the second largest national population on the planet. This population is expected to rise by an additional 0.2 billion people by 2030 (FAO and World Bank, 2017).

The Human Development Index (HDI) is a composite index measuring average achievement in three basic dimensions of human development: a long and healthy life, knowledge and a decent standard of living. The HDI places India in 131st position out of 188 countries (UNDP, 2016). However, India's index has risen annually by an average of 1.52% over the last 27 years (UNDP, 2016). Similarly, despite the economy of India ranking 141st out of 188 countries by GDP per capita in nominal value, the country has had a high average economic growth of 6.6% annually over the last 25 years (IMF, 2017). It is projected that by 2040 India's GDP will exceed that of United States of America (USA), in purchasing power parity terms, which account for different price levels across countries. This would make India the second largest economy in the world, after China (PwC, 2017). Despite a growing economy and measures of development India continues to battle high poverty and food insecurity rates. According to the national baseline figures, 21.9% of the population lives below the poverty line and the World Bank reports that 21.2% of the population subsists on an income of less than two United States (US) dollars per day (UNDP, 2016). The proportion of the population living below the poverty line increases to 80% in rural areas where the majority (67.3%) of Indians live (UNDP, 2016, World Bank, 2017).

India continues to be largely an agrarian country with 46% of total land area cultivated and 57% of the labour force dependent on agricultural activities (UNDP, 2006). Out of the 121 million agricultural holdings, small and marginal farms account for more than 80% of total farm households and their average land size has declined from 2.3 ha in 1970 to 1.37 ha in 2000 (Chand et al., 2011). The agricultural sector currently contributes 17.4% to India's GDP however that amount is declining year on year as the contribution of the service sector increases (FAO, 2017b). Even with a better distribution of food and a reduction in food waste, agricultural productivity will need to increase to reduce food insecurity and to feed the rapidly growing population (FAO, 2017a). Such an increase will need to occur alongside the decreasing popularity of agriculture as a livelihood and changing consumption patterns that come with increased wealth, such as an increased demand for meat products (Aiking, 2011). Increasing demand for agricultural products and changing consumption patterns are likely to lead to more pressure on India's environment.

India has a rich biological diversity that includes more than 400 mammal species including the largest wild populations of tigers (*Panthera tigris)* and Asian elephants (*Elephas maximus*). The country has two global biodiversity hotspots, the Eastern Himalayas and the Western Ghats (Bawa et al., 2007, Karanth et al., 2009). This study is based within the latter. Nationally, agricultural expansion has already led to significant deforestation. In 1880, 32% of land was cultivated and 32% of land was under forests (Flint, 1998). By 2014, 60.4% of land was cultivated and forest cover had shrunk to 23% of land area, with agriculture expansion being the main driver (FAO, 2014). It is predicted that in the future the intensification of cropland rather than its expansion will pose the largest threat to Indian biodiversity (Kehoe et al., 2017). Timely land-use planning will be crucial to proactively mitigate biodiversity loss from agricultural development (Kehoe et al., 2017). Assessing *ex ante* land use policies that have been put forward, such as LS/LS strategies, could provide valuable insights in formulation of more meaningful and effective policies (e.g. Lee et al., 2014).

2.2 Land sharing and land sparing in the Indian context

Despite not being explicitly labelled as such, both LS/LS strategies have long been present on the Indian subcontinent. In India the land sparing argument is most frequently made with respect to the Green Revolution. Green Revolution technologies increased wheat production five-fold between the 1960s and early 1990s, while acreage only expanded by approximately 75% (Waggoner, 1996). By 1991 an additional 44 million hectares of agricultural land would have been necessary to generate the same level of production if modern technology hadn't supplemented low-input strategies (Waggoner, 1996). Thus, it is argued that through technological improvements and crop intensification millions of hectares of natural land were spared from conversion (Lee and Barrett, 2001). However, contradicting views suggest that agricultural intensification has actually promoted deforestation in India by raising land value for growing crops (Foster et al., 1999). Even in its early days, the Green Revolution has been associated with deterioration in soil structure and fertility, along with an increase incidence of pest, disease and weed problems (Conway and Barbie, 1988). Furthermore, it led to a decrease in individual food security, increased dependency on corporate sellers and decreased control over their food supply for the most vulnerable people (Patel, 2012, Patel, 2013, Shiva, 2016). The push for the industrial agricultural model has altered the foundations of India's agriculture, making farming unremunerative for millions of India's small and marginal farmers (Narayanamoorthy, 2006).

In terms of land sharing, the cultivation of areca, cardamom, coffee, rubber and tea agroforestry are classic Indian examples (Bhagwat et al., 2008, Anand et al., 2010, Robbins et al., 2015). Multiple studies have demonstrated that agroforestry landscapes could help 'produce' wildlife and provide conservation opportunities (Puri and Nair, 2004, Bali et al., 2007, Ranganathan et al., 2010, Garcia et al., 2010, Nath et al., 2011, Karanth et al., 2016) without necessarily minimizing optimum production (Tscharntke et al., 2012). Agroforests could benefit livelihoods and food security, with areca nut doing so for more than 2,000 years (Ranganathan et al., 2008, Shiva, 2016). Land sharing has, however, also been shown to have negative impacts on yields, biodiversity and livelihoods (see review by Murthy et al., 2016). For example a doubling of the area of shade-grown coffee plantations between 1977 and 1997 coincided with a 30% reduction in forest cover (Garcia et al., 2010). In the same study it was shown that multipurpose agroforestry trees on farms, that aimed to serve as alternative sources of fuel wood, were often not accessible to the poor since the landless population (e.g. tribal groups, migrants, labourers) neither had legal access to fuel wood from state-controlled forests nor from private lands (Garcia et al., 2010).

If LS/LS interventions continue to be taken forward, a holistic assessment that can capture the interaction between agriculture, biodiversity, livelihoods and food security is imperative to ensure more effective and targeted policies that can minimise or overcome some of the unintended consequences observed so far. To explore these interactions, research was conducted in the Western Ghats district of the Nilgiris. The area is densely populated, relies primarily on agriculture, is rich in biodiversity and the protected areas that house viable source populations of many species are embedded in matrices of cultivated agroforestry landscapes (Robbins et al., 2015). The history of the Nilgiris and the research context are related to the wider landscape of Western Ghats. Therefore the chapter will start with a brief overview of the Western Ghats landscape.

2.3 Overview of the Western Ghats landscape

2.3.1 A biodiversity hot spot

The Western Ghats is formed by the Malabar Plains and the chain of mountains running parallel to India's western coast, about 30 to 50 kilometres inland. They stretch for 1,600 km from the country's southern tip to Gujarat in the north and cover an area of about 160,000 km^2 over five states: Goa, Karnataka, Kerala, Maharashtra and Tamil Nadu (Figure 2.1).

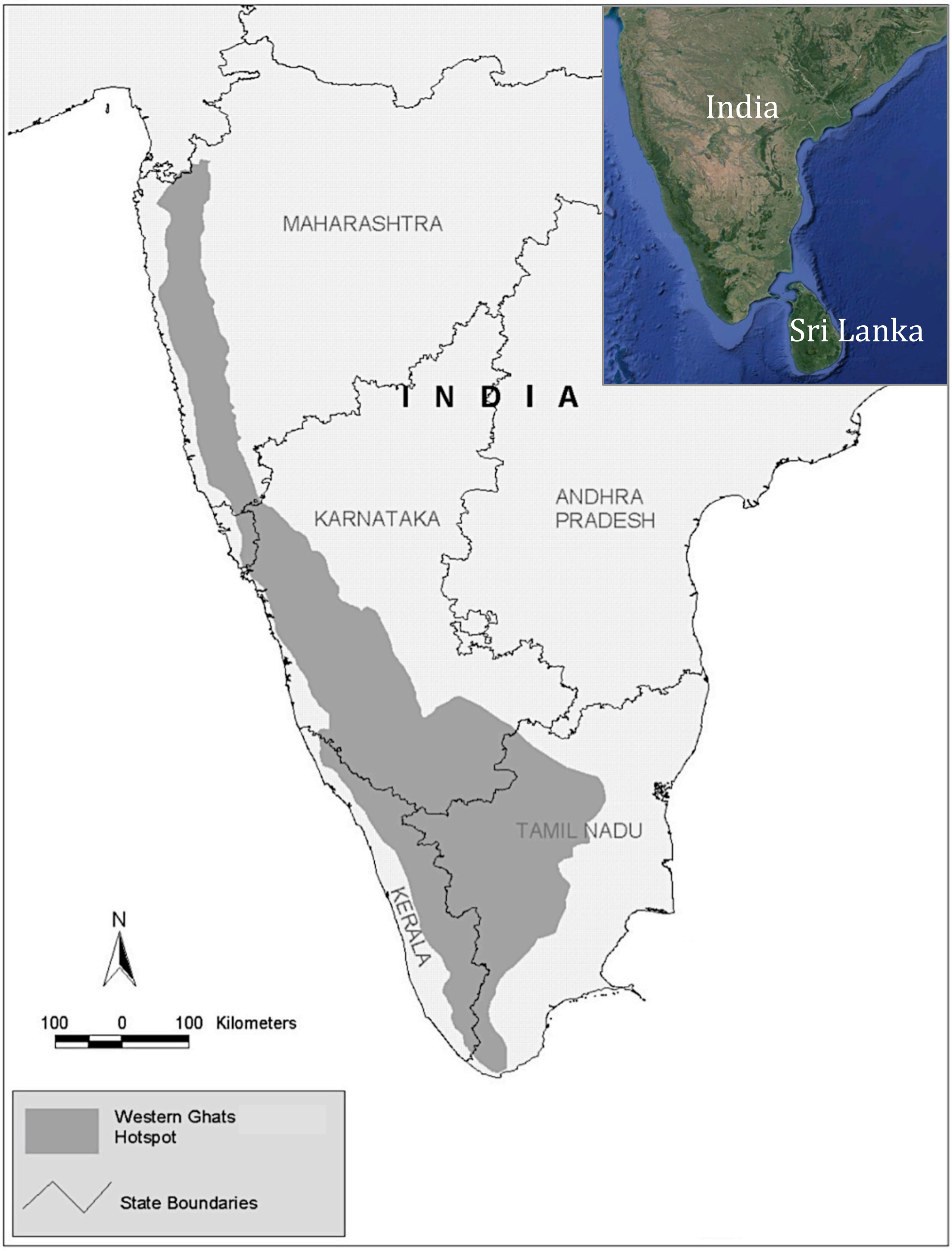


Figure 2.1 The Western Ghats landscape *Source: Bawa et al., 2007, Google Map of India, 2017*

The highest peaks of the Western Ghats reach over 2,500 m. Monsoon winds bring heavy rain between June and September that feeds into the mountain's riverine system providing 40% of India's drinking water and power for approximately one quarter of the country's population (Bawa et al., 2007). Variations in rainfall patterns, altitudes and temperature gradients across the range produce a rich diversity of vegetation types, distributed between four tropical and subtropical moist broadleaf forest eco regions, making the Western Ghats one of the world's biodiversity hotspots (Myers et al., 2000, Bawa et al., 2007, Mittermeier et al., 2011). The area is home to 7,402 species of flowering plants (Nayar et al., 2014) and a large number of fauna species. Among vertebrates, birds represent the largest number of known species (508 species), followed by fish (218), reptiles (157), mammals (137), and amphibians (126). At least 325 globally threatened species occur in the Western Ghats (Myers et al., 2000, Dahanukar et al., 2004). Many of these species found within the mountain range are endemic to the Western Ghats region. Among the most charismatic species are Asian elephants (*Elephas maximus*), Bengal tigers (*Panthera tigris tigris*), lion-tailed macaques (*Macaca silenus*), sloth bears (*Ursus ursinus*) and Nilgiris tahrs (*Hemitragus hylocrius*).

2.3.2 Western Ghats as a human-modified landscape

The landscape of the Western Ghats can only be understood through its relationship with human factors. Western Ghats is by far the most densely populated global biodiversity hotspot (Cincotta et al., 2000). The regional population is characterised by a richness of cultures, traditional knowledge systems and ethnicities including indigenous tribes. Human activity in the area dates back over 12,000 years before present, mostly in the form of hunting and gathering (Chandran, 1997).

Agricultural landscapes were established at least 2,000 years ago (Ranganathan et al., 2008). Since then the Western Ghats landscape has been significantly, but not completely, converted from native vegetation to other types of land use including agriculture, forestry, urban space, and areas for the extractive use of natural resources. Such alterations make Western Ghats a typical human-modified landscape, following Gardner et al's. (2009) criteria. Compared to other tropical human-modified landscapes such as Mexico (Greenberg et al., 1997), the Dominican Republic (Wunderle, 1999) and Colombia (Armbrecht et al., 2005), the Western Ghats typically feature greater habitat heterogeneity and structural complexity while retaining considerable native forest cover (Anand et al., 2010).

More specifically, the remaining natural habitats cover close to one-third of the extent of the Western Ghats, with the protected area network comprising 58 parks spanning 13,595 km^2, less than 9% of the total Western Ghats area (Bawa et al., 2007). The network is highly fragmented and embedded in a heterogeneous matrix of human land use including human inhabitations, artificial reservoirs, open agriculture such as paddy (*Oryza spp.)* and vegetables, and plantations of coffee (*Coffea spp.),* tea (*Camellia sinensis*), rubber (*Hevea brasiliensis*) and cardamom (*Elettaria cardamomum*) interspersed with a variety of other cash crops (Daniels et al., 1990).

Forested and human-modified landscapes interact in several ways. Wild species that otherwise inhabit continuous forest landscapes frequently occur in the human-used matrix foraging for resources, such as wild bees residing in forest fragments and foraging within coffee plantations (Ghazoul, 2007), or elephants foraging/raiding cereal crops (Thomas, 2005). Wild species also use the human-modified landscape to disperse between patches of suitable habitat, such as wild elephants dispersing through tea plantations (Kumar et al., 2010). Flora exchanges occur between forest and human-modified landscapes too. For example, populations of invasive shrubs and herbs (*Eupatorium glandulosum*, *Ulex europaeus* and *Cytisus scoparius*) coming from plantation crops have been reported in the native forests (Bunyan et al., 2012). Finally, the matrix also supports viable populations of generalist species (Bali et al., 2007).

2.3.3 Agricultural expansion and forest loss

Much of tropical Asia was forest dominated even in the 1950s (Kummer and Turner, 1994). In the Western Ghats widespread logging and clear felling for plantations of timber, tea, coffee, fibre and agriculture started much earlier, about 200 years ago with the arrival of the British (Prabhakar, 2005, Chandran, 1997). Subsequently, between the 1920s and 1990s, the central and southern Western Ghats witnessed a 40% loss in forest cover, predominantly due to conversion to open or cultivated lands (76%) or plantations (16%). The number of forest patches increased fourfold while the average patch area reduced by 83%, both clear indicators of extensive forest loss and fragmentation (Menon and Bawa, 1997). Today plantations account for the largest proportion of commodity crops across the landscape. They span over 10,000 km^2, covering an area almost as large as that of protected parks, and are predominantly in the central and southern reaches of the Western Ghats (Figure 2.2).

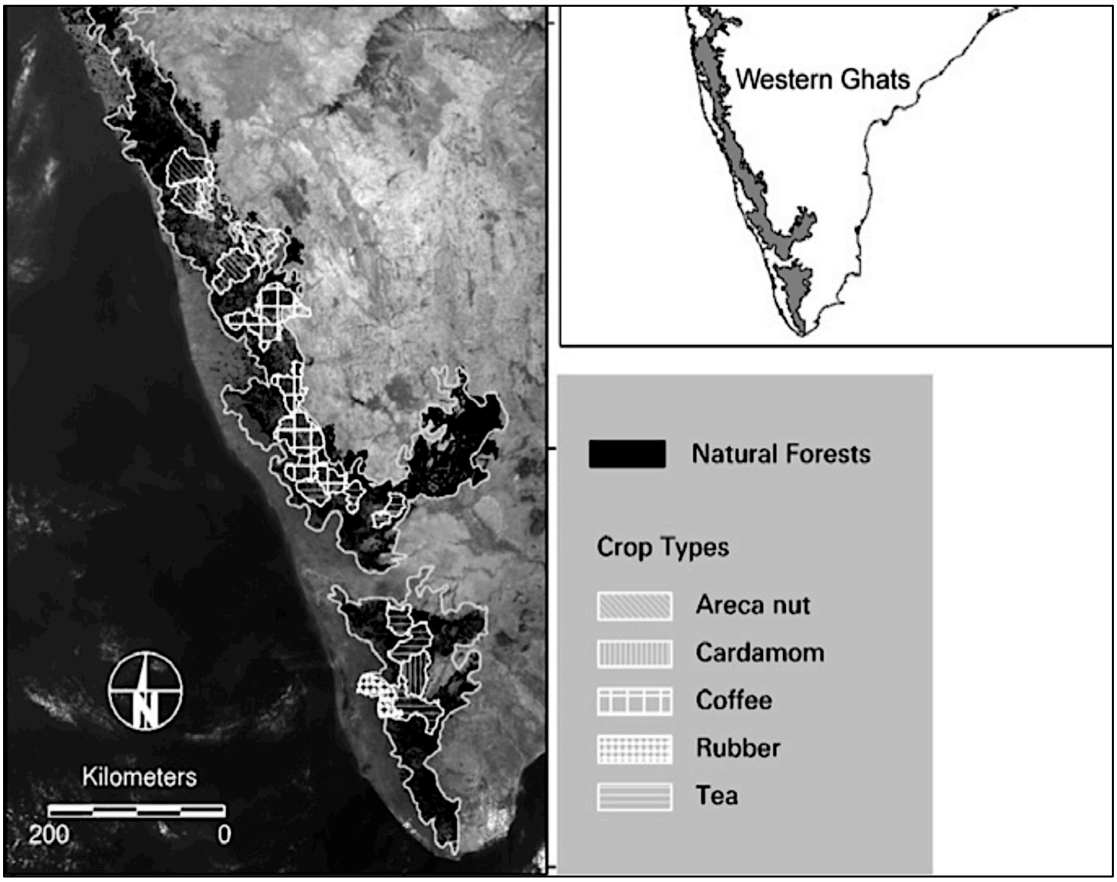


Figure 2.2 The distribution of commodity crops and natural forests. *Source: (Anand et al., 2010)*

2.4 The Nilgiris

The Nilgiris district, located in the heart of Western Ghats is representative of the wider human-modified landscape. The Nilgiris covers 2,545 km^2 and is the most westerly district of Tamil Nadu (Department of Economics and Statistics, 2017). The district is situated at the meeting point of three states: Karnataka, Kerala and Tamil Nadu (Figure 2.3). It comprises 6 sub-districts known as Taluks: Pandalur, Gudalur, Udhagamandalam, Kundah, Coonoor and Kotagiri. The district capital is officially called Udhagamandalam, known universally as 'Ooty'. It is also the place where plantation industries are administratively headquartered, being the home for the United Planters' Association of Southern India (UPASI) and the Tea Board's South India office.

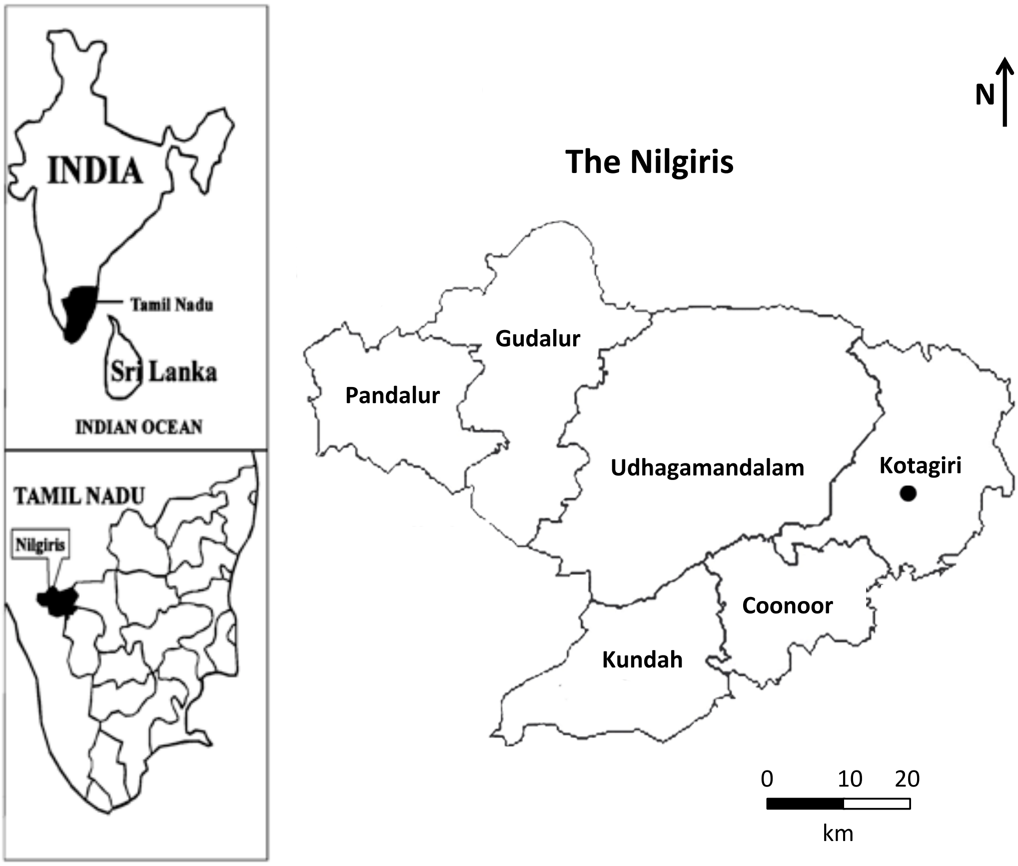


Figure 2.3 Map showing the study area, the Nilgiris district in the Southern Indian state of Tamil Nadu.

The Nilgiris is an undulating plateau mostly over 1,000 m altitude and rising to 2,637m (at Doddabetta peak), the highest peak of Southern India. The area has innumerable perennial streams draining into Moyar and Bhavani, which further join together on the plains to form a tributary of the river Cauvery. The annual rainfall of the reserve ranges from 500 mm to 7,000 mm with temperature ranging from 0°C during winter to 41°C during summer.

Within the district are various categories of protected areas, including Wildlife Sanctuaries and National Parks. The entirety of the Nilgiris district forms part of the Nilgiris Biosphere Reserve (NBR), which expands over the district's boundaries (Figure 2.4). NBR is India's first man and biosphere reserve designated in 1986 and prides itself on having about 80% of the flowering plants reported from Western Ghats (Bawa et al., 2007).

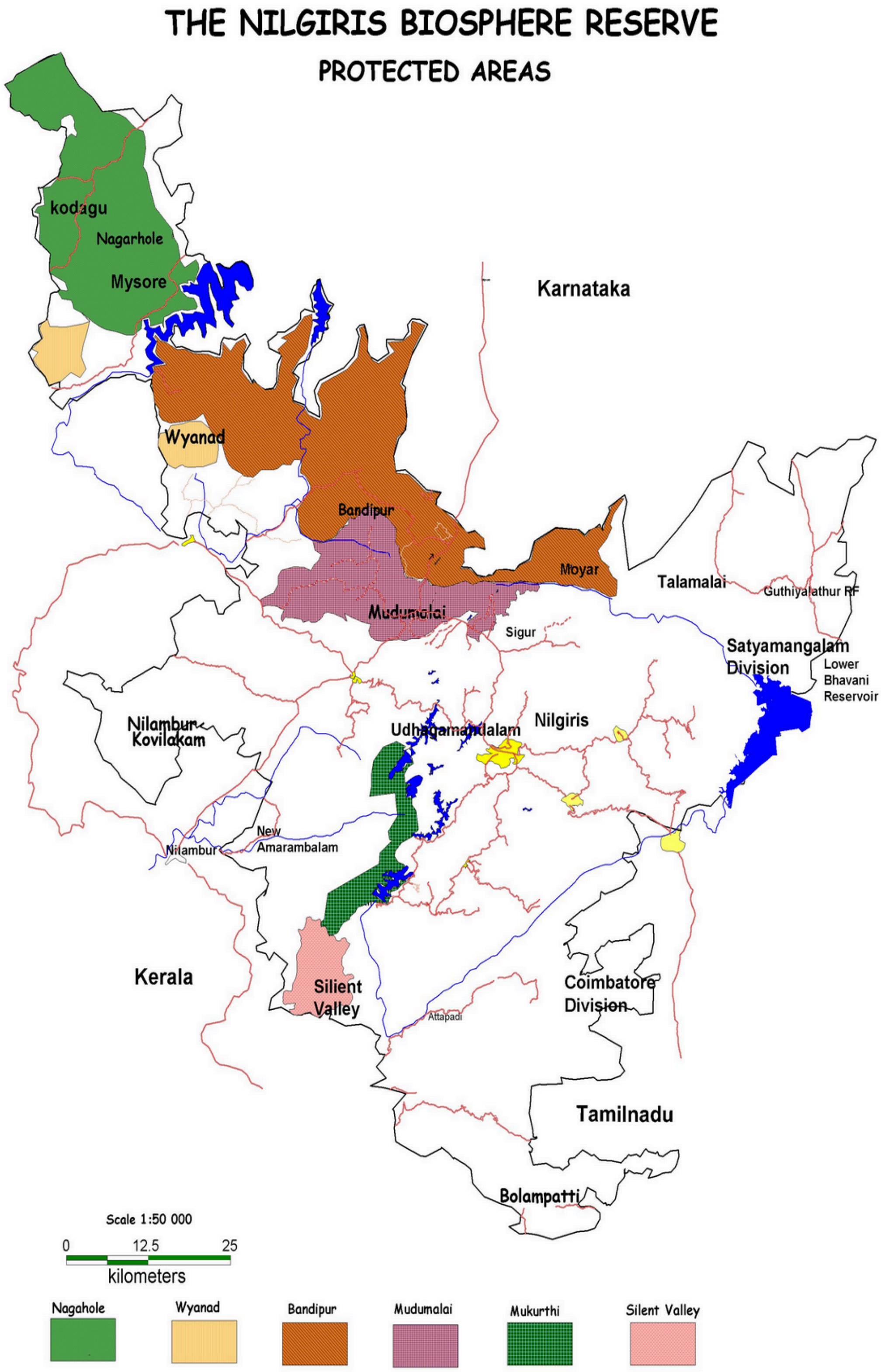


Figure 2.4 Map showing Nilgiris Biosphere Reserve, which includes the Nilgiris district. The reserve has 5520 km^2 and is formed of four National Parks: Nargahole, Bandipur, Mukurthi and Silent Valley and two Wildlife Sanctuaries: Mudumalai and Waynad. Source: *Keystone Foundation*

2.4.1 A short history of the Nilgiris

The history of the Nilgiris dates back to the eleventh century. The Name 'Nilgiris' means Blue Mountains in Sanskrit. There is a belief that the people living in the plains at the foot of the hills, gave the name after the violet blossoms of 'kurinji' flower (*Strobilanthes kunthianus)* enveloping the hills every 12 years (Hockings, 2012). The Nilgiris was ruled by most of the rulers of South India over several centuries. In 1799 after the fall of Tipu Sultan, a Treaty of Srirangapattanam ceded the Nilgiris to the East India Company, but it wasn't until 1812 that the area became known to the British (Venugopal, 2006).

John Sullivan, an Englishman and Collector of Coimbatore, had a great cultural and economic impact on the Nilgiris hills. He was a lover of nature and had propensity for agriculture and gardening. He was the first European official to build a house and settle there in 1819. John Sullivan introduced a number of varieties of exotic plants from Europe and South Africa, which form part of the Nilgiris flora today (Venugopal, 2006). Along with these, he introduced two main crops, tea and 'English' vegetables. The socio-ecological history of Nilgiris (Diagram 2.2) shows how gradually tea and vegetables became an important pillar of the local economy at the detriment of local forest (Hockings, 2012). At present, tea plantations, in particular, cover over 70% of the Nilgiris cropland and account for half of South India's tea production, registering the highest yields in the country due to a favourable altitude and climate (Pritchard and Neilson, 2009).

The original human inhabitants of the Nilgiris plateau are Todas, Kurumbas, Irulas, Kotas and Badagas, who live at higher elevations, while Panias are the dominant indigenous group in the lowlands (Hockings, 2012). Apart from Badagas, all the other groups are classified as Scheduled Tribes or adivasi communities, a collective term for the indigenous people of mainland South Asia. For decades, the Nilgiris has attracted the attention of anthropologists, because the relationships between these groups has been argued to present key clues into the evolution of human societies (Hockings, 1989).

Today, alongside these communities live people belonging to the Scheduled Caste, mainly comprising Tamils of Sri Lankan origin that arrived in the area after 1960. Both the Scheduled Castes (SC) and Scheduled Tribes (ST) are officially designated groups of historically disadvantaged people in India (Government of India, 2012).

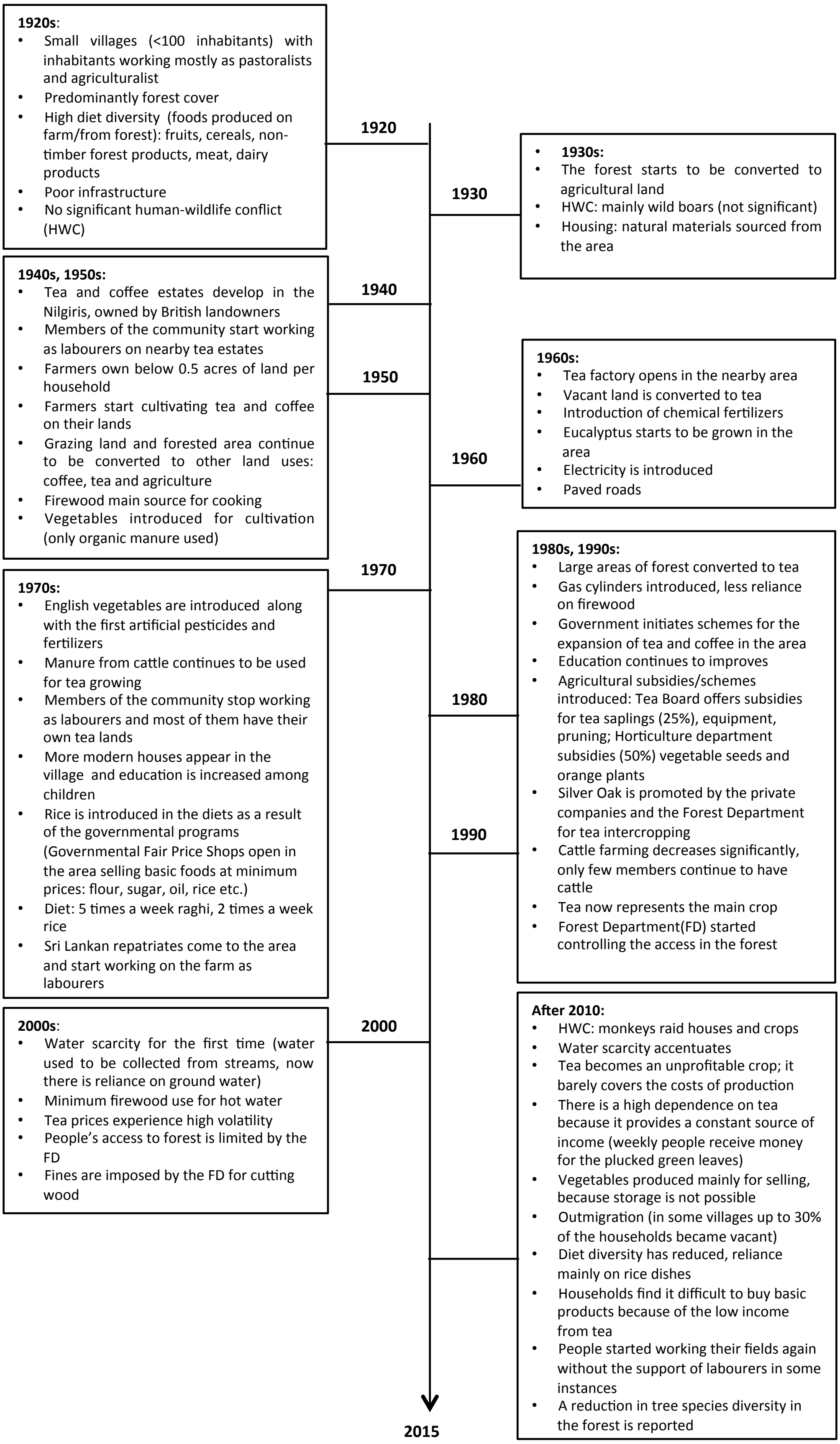


Diagram 2.2 Socio-ecological timeline of the Nilgiris between 1920 and 2014 based on focus group discussions carried in 6 villages (Sundatty, Thuneri, Battagorai, Nedugula, Milidhen, Denadu, Kaggula, Kercombai) during fieldwork, 2014-2016.

2.4.2 Socioeconomic aspects

The Nilgiris district has a population of 735,394 inhabitants of which 41% live in the rural area (Census of India, 2011). There are 64,369 households (Department of Economics and Statistics, 2017). The population density of 287 persons per km^2 is considerably less than the Tamil Nadu state average of 555 persons per km^2 (Census of India, 2011). With the exception of the most recent census, data show a continuously increasing population in the Nilgiris from the beginning of 20th century with a boom between 1920 and 1980 (Table 2.1).

Table 2.1 Comparison of decadal population growth rates through the 20th and early 21st centuries. *Source: Census of India, 2011*

Year	Population growth rate (%)
1901 - 1911	+ 5.1
1911 - 1921	+ 6.7
1921 - 1931	+ 33.8
1931 - 1941	+ 23.9
1941 - 1951	+ 48.7
1951 - 1961	+ 31.3
1961 - 1971	+ 20.7
1971 - 1981	+ 27.6
1981 - 1991	+ 12.7
1991 - 2001	+ 7.7
2001 - 2011	- 3.51

Out of the total population of the Nilgiris 43% are working: 4% are cultivators, 22% are labourers and the rest are employed in other economic sectors (Department of Economics and Statistics, 2017). The literacy rate is 85.2%, one of the highest across Indian states. The main religions are Hinduism, which accounts for over 70% of the population, followed by Christianity and Islam both with 10% (Nilgiris Statistical Handbook, 2009).

The primary economic sector of the Nilgiris remains agriculture even if, at state level, a reduction in the agriculture contribution to the economy from 11.65% in 2004 -2005 to 8.7% in 2011-2012 has been observed (Government of Tamil Nadu, 2017). In the same period the area under agriculture reduced, but production has increased by 0.18 million metric tonnes due to an increase in productivity (Government of Tamil Nadu, 2017). In 2010-2011, 92% (7,448,169) of operational farms in Tamil Nadu belonged to the marginal and small farmer category (Government of Tamil Nadu, 2017).

The main crops grown in the Nilgiris are tea, coffee and vegetables (Table 2.2). The average land size is 1.25 hectares (Department of Economics and Statistics, 2017).

Table 2.2 Crops grown in the Nilgiris by total area and percentage of total cropland for the year 2011-2012 (Horticulture Department, 2015)

Name of crops	Area (ha)	Percentage of total cropland
Plantation crops	***64,096.38***	***85.6***
- Tea	55,503.95	*74.1*
- Coffee	8,176.92	*10.9*
- Others	415.51	*0.6*
Agricultural crops	***7,043.24***	***9.4***
- Vegetables	5,617.95	7.5
- Other food crops	304.88	0.4
- Oil seeds	63.7	0.1
- Sugar crops	3.71	0.0
- Other Non-Food crops	1053	1.4
Fruits	***909.74***	***1.2***
Spices and condiments	***2,707.11***	***3.6***
Flowers	***111.7***	***0.1***
Medicinal plants	***1.6***	***0.0***
Total	**74,869**	**100**

Tea (*Camellia sinensis)* is grown on hilly slopes and it is generally intercropped with fast growing exotic tree species like Silver Oak *(Grevillea robusta)* (Figure 2.5). Vegetable fields (Figure 2.5) are found in the valleys or on terraces and coffee is grown in the lower western part of the district.

Figure 2.5 Photos showing typical tea fields intercropped with Silver oak (left) and terraced vegetable fields (right) in the Nilgiris district

Scheduled Castes, the Badaga community and Scheduled Tribes account for 32.08%, 23-27% and 4.46% of the total population of the Nilgiris respectively (Census of India, 2011, Hockings, 2012). The remaining ethnic groups are Tamils, Malayali, Kannada or other minorities.

2.4.3 Communities of the Nilgiris: livelihoods, food security and land use practices

The three main communities (SC, Badaga and ST) are very distinct within the Nilgiris with different histories, livelihoods, food security and land use practices.

2.4.3.1 Scheduled Tribes

The Nilgiris is home to over 30 adivasi communities, amongst them some of the least developed groups in Southern India, including one of the surviving hunter-gatherer groups of the Indian sub-continent (Keystone Foundation, 2007). They represent distinct ethnic groups, have small populations and live in geographical concentrations, often distinct from one another. Traditionally, most of these communities were cattle herders, agriculturalist or hunter-gatherers. They grew mixed crops of millets through the practice of shifting agriculture and centred their cultural and husbandry activities in or around forests. The forests used to be, and in many cases still are, utilised as a producer of non-commercial commodities especially local medicine, food, fuel, fodder, timber and fibre.

After the start of British rule in 1819 the forestland was taken over by the state and the ancestral domains of the adivasi communities were not acknowledged, including deified forests nurtured as 'sacred groves' (Keystone Foundation, 2007). From that time onwards a long process of land alienation started and continues to the present day. In 1998 a survey carried out by the Keystone Foundation estimated that 39% of the households from the Coonoor and Kotagiri sub-districts of the Nilgiris were landless and 49% had less than 0.8 hectares of land (Keystone Foundation, 2007). In 2010 official data showed that 55% of the adivasi families in rural areas are either landless or have less than 0.5 hectares (Department of Economics and Statistics, 2017).

Among those households that own land commercial crops have largely taken over from homesteads and marginal lands. The crops cultivated now are tea, coffee, vegetables, paddy, banana, ginger, corn and millet. Mixed agriculture has been drastically reduced and is not followed as an intensive practice due to climate, geography, lack of funds and access to extension services (Keystone Foundation, 2007).

Referred to as 'ecosystem people' the adivasi have maintained a lifestyle that did not have unsustainable impacts on natural resources (Keystone Foundation, 2007). However, surrounded by more prosperous communities, they often replicated the livelihood practices of these communities, which has changed their cultural practices, food, livelihoods and well-being (Devi and Kumar, 2011, Demmer, 2014). For example, with the introduction of plantations adivasi dependence on paid labour on Badagas' lands increased and more and more adivasi people refrained from traditional activities such as non-timber forest products collection and agriculture (Hockings, 1989). Similarly slash and burn agriculture and a ban on hunting have increased dependence on subsidized ration rice (*arisi*) and a loss of food sovereignty with impacts on nutrition and health (Keystone Foundation, 2007). Some of the most commonly reported health problems are anaemia and child bearing problems (Ramasamy et al., 1994, Brindha and Prashanthi Devi, 2014).

2.4.3.2 Scheduled Caste

There is a large number of communities that fall under the Scheduled Caste classification (Government of India, 2012). In the Nilgiris, the Scheduled Caste is primarily comprised of Sri Lankan repatriates that settled in the area after the Indian-Sri Lankan agreements (1964 and 1974) for the repatriation of almost 1 million stateless persons (Hockings, 2012). The Scheduled Caste are mainly landless; with 77% either landless or owning less than 0.5 hectares (Department of Economics and Statistics, 2017).

Scheduled Caste represent the main work force in the area. Most work on Badagas' tea plantations, commercial plantations or are employed either permanently or temporarily by TANTEA-Tamilnadu Tea Plantation Corporation Limited (TANTEA, 2011). The Government of India set up TANTEA in 1975 when it took over from the Forest Department, which in 1968 converted vast areas of forest to tea in order to rehabilitate Sri Lankan repatriates. Today, about 11,200 people (or 5% of the SC population) work on TANTEA plantations. Two members in each family of repatriates are given permanent employment besides seasonal work for their dependents (TANTEA, 2011). They live in governmental housing and their economic status is somewhat superior to that of the Scheduled Tribes. Like STs, the SCs also rely predominately on fuelwood for cooking.

Although their access to education, health and the availability of improved housing has increased since their arrival in the Nilgiris, SC are still facing impoverished livelihoods and food security problems (Pritchard and Neilson, 2009). Similar to Scheduled Tribes, the Scheduled Caste relies on the benefits of the Zero Hunger Programme introduced in 2011 by the government as a scheme that provides access to free rice to all families based on a family card. Additionally, governmental Fair Price Shops allow all members of the community to buy basic goods such as oil, flour, sugar or rice at discount prices.

2.4.3.3 Badagas

Badagas constitute the largest single ethno-linguistic entity in the Nilgiris district. The origin and dispersion of the Badaga in the landscape has been traced back to the sixteenth century, but this remains a source of debate to date (Heidemann, 2006). Badagas mainly practice Hinduism and continue their original practice of ancestral worship. Traditionally, Badagas were tillers and herdsmen that practiced slash and burn agriculture. Now the community members have a large variety of livelihoods.

Badagas occupy more than 350 hamlets or *hatti* across the district and speak *Badaga* or *Badagu,* a language which has no script (Young Badaga Association, 2015). The community is scattered in the entire Nilgiris, but with a higher density in three of the Taluks: Kotagiri, Coonoor and Udhagamandalam. Landownership among Badagas is high. About 47% of the Badaga households own at least 0.5 hectares of land (Department of Economics and Statistics, 2017). Unlike most of the households in the other two communities, STs and SCs, Badagas have recognised land rights (*patta*).

Over centuries the Badagas have maintained a congenial co-existence with the other indigenous groups, but their villages are still exclusive. Badagas villages typify the position of their inhabitants in the lower rungs of rural India with housing that is sturdy and well equipped, including with washing machines, new foam beds, and electric mixers. Cooking is performed with gas, kerosene or fuel wood (Pritchard and Neilson, 2009). Because of the large number of Badagas and the extent to which they own land (with property rights) they represent the main community of focus for this study.

After the British came to the Nilgiris, it was Badagas who took to change and modernity. Tea was initially cultivated by the British land owners, but with India's independence in 1947 and the increase of tea prices in the 1960s many of the Badaga communities stopped working as labourers on the surrounding estates and gradually gave up their fruit gardens, grain cultivation and cattle farming in favour of tea and vegetable cultivation (Hockings, 2012). Diverse agricultural land and pastures were soon converted to cash crop monocultures. The attraction of tea was not only prompted by its financial value but also by its ease of

management, the fact that it is a perennial crop, with continuous yields throughout the year, and a constant flow of income (Pritchard and Neilson, 2009).
For several decades tea plantations continued to expand and the economic prosperity brought by tea plantations improved the livelihoods of the Badagas. This was reflected in better housing, infrastructure development, and access to education (Bandhu, 2017). However, their diet diversity reduced as lowland rice and foods from local markets and shops replaced grains such as millets, raghi and wheat that were once produced in the area along with mixed vegetables grown on their own farms and dairy products coming from personal livestock (Young Badaga Association, 2015). One dietary aspect that distinguishes Badagas from the other two communities is that they are predominantly vegetarian.

At the turn of the twenty-first century, the Nilgiris had 60,389 tea smallholders (mainly Badagas) that contributed some 40% of total South Indian tea production. 86% of them grew no other crops except tea (Tea Board of India and UPASI, 2001). Since then, horticulture and floriculture have been growing fast, but tea remains the dominant crop.
A decrease in tea production that started after the late 1990s coincided with a tea price crisis between 1998 and 2002 when South India lost its main buyer, Russia. From then on South Indian tea prices have been in free fall whilst the higher-quality North Indian teas have been less exposed to these problems due to different market strategies (Sanjith, 2004). What followed was a spiralling effect that forced the Badagas into an economic crisis. In trying to reduce the cost of production essential field practices such as regular pruning, application of fertilizers and pest and disease management were often abandoned with important consequences for the productivity and the quality of the tea. Moreover, in their desperate need to make up lost income, the felling of shade trees for sale as timber has become common, again with implications for the future productivity of tea gardens (Pritchard and Neilson, 2009). Environmental conditions including declining soil fertility and water scarcity, along with an aging of plantations decrease yields further (Sahoo and Muralidharan, 2017). Subsidies offered by the Forest Department for tree saplings for intercropping or by the Tea Board and UPASI to cover the costs of pruning and tea saplings, were not sufficient enough to compensate the cost of production.
The heavy reliance on tea meant that most households were faced with a decrease in their standard of living (Bandhu, 2017). In this period the price of tea fell 50% and it was estimated that it generated a drop in smallholder income of around 83%, with incomes making a minor

addition to material-livelihoods and food security (Pritchard and Neilson, 2009). Like the other two communities, the Badagas now have to rely on governmental programmes to ensure minimum food security. Households requiring urgent cash would pawn their gardens for an average fee of $1,100 for three years. If after three years they can't repay the debt, the pawn-holder would work the fields for a further three years, after that it would be sold if the debt were not returned. In one of the areas surveyed in the Nilgiris it was estimated that 10% of the local smallholders have been forced into such arrangements since the onset of the tea crisis (Pritchard and Neilson, 2009).

Although the Tea Board reported that in 2006 the number of tea smallholders dropped by about 10,000 (to 50,329), many Badagas live with the hope that tea will once again bring prosperity to the Nilgiris (Venugopal, 2004). Thus, the view of the future landscape is one of high controversy. The dependency on a declining tea market may continue to push producers into a financial crisis, decrease food security, boost outmigration and pressure natural resources. Alternatively new livelihood substitutes may be proposed in time to overcome these threats. The price the natural habitat and biodiversity will have to pay and who will win and lose and who has greater power to take decisions in the landscape remain undefined.

2.4.4 Land use change and drivers of change

Prior to the first incursions by the colonial British in 1819, the Nilgiris was blanketed in primary forest known as *shola* and vast areas of grasslands. Though occasionally found at altitudes as low as 1050 m, the shola-grassland ecosystem mosaic is generally representative for landscapes of 1700 m or more and consists of rolling grasslands with shola fragments restricted to sheltered folds and valleys in the mountains separated from the grasslands with a sharp edge. Since sholas frequently have persistent cloud cover they can be classified as upper or lower montane cloud forest, depending on their elevation (Bunyan et al., 2012). The first records of land use cover date from 1849 (Table 2.3) and refer to the Nilgiris Biosphere Reserve. They show that grasslands covered the majority of the landscape whilst sholas and cultivation land covered 17% and 22% of the area respectively.

Table 2.3 Comparison of the different types of vegetation in the Nilgiris Biosphere Reserve between the years 1849 and 1992. The table does not include all types of land uses and land covers of the landscape, but only those for which information was available. *Source: Ministry of Environment and Forest, 2015*

Vegetation Type	1849		1992	
	Size (ha)	Percentage of vegetation type	Size (ha)	Percentage of vegetation type
Sholas	8,600	17	4,225	9
Grasslands	29,875	61	4,700	10
Cultivation	10,875	22	12,400	26
Tea	0	0	11,475	24
Wattle	0	0	9,775	20
Eucalyptus	0	0	5,150	11

The history of change from traditional cropping to the newer commercial cash crops of tea, coffee and vegetables began in the 1820s when the British first introduced vegetables. The Badagas, in the plateau area of the Nilgiris took to the cultivation of potatoes, beans, cauliflower, cabbage and carrots on a large scale. Coffee was also introduced on the slopes of the hills in 1838 (Keystone Foundation, 2007). This was the zone where the adivasi communities lived and they soon spread the crop within the forested lower zones. The main coffee plantations were in the west region of the district but some also occurred on the eastern slopes. Coffee soon became an integral part of the homesteads of tribal people and a popular beverage but due to climatic conditions it never expanded to the same extent as tea.

Over the past century much of the primary forest vegetation within the region has been replaced by plantation crops (mostly tea), wetlands have been converted into vegetable fields and commercial monoculture forests, especially eucalyptus (Eucalyptus *sp.*) and wattle (*Acacia dealbata* and *Acacia mearnsii*), have replaced the original, multispecies habitats within high altitude wilderness zones. By 1992 the grasslands had reduced by 85% compared to 1849 and the sholas reduced by more than a half, with tea accounting for the single largest cause of deforestation (Table 2.3). A recent study (Satish et al., 2014) provides insight into the pattern of forest cover change that occurred in the Nilgiris Biosphere Reserve between 1920 and 2012 (Figure 2.6).

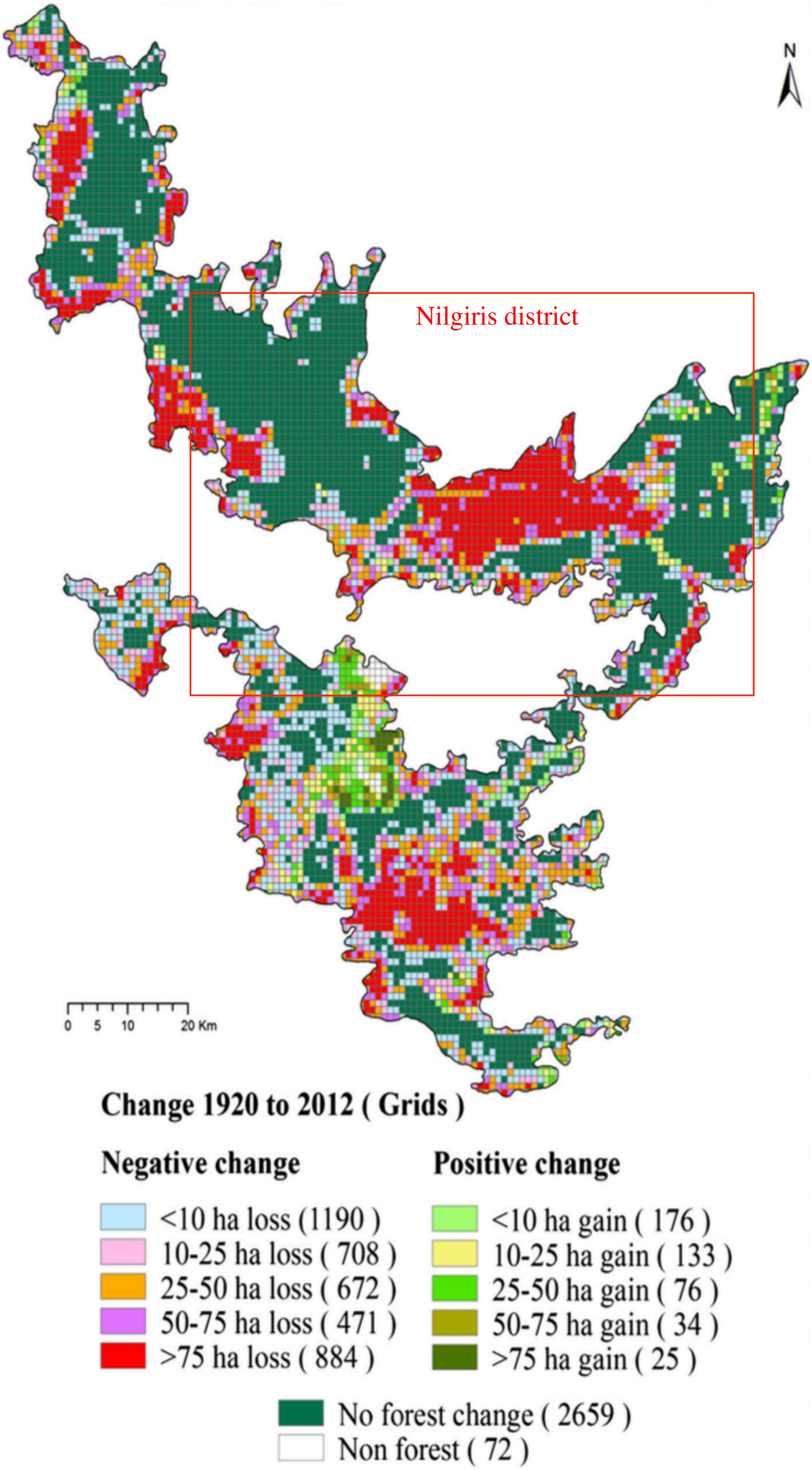


Figure 2.6 Spatial forest cover change of Nilgiris Biosphere Reserve: 1920–2012. *Source: Satish et al., 2014*

During this period the total forest area of the biosphere reserve reduced by 24.5% from 5,806.5 km^2 (93.8 % of total geographical area) to 4,382.9 km^2. Grid wise analysis, where a grid cell is 1 km x 1 km, indicates that 851 grids have undergone large-scale negative changes of >75 ha of forest loss during 1920–1973 while, only 15 grids have shown >75 ha loss during 1973–1989. The average annual rate of deforestation for the period of 1920 to 1973 was estimated at 0.5% whereas between 1973 and 1989 it was 0.1%. The reduction in deforestation in the second period is attributed to an increase in the degree of forest protection that followed from the declaration of the area as a biosphere in 1986 (Kumar and Bhagavanulu, 2008, Satish et al., 2014, Kumari, 2015).

The different studies conducted in the Nilgiris Biosphere Reserve or the Nilgiris district show differences in the most recent LULC data and in the patterns of change over time (Figure 2.7-Figure 2.9; Table 2.4). Some of the variation between the studies is the result of different: definitions used for the land use classes, Landsat data used or the different collection and analysis methodology. Based on personal observations during fieldwork, the state institutions or local NGOs do not trust the outcomes of these maps. At the same time they could not provide maps that they consider representative of the reality in the field. In an attempt to compare the outcomes of the different maps I found that the definitions used to outline the different land use classes are missing or are often too loose to allow comparison. Instead I have focused on the common narratives that the stakeholders agreed on, such as: deforestation has reduced in the last three decades, an increase in the forested area has been observed mostly from commercial monoculture forests and the tree species variety has reduced in the primary forests. Given the low commercial value of tea, which reduced the pressure on forest, and the increase in forest cover, Nilgiris does not represent a typical frontier landscape.

In the next section I will look at some of the similarities and differences between the LULC studies and official data.

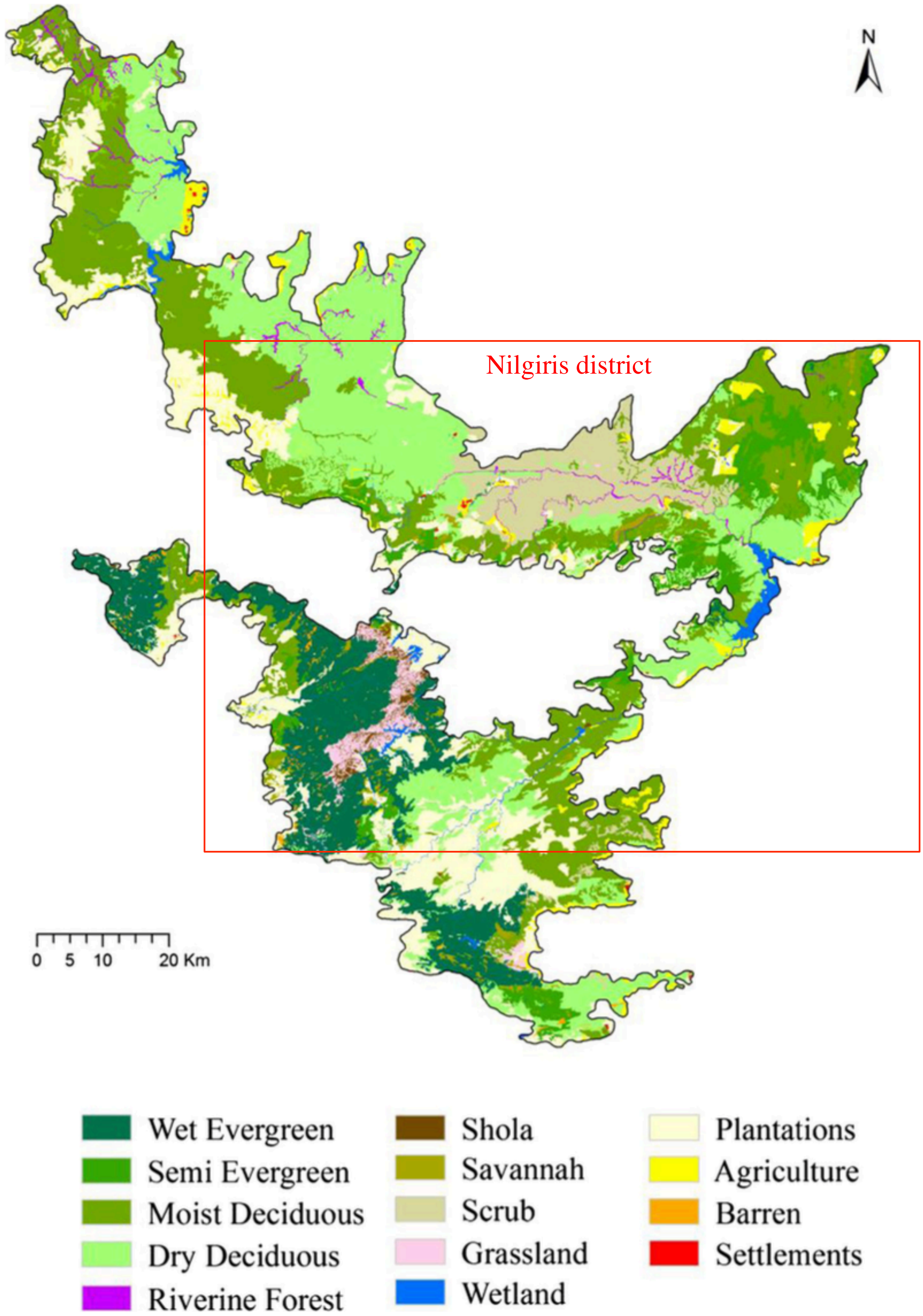


Figure 2.7 Classified map showing vegetation types and LULC of Nilgiri Biosphere Reserve, 2012. *Source: Satish et al., 2014*

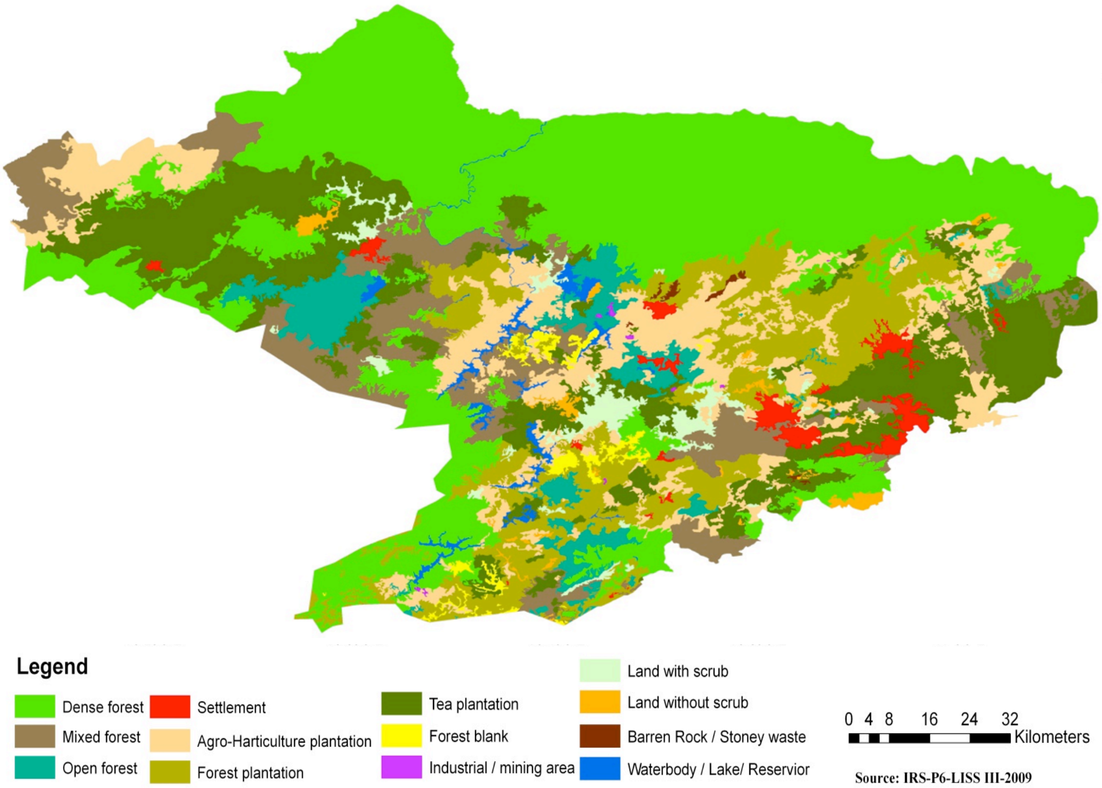


Figure 2.8 Land use and land cover of the Nilgiris district, year 2009. *Source: Lakshumanan et al., 2012*

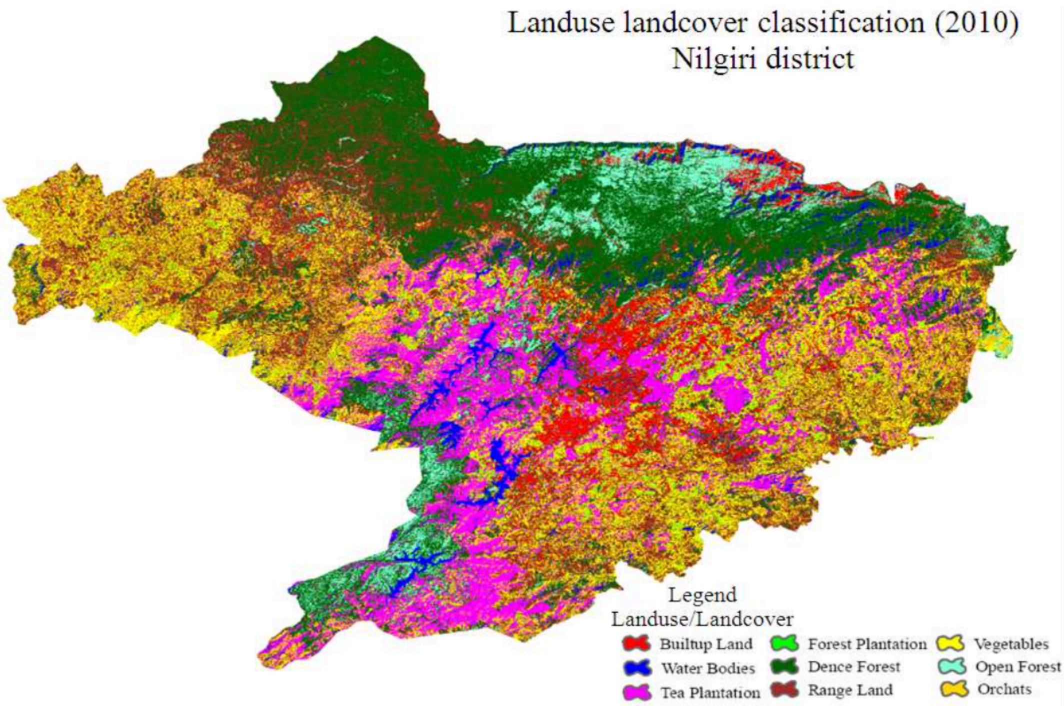


Figure 2.9 Land use and land cover of the Nilgiris district, year 2010. *Source: Nalina et al., 2014*

For example, between 1973 and 2009 the forest cover was reported to have increased from 41.4% to 53.8% (Table 2.4; Lakshumanan et al., 2012). After 2013 official data reported that the forest cover reached 56% (Table 2.4; Horticulture Department 2013, Department of Economics and Statistics, 2017). These data are however contested by Nalina et al., 2014, which estimated the forest cover to be less than 40% (Table 2.4).

Over the same time period (1973 - 2009) the land allocated to tea plantations and agriculture has decreased, so that in 2009 they occupied 17.2% and 11.3% of the LULC respectively (Table 2.4; Lakshumanan et al., 2012). Similar sizes have been reported in the official data for the year 2016 (Table 2.4; Department of Economics and Statistics, 2017). The other two studies (Horticulture Department 2013, Nalina et al., 2014) show significantly different percentage LULC, particularly for agro-horticulture plantations (Table 2.4). Comparison between the two LULC maps of the Nilgiris district (**Figure 2.8**, Figure 2.9) also show there is very little agreement in terms of the type of forests present in the north and the distribution of tea and agro-horticulture plantations throughout the entire landscape.

Table 2.4 Land use and land cover in the Nilgiris district. Comparison between different data sources.

		Lakshumanan et al., 2012					Nalina et al., 2014	Department of Economics and Statistics, 2017	Horticulture Department, 2013
No.	Land use and land cover (LULC) class	Area (km^2)		Percentage of LULC		Percentage difference between	Percentage of LULC	Percentage of LULC	Percentage of LULC
		1973	**2009**	**1973**	**2009**	**2009 and 1973**	**2010**	**2016**	**2013**
1	**Forest (total)**	1055.1	1373.5	41.4	53.8	**12.5**	38.33	56	56
	Dense forest	656.9	993.3	25.8	38.9	13.2	18.48	-	-
	Open forest	67.3	116	2.6	4.6	1.9	12.47	-	-
	Mixed forest	248.3	239.7	9.7	9.4	-0.3	7.38	-	-
	Forest blank	82.6	24.4	3.2	1	-2.3	-	-	-
2	**Forest plantation**	469.2	305.4	18.4	12	**-6.4**	-	-	-
3	**Tea plantation**	483.5	437.6	19	17.2	**-1.8**	16.71	18	21
4	**Agro-Horticulture plantation**	400.7	288.6	15.7	11.3	**-4.4**	7.68	12.1	2.2
5	**Settlement**	7.5	44.3	0.3	1.7	**1.5**	6.05	-	-
6	**Waterbody/ Lake/ Reservoir**	32.9	29.3	1.3	1.2	**-0.1**	2.65	-	-
7	**Land with scrub**	40.2	47.7	1.6	1.9	**0.3**			
8	**Barren rock/ Stony waste**	34.3	3.5	1.3	0.1	**-1.2**			
9	**Industrial/ Mining area**	2.9	1.5	0.1	0.1	**-0.1**			
10	**Land without scrub**	25.3	20.4	1	0.8	**-0.2**			

Personal discussions with the Forest Department favoured the Lakshumanan et al., 2012 results over the other sources, but there is still a great deal of ambiguity in the LULC maps of the Nilgiris. While these contradictions remain, there is agreement that the shola forests and grasslands continue to be affected by illegal and select cutting of valuable species including teak, sandalwood or rosewood. Additionally slash-and-burn practices, over-grazing, fires, landslides and the intensive use of pesticides and fertilizers place additional pressure on shola forests (Settle, n.d.). The Forest Department played and continues to play an important role in their conservation.

The role of the Forest Department

Historically, the Forest Department (FD), the main state-based conservation agency in India, has played a double role in the conservation of native habitats and biodiversity. On one hand the designation of protected areas prevented further forest encroachment and the maintenance of vast areas of native shola forests where hunting was strictly prohibited and punished under criminal law. On the other hand the institution was responsible for clearing of vast areas of forest to allow for expansion of tea with the arrival of Sri Lankan Tamils. The FD was also responsible for the introduction and promotion of exotic species including Silver Oak and wattle that gradually replaced or diminished native tree cover (Kumari, 2015).
Furthermore, the changes brought by conservation acts and policies have had an impact on human-nature relationships. Firewood collection once common in the area is now prohibited by the Forest Department, which has started to impose fines. The group that has been mostly affected by changing forestry policy is the tribal community, which lost their forest tenure rights leading to a breakdown in community governance systems (Keystone Foundation, 2007).

Today the Forest Department represents one of the major suppliers of non-native Sliver Oak saplings, used mainly for tea intercropping. Additional jungle wood nurseries are used for forest restorations and projects that look into how native trees could be just as successfully introduced in plantation crops (Nath et al., 2011). These could offer more sustainable and biodiversity-friendly alternatives to the current practices promoted by the FD.

2.5 Current threats to the environment and Interventions in the landscape

2.5.1 Current threats

The current threats faced by the Nilgiris Biosphere Reserve are similar to the ones in the wider landscape of Western Ghats (Table 2.5).

Table 2.5 Current threats to the environment in Western Ghats and those specific to the Nilgiris Biosphere Reserved (NBR) marked with 'X'. *Source: Daniels, 1996, Bawa et al., 2007, Kumari, 2015*

Threats identified in Western Ghats Protected Areas	Threats identified in NBR
Local hunting	X
Illegal timber felling	X
Presence of exotic and invasive species	X
Fuelwood/Fodder removal	X
Conflict with large wildlife and retaliation	X
Livestock grazing	X
Medicinal forest plants collection	X
Non-timber forest products collection	X
Tourism	X
Fire	X
Encroachment	X
Organized poaching and animal trade	
Highways and roads	X
Presence of enclosures	
Plantations	X
Transmission lines (power/telecom)	X
Power and irrigation projects	X
Cultivation of Marijuana	
Leaf litter collection	
Mining and ancillary activities	
Logging by state, including of dead and fallen wood	X
Water scarcity	X

NBR experiences high incidences of human wildlife conflict (Thomas, 2005). Important drivers of conflict include crop and infrastructure damage and human mortality by elephants and domestic cattle predation by leopards (*Panthera pardus*). Human wildlife conflict is especially prevalent in areas where people have encroached on forested land or have been allocated private land in the middle of the forest.

Intensive felling of native trees is another regional problem (Kumari, 2015). The influx of people in the landscape in the last century continues to put pressure on the local forests and in turn destroys the habitat of species like the Nilgiris wood pigeon (*Columba elphinstonii*), Nilgiri pipit (*Anthus nilghiriensis*) and Nilgiri langur (*Trachypithecus johnii*) that are endemic to this region and have become highly endangered.

Furthermore, the extensive tea monocultures along with excessive use of fertilizers have degraded the soil quality. The tea bushes require frequent application of fertilizer, which has made the soil porous. During heavy rain, these slopes are easily washed away resulting in landslides (Kumar and Bhagavanulu, 2008).

Water scarcity in the landscape has been widely reported and it has been linked to the introduction of the eucalyptus in the landscape by the Forest Department (Daniels, 1996). The Central Soil and Water Conservation Research and Training Institute carried out research showing that eucalyptus absorbed enormous quantities of subsoil moisture.

Although the livestock population inside the NBR is very low, the livestock population in the periphery is very high and the sholas and high value biodiversity grasslands are used as grazing sites. The unintended consequences are degradation of low and high level grasslands, which harbour a large number of endemic species along with soil erosion and micro climatic changes in shola forests (Thomas and Palmer, 2007). Additional pressure on the forest is exercised by an increasing rate of Non-Timber Forest Products (NTFPs) collection. The collection of these products is becoming less sustainable, leading to low populations or sometimes the disappearance of species from the area (e.g. medicinal plants such as *Saraca asoka*). The different set of rules applied in each state (Tamil Nadu, Karnataka and Kerala) opens opportunities for trans-border transactions in order to avoid the regulations (Keystone Foundation, 2007).

Finally, the NBR is also an important tourist centre in South India, attracting a large number of tourists. Numerous hotels, clubs, resorts, gardens and roads have emerged rapidly, degrading the natural vegetation, overexploiting water resources and polluting the environment (Venugopal, 2004, Kumari, 2015).

2.5.2 Synopsis of current interventions in the landscape

In order to address some of the challenges identified in the landscape various interventions and strategies have been proposed and/or implemented. The type of interventions should be understood in the context of the wider landscape of Western Ghats, which, as one of the world's biodiversity hotspots, attracts significant funding and conservation interest.

Western Ghats has an exceptionally high density of conservation-related interventions funded by donors and implemented by institutions and organisations, such as:

i) The government, through its agencies (e.g. Ministry of Environment, Forest and Climate Change);
ii) Multilateral and bilateral donor agencies (e.g. The World Bank Group, GEF, Asian Development Bank, Australian Agency for International Development, UNDP, DFID, U.S. Agency for International Development)
iii) Research institutes (e.g. Tropical Botanic Garden And Research Institute, Indian Institute of Science, Mysore and Pune University, Pondicherry University)
iv) National NGOs (e.g. Asian Nature Conservation Foundation, Keystone Foundation, Foundation for Ecological Research, Advocacy And Learning, Center for Wildlife Studies, Nature Conservation Foundation, ATREE)
v) International conservation NGOs (e.g. Ford Foundation, WCS, BirdLife International and Rainforest Alliance).

These groups often work together or fund each other, so there are lots of overlaps between them.

With such a diversity of actors in the landscape there are few types of conservation interventions that the Western Ghats landscape has not experienced first hand (ATREE and CEPF, 2013). The interventions range from purely nature-centred (ecological programmes) to human-centred ones (livelihoods projects), they employ both monetary (e.g. payment for ecosystem services, certification schemes) and non-monetary (e.g. sacred groves) incentives, they have funds that range from thousands to millions of dollars, and whilst some focus on the wider landscape (e.g. landscape corridors) others focus on more local environments (Bawa et al., 2007). Interventions that occur in Western Ghats focus both on strengthening the conservation of protected areas as well as biodiversity in the adjoining unprotected areas (ATREE and CEPF, 2013).

This section focuses on a small number of agricultural and conservation-related interventions that have been proposed, or are being undertaken in the landscape with the intention of driving changes in land use. The aim is to provide an overview of the diversity of interventions encountered in the landscape. Where relevant, parallels are drawn with LS/LS approaches.

***Implementer**: The Ministry of Environment and Forests*

***Intervention:** Madahav Gadgil Panel for Western Ghats Ecology Expert Panel (WGEEP) and Kasturirangan Panel for High Level Working Group (HLWG)*

WGEEP has studied the impact of population pressure, climate change and development activities on the Western Ghats and proposed to turn the entire Western Ghats region into an Ecologically Sensitive Area with three categories of protection regimes and listed activities that would be allowed in each, based on the level of ecological richness and land use. The Gadgil panel proposed to put in place a blanket ban on all activities which may have harmed or will harm the environment including: a ban of pesticide use, a ban on genetically modified crops, decommissioning hydropower projects and a gradual shift from plantation to natural forests (Ministry of Environment and Forests, 2011). Deemed out of line with on the ground realities, the report was followed by the HLWG, which aimed to relax the recommendations of WGEEP. As a result the Kasturirangan panel focused on how to protect remaining ecological richness and environments untouched by human activities. The Kasturirangan panel removed many of the restriction imposed by the previous panel and in doing so it was criticised for being anti-environmental (Ministry of Environment and Forests, 2013, Shanavas et al., 2016).

The suit of measures proposed by the panels would create landscapes that resemble forms of both land sparing (through land use zoning) and land sharing (through encouraging forms of wildlife-friendly practices in agricultural areas adjacent to ecologically sensitive areas). It is expected that without the consultation of direct beneficiaries the recommendations are going to be met with resistance by local farmers.

***Implementer**: The Government of India (MoEF, 1988)*

***Intervention:** Joint Forest Management (JFM)*

A long running government program that offers fiscal incentives to local communities to protect and manage regenerating forests on their private lands. Although schemes vary from state to state, usually a village committee known as the Forest Protection Committee and the Forest Department enter into a JFM agreement. Villagers agree to assist in the conservation of forest resources through protection from fire, grazing, and illegal harvesting in exchange for which they receive NTFPs and a share of the revenue from the sale of timber products.

Implementer*: ACCORD (ACCORD, 2017)*

Intervention: *The role of sacred groves in biodiversity conservation*

This intervention is led by a local NGO and it is centred on tribal communities. It aims to understand, document and promote recognition of the role of sacred groves in biodiversity conservation. Additionally, it supports the adivasi communities to claim community forest rights under the Forest Right Act (FRA) of 2006 and strengthen the capacity of these communities to conserve forest resources. The FRA refers to land rights restitution to tribal communities.

Implementer*: Foundation for Ecological Research, Advocacy and Learning (ATREE and CEPF, 2013)*

Intervention: *Sustainable Agricultural Practices*

The local NGO promotes the adoption of sustainable land use practices in rubber plantations by developing local indicators for certifying rubber products that comply with global standards and respect local tradition. Additionally they provide guidance to rubber plantation managers about priority actions needed to achieve certification. This intervention resembles land sharing at farm level.

Implementer*: Nature Conservation Foundation and Rainforest Alliance (RA) (ATREE and CEPF, 2013)*

Intervention: *Sustainable Agriculture Standard*

The partnership between a national and international organisation aims to promote a market-based approach to enhance ecological connectivity and introduce Rainforest Alliance 'Sustainable Agriculture Standard' into coffee and tea estates in order to promote sustainable agricultural practices that resemble forms of land sharing on the farm.

Despite their proliferation, evidence of the interventions' impact on sustainability and the perception of the beneficiaries of the interventions is limited. So far, data suggest both positive and negative reactions and consequences. For example, the High Level Working Group has been highly controversial. Once the report was out the government initiated steps to implement its recommendations and declared 4,156 villages in six States (Goa, Gujarat, Karnataka, Kerala, Maharashtra and Tamil Nadu) as Ecologically Sensitive Areas with the intention to impose restrictions of certain land use practices in all these villages. This bureaucratic step provoked widespread resistance and protest actions from the local population, which continue to escalate (Shanavas et al., 2016, Haneef, 2017). In another example, Bose et al. (2016) found that the experience of coffee growers that participated in RA certification has been one of business-as-usual thereby leading to a growing discontent with conservation measures. The Joint Forest Management programme was deemed inadequate largely as a result of ineffective and undemocratic institutions that implement these programs (ATREE and CEPF, 2013).

Other examples from Western Ghats show how responses to interventions have been motivated by the perceived justice and injustice surrounding them and that those proposing more inclusive forms of governance in terms of participation in decision-making have been associated with better conservation outcomes and satisfaction among beneficiaries (Martin, 2017). This shows the growing need to facilitate a more coordinated and collaborative approach between policy makers, implementers and beneficiaries in order to achieve the intended aims.

The next section is taking a closer look at the forest-agriculture relationship that led to the current interventions in the heart of the study area, the Nilgiris district.

Understanding the forest-agriculture relationship and interventions in Nilgiris district

The Nilgiris forest-agriculture relationship has been shaped over time by a series of public policies that have defined land ownership and access rights and the purpose specific lands should be put to. It is only in the more recent history, after 1990, that non-state actors have started to play a more important role in influencing this relationship. This section will provide a brief overview of how the forest-agriculture relationship changed over time and its impact on local communities as a result of state interventions. The section will conclude with an overlook of the current interventions in the Nilgiris district.

Pre-British period the divide between primarily forest-dependent communities and agriculture-dependent communities was not straightforward. While Irulas and Kurumbas grew crops such as bananas, chilies, citruses and edible roots on land near their homes they also used to clear the forest and practice swidden agriculture in order to grow millet varieties. At that time, forests constituted ‘open access’ resources that met multiple needs of almost all communities.

The arrival of British stemmed an ample change to the landscape resulting from the introduction and expansion of cash crops such as tea and coffee, paired with new law enforcement. The Revenue and Forest Department’s jurisdictions were to assess existing cultivated lands and demarcate forests and settling rights of communities that might have claim to forest lands. Given the ambiguous border between what constituted agricultural fields and forests, for many agrarian communities the process of forest reservation resulted in significant hardship. A number of practices were banned, including the felling of trees, the cutting of branches and shifting cultivation, all of which impacted communities dependent on fuelwood or agriculture within forests. For the adivasis their life in the forest became illegal. Shola forests and grasslands became reserved areas under the Madras Forest Act of 1882 and the felling of trees was banned. This, however, did not prevent the expansion of tea plantations into forestland. The Forest Department also extended its jurisdiction to trees on private lands and as a result cultivators were discouraged to grow trees on private lands. Another important aspect of this state-driven change is that unlike in the plain areas, social forestry (forested areas that meet the needs of communities outside of the reserved forests) was trivial. Almost all non-forest lands were under cultivation, leaving little land available for private plantations.

Post-independence several other important changes, that influenced the forest-agriculture relationship and consequently the interventions that derived from there, occurred or mirrored colonial policy. Most notable was the continued need for timber extraction, which led to cultivation of exotic tree plantations by the FD. After 1970 water scarcity problems particularly associated with eucalyptus plantations shifted the FD’s priority towards the conservation of the local forests. By this time the use of forest products for most of the communities has already been restricted. Since then, fuelwood and fodder needs have been met from small private holdings or estates. Tea bushes have represented very common sources of fuelwood throughout the region as well as branches of silver oak intercropped in tea and coffee plantations.

This history has important implications for understanding the type of forest-agriculture interventions that proliferated in the Nilgiris landscape. Based on personal observations the interventions fall primarily under two categories. The first category targets the livelihoods of adivasi communities and their rights and relationship with local forest. Both state and non-state actors play an important role. For example, local authorities (Forest, Revenue and Tribal Welfare departments) are responsible for screening and approving the resolutions that aim to restitute forest rights to tribal communities under the Forest Right Act (FRA) of 2006. The restitution of rights will give adivasi the right to self-cultivation, pastoralist activities and use of NTFPs among other freedoms. This law is widely contested. On one hand there are supporters of adivasi rights and those that see an opportunity for more sustainable conservation of the forest, while on the other hand opponents of the law consider that the restitution of rights will lead to forest destruction. In parallel, non-governmental organisations have also engaged with adivasi communities. For example, Keystone Foundation has focused on a livelihoods-conservation-enterprise model. Adivasi are encouraged to continue sustainable traditional agriculture and NTFP harvesting processes and the organisation helps them sell a part of their products (e.g. millets, honey, gooseberry, nuts) on the local markets, through specialised shops. To diminish the HWC generated by cultivation of crops in the forests, World Wide Fund for Nature NGO has trialled the use of electric fences to prevent elephants raiding the agricultural plots of one adivasi community.

The second category of interventions is dominated by state actors and focuses on tea cultivation. Given land ownership in Nilgiris, the Badagas are the main recipients of these interventions. Institutions such as the Hills Development Programme, Tea Board, the Horticulture Department, The United Planters' Association of Southern India (UPASI) and the Forest Department have implemented a suite of interventions that aim to increase productivity on the farms or make tea cultivation more biodiversity friendly through the use of organic manure and tree intercropping with Silver Oak. Details of the intervention or policy under each institution are presented in *Section 4.3.7.3*. The type of interventions promoted by these institutions appears to focus more on increasing tea productivity or farm profitability with limited environmental benefits. For example, the FD is providing exotic trees saplings for tea intercropping, completely disregarding the native jungle wood varieties. Furthermore, the institutions continue to treat the relationship between agriculture and forest in isolation, disregarding the multifunctionality of the landscape and its livelihood implications. Thus, there is great scope for future programmes to move beyond these limitations and propose new and more integrated approaches.

2.6 Conclusions

India is a populous democracy with high levels of poverty and an economy that continues to rely primarily on the agricultural sector. The rapid growth of the economy threatens its most biodiverse habitats, including the Western Ghats landscape. With an agricultural history that spans at least 2,000 years, the Western Ghats landscape has been significantly, but not completely converted from native vegetation to other types of land use, with plantation crops playing a major role in this transformation. A tea-growing region situated at the heart of the Western Ghats landscape, the Nilgiris is representative of the wider landscape and an ideal location for addressing the research aims of this study due to its need to reconcile agricultural production with biodiversity conservation while considering the food security and livelihoods of one of the most impoverished communities.

Chapter 3

Methodology
Companion Modelling

3.1 Summary of methodology and methods

This chapter explains the methodological strategy undertaken to collect and analyse primary data and justifies these choices against other plausible approaches. The study makes use of both quantitative and qualitative data and has three main stages in data collection and analysis, dictated by the research questions.

In the first part of the study, data were collected to enable the description of the local environment, a characterization of the farming systems and land use, and that of local livelihoods and food security. These data were supplemented by the construction of a library of *what-if* scenarios to add further depth in understanding how households might respond to possible future scenarios including the introduction of land use interventions. A range of methods were utilised for primary data collection in this part of the study, including: key informant interviews, in-depth household surveys and focus groups. Secondary data from literature reviews and local organizations' archives were used to triangulate and enrich the findings of primary sources. Data analysis included frequency tables, univariate analysis, multivariate statistical analysis and regression models.

Participatory methods were used to identify feasible LS/LS interventions in a real-world landscape. The aim was to assess if stakeholders that play a key role in the success of a land use policy could reach consensus on potential LS/LS strategies in a given landscape and if so how these strategies would look. Mapping key stakeholders was followed by participatory workshops and stakeholder interviews to allow the proposal and negotiation of different land use policies. This process was aided by the co-development of a role-playing game (RPG) intended for the beneficiaries of the land use strategies. The RPG was conducted in day-long sessions and was used to:

i) Increase knowledge and understanding of direct land users (farmers) decision-making;
ii) Observe how the policies proposed by stakeholders could translate into practice;
iii) Provide information on the land use processes that occur in the landscape and the factors that might prompt farmers to adopt or reject different land use policies.

Alongside data from the first phase of the research, the outcomes of the RPG were used to develop a computer simulation model, known as an agent-based model (ABM). The simulation was designed to reproduce the landscape dynamics observed during the RPG and project them into a decades-long timeframe under the different policy scenarios proposed by the stakeholders. The model offered insight into the potential adoption of the different policies at landscape level and their environmental, production, livelihoods and food security outcomes.

The combination of methods used in this study is associated with a trans-disciplinary participatory modelling approach referred to as Companion Modelling (ComMod). By combining qualitative and quantitative methods it provides the benefits of both approaches: the robustness of quantitative results and the depth and richness of qualitative interpretation.

This chapter begins by outlining and justifying the choice of the overarching methodology used in this research, the ComMod approach (*Section 3.2*), and the research design with three stages, referred to as ComMod loops (*Section 3.3*). It then goes on to give details of the methods used to collect and analyse data under each of the ComMod loops: land use and socioeconomic household profile data (*Section 3.4*), the development and implementation of a RPG (*Section 3.5*), and the development and implementation of an ABM (*Section 3.6*).
The methods for data collection and analysis introduced here are further complemented by specific information under the relevant chapters.

3.2 The choice of Companion Modelling methodology

It is generally agreed that better decisions are implemented with less conflict and more benefits for biodiversity conservation when they are driven by stakeholders in participatory processes (Redpath et al., 2013). Yet the efficiency of the participatory process depends on social interactions between the stakeholders, their ability to communicate and exchange information, and the skills and methods that can assist them in doing so (Voinov and

Bousquet, 2010). Over the last decade there has been a proliferation of stakeholder engagement methods (Reed, 2008), with participatory modelling accounting for an important segment (Voinov et al., 2016).

The term participatory modelling describes the use of modelling in support of a decision-making process that involves stakeholders. Many studies have stressed the benefits of stakeholder participation in environmental modelling, including: increased natural resources management legitimacy and effectiveness, increased sense of ownership of the decision process and more chance that new proposed policies are ultimately accepted (e.g. Zorrilla et al., 2010, Röckmann et al., 2012, Carmona et al., 2013). Furthermore, participatory modelling contributes to more structured discussions between stakeholders and scientists about uncertainties, and it advances scientific understanding and collective learning (Lamers et al., 2010).

In the context of the current research, the impact of agriculture on the environment has largely been dealt with reactively (Balmford et al., 2012) and advocates of the LS/LS framework have promoted policies in a top-down approach (Phalan et al., 2016) disregarding stakeholders' diverse interests. The main values of participatory modelling lie in: i) creating models that are better adapted to local contexts, ii) engaging actors in exploring potential land use polices in a bottom-up way, and iii) assessing *ex ante* the impact of policies on agriculture, biodiversity and local livelihoods; thus assessing the effectiveness of such policies from an early stage (Bontkes and Keulen, 2003, Happe et al., 2006, Doglioni et al., 2009, Lee et al., 2014).

Some of the most commonly utilised participatory modelling tools available in the literature are Group Model Building (Andersen et al., 2007), Mediated Modelling (van den Belt, 2004), Collaborative Learning (CL, 2017) and Companion Modelling (Barreteau et al., 2003, Etienne, 2010). In many cases the differences between these strategies are quite subtle but in essence they tend to be doing relatively the same things (Voinov and Bousquet, 2010). This study favours Companion Modelling (ComMod) because it is versatile with different software platforms, is increasing in popularity, has a widespread and active support community, and a ComMod core team that provides regular trainings and meetings for researchers.

3.2.1 Definition

Companion Modelling or ComMod has been formulated since the mid 1990s, by researchers from Centre de Coopération Internationale en Recherche Agronomique pour le Développement or CIRAD (France). It belongs to a family of trans-disciplinary participatory modelling approaches used to support and accompany collective decision-making processes (Groot and Maarleveld, 2000; Ramirez, 2001, Borrini-Feyerabend et al., 2004). ComMod involves the co-construction, and use with stakeholders, of a model representing the functioning of their socio-environmental system (D'Aquino et al., 2002, Barreteau et al., 2003, Becu et al., 2006). Further, it allows stakeholders to evaluate different scenarios of interest (Etienne, 2010). In doing so it facilitates collective information sharing and learning and it is hypothesised that it produces a model better fitted to stakeholders' needs and, consequently, is of more use (Barreteau et al., 2003).

The development of a model typically follows an iterative methodological process that alternates between complementary field and desk-based activities. It typically entails two objectives: to understand a complex and uncertain social and environmental system by investigating their interactions and, to support negotiation and collective decision-making in managing common resources (Barreteau et al., 2003). The two aims are complementary and are not mutually exclusive, as the first objective needs to be fulfilled before proceeding to the second.

ComMod processes usually make use of synergies between two key mediating tools: RPGs and ABMs (Barreteau and Abrami, 2007, Etienne, 2010). ComMod encourages the mutual and interactive participation of stakeholders during the design, implementation, calibration and validation steps of the models, as well as exploration of possible scenarios.

3.2.2 Application

The approach has been tested over the last 17 years (Figure 3.1) and it is increasingly being used across diverse domains (Figure 3.2) with a focus on social, environmental and computer sciences.

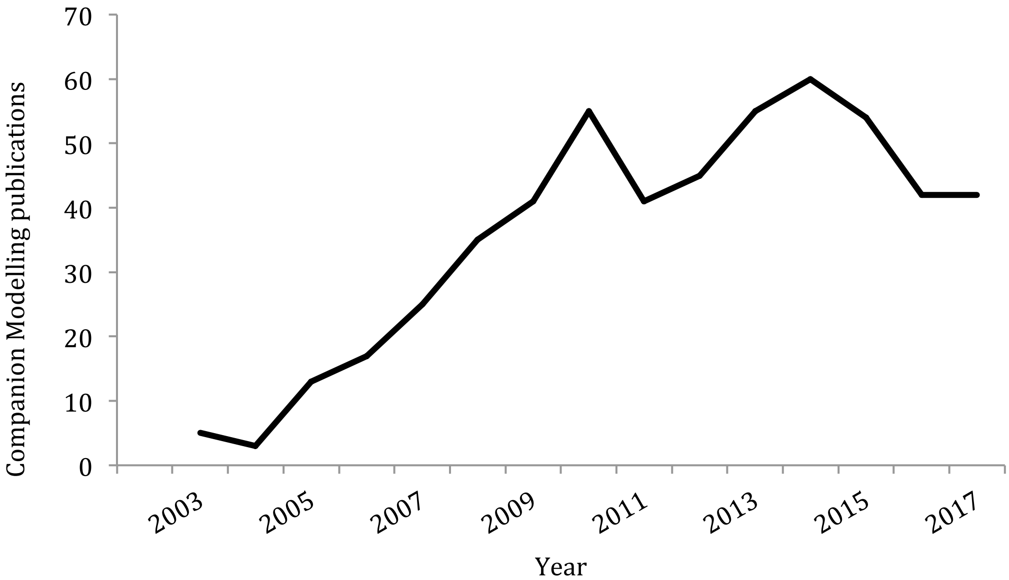


Figure 3.1 Chart showing the number of Companion Modelling publications per year since the first Companion Modelling publication, Barreteau et al. (2003). *Source: Scopus (keyword search "Companion Modelling", November 2017)*

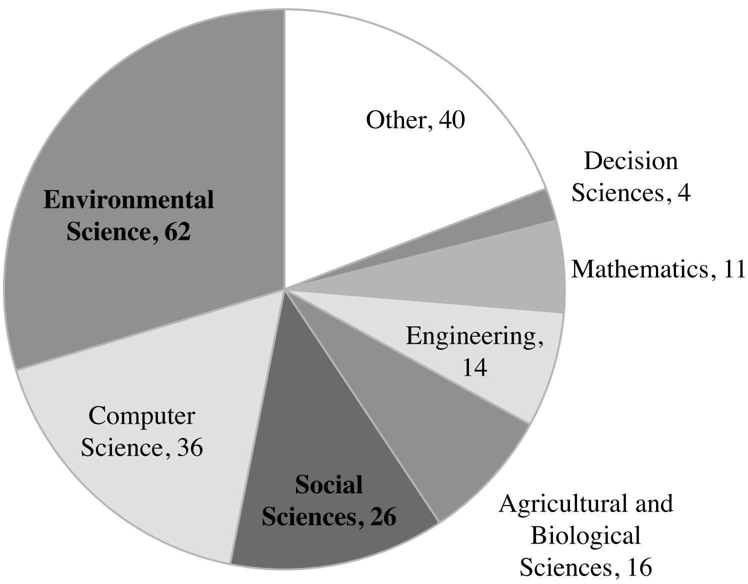


Figure 3.2 The approximate number of Companion Modelling studies published by subject area since 2003 *Source: Scopus (keyword search "Companion Modelling", November 2017)*

Globally a broad range of topics that have been addressed using ComMod approach. Some of the studies have looked at: integrated renewable resources management (Ruankaew et al., 2010), social agro-ecological systems in Thailand (Naivinit et al., 2010), community-based forests management in the Philippines (Campo et al., 2009), land use mediation

(Dumrongrojwatthana et al., 2011), peri-urban catchment in Brazil (Ducrot et al., 2015), environmental management policies in West Africa (D'Aquino and Bah, 2013) and aspects of food security and policy implications in agricultural systems (e.g. Dixon et al., 2009, Dolinska, 2017; see *ComMod.org* for a library of studies from 2002 to present).

3.2.3 Relevance to current research

The overarching advantage of using ComMod is that it is an ever-evolving and iterative process that allows a constant improvement of results. It uses mixed methods in a complimentary way, to build an expanding library of information that transcends disciplines, particularly that of natural and social sciences, a feature central to this research in the context of the LS/LS framework. One of the key advantages of ComMod for understanding the social acceptability of the LS/LS strategies in a real-world landscape is its versatility, due to its range of associated methods. Although the questions within this research project are very different in nature, they can be addressed using the methods associated with ComMod.

Understanding the feasibility of LS/LS interventions is complex given the diverse interests of stakeholders. Workshops and RPGs allow an understanding to build on collective exploration of possible policies in a participatory and inclusive manner. ComMod encourages direct negotiations between stakeholders and reflexivity on the expectations from each participant. It prevents the researcher's own epistemology from imposing a frame of reference or emphasising pre-determined assumptions. Thus, it moves away from top-down solutions, which contrasts with most of the LS/LS studies to date. Central to this process is the formulation of a conceptual model, by the stakeholders, that describes the interaction between human and local environment. For this research it means looking at how households' land use decision-making processes affect the environment and how the changes in the environment affect them in return.

The second research question looks at the adoption of hypothetical LS/LS interventions and uses RPGs to identify functional land use policies. Identifying land use policy interventions deemed viable by stakeholders does not necessarily or automatically lead to legitimacy and support of policies (e.g. Korfmacher, 2001). Pre-assessment of how potential adopters might respond to them is valuable to understand if the policies are going to be accepted and under what conditions. By using RPGs such assessments can be conducted and decision-making processes that arise from testing of polices can be observed and documented. A great advantage of RPGs is that unlike conventional surveys (which are valuable complimentary tools to better understand a system) the RPGs are able to capture these emergent phenomena. They are 'dense methodological tools' that condense time and space and help make problems clearer by synthesizing essential characteristics of complex systems (Pak and Brieva, 2010). They also capture respondents' attention with more ease, making them more focused on the answer itself rather than on internal deliberations such as reflexivity towards the researcher, or whether to impart sensitive personal information, which can distract the respondent in an ordinary survey (Souchère et al., 2010). Furthermore, the RPG facilitates a common language between actors and researchers.

Finally, once information about the adoption is available, testing how different interventions impact on socioeconomic aspects of the households and on the natural environment, over longer periods of time, requires tools that are equipped to deal with complexity and future scenario exploration. ABMs (see Box 3.1 for definition) have been particularly designed to deal with such complexity. They can encapsulate all the previously obtained data about the processes of adoption, the heterogeneity of decision-making of households and their interaction with the environment. Scenarios can be tested over long periods of time and depending on the software there can be a spatially explicit representation of a landscape. The changes observed under different scenarios can be visualised by stakeholders and be used as a platform for further deliberation. *Section 3.6* provides more information about why ABMs were considered suitable for this research and the advantages and disadvantages of engaging such tools.

Box 3.1 Agent-based model origins, definition and application

ABMs originate from the field of computer science and Artificial Intelligence (Janssen and Ostrom, 2006). ABM along with Cellular Automata is a class of automata approaches that are pre-set with rules and initial characteristics, allowing them to respond to exogenous inputs. ABMs are characterized by a number of 'agents' that interact with each other and with their environment. Agents are able to make decisions and decide their actions based upon these interactions (Macal and North, 2014). The defining feature of an agent is a capability to act autonomously, without external direction, in response to situations it encounters (Macal and North, 2009). Thus, an agent can be anything from an individual or an institution to a market or the environment as long as it has behaviour and functions independently. Agents can interact both directly with each other, for example through social networks, and indirectly through the collective environment. They can update their knowledge base by learning from and adapting to the changing environment (e.g. Tang and Bennett, 2010) and other agents (e.g. Le et al., 2010).

ABMs have been utilised across a wide range of topics pertinent to biodiversity conservation, including: ecosystem management (Moreno et al., 2007), water management (Becu et al., 2003, van Oel et al., 2010), urban development (Haase et al., 2012), farming (Schreinemachers and Berger, 2011) and climate change mitigation (Troost and Berger, 2015).

3.3 Companion Modelling research design

The common element between all ComMod studies is the co-construction of a conceptual model with the stakeholders in order to create a shared representation of how the system functions according to an overarching, negotiated, development question (Etienne et al., 2011). The next step in the ComMod process is to transform it into modelling tools particularly adapted to the representation of complex systems via ABMs and/or RPGs. With these tools, future scenarios can be explored along with or without the stakeholders, depending on the initial objective of the study.

ComMod typically follows an iterative methodological process in which each loop – also called iteration – corresponds to a succession of conceptualisation, implementation and validation phases. Whilst the three principal phases of the sequence proposed by ComMod are linear, a core strength of the approach is that it is based on repetitive back and forth steps between the model and the field leading to ComMod being referred to as a loop process (Étienne, 2010; Box 3.2).

Box 3.2 ComMod phases

There could be up to 12 phases in each loop. Étienne (2010, 2014) offers a detailed reference manual. Here, I provide a succinct description of the 12 phases:

1. Informing those involved in development issues of the ComMod approach and its possible applications in local problems
2. Definition of the question raised between project holders
3. Inventory of scientific, nonprofessional or expert knowledge, available through surveys and diagnostic studies and analysis of the literature
4. Eliciting knowledge for the model through surveys and interviews
5. Co-construction of the conceptual model with relevant stakeholders
6. Choice of a tool (computerized or not) and implementation of a model
7. Calibrating, verifying and validating the model with local stakeholders
8. Definition of a scenario with local stakeholders
9. Exploratory simulations with local stakeholders
10. Diffusion among stakeholders who have not participated in the process
11. Monitoring and evaluation of the effect of the process of participants
12. Training the stakeholders interested in using the tools developed

Even if the phases are not all included in an iteration or follow a slightly different order they represent a standard succession or a kind of complete model for the Companion Modelling approach (Étienne, 2010). Hence, there is a diversity of Companion Modelling study designs that entail between one and several iterations and include only a segment or all 12 phases (e.g. Simon and Etienne, 2010, Naivinit et al., 2010, Salvini et al., 2016)

To answer the research questions about the social acceptability of LS/LS interventions this study was designed around three main loops (Figure 3.3) that correspond to the first three parts of the study, as presented in Chapter 1 (Diagram 1).

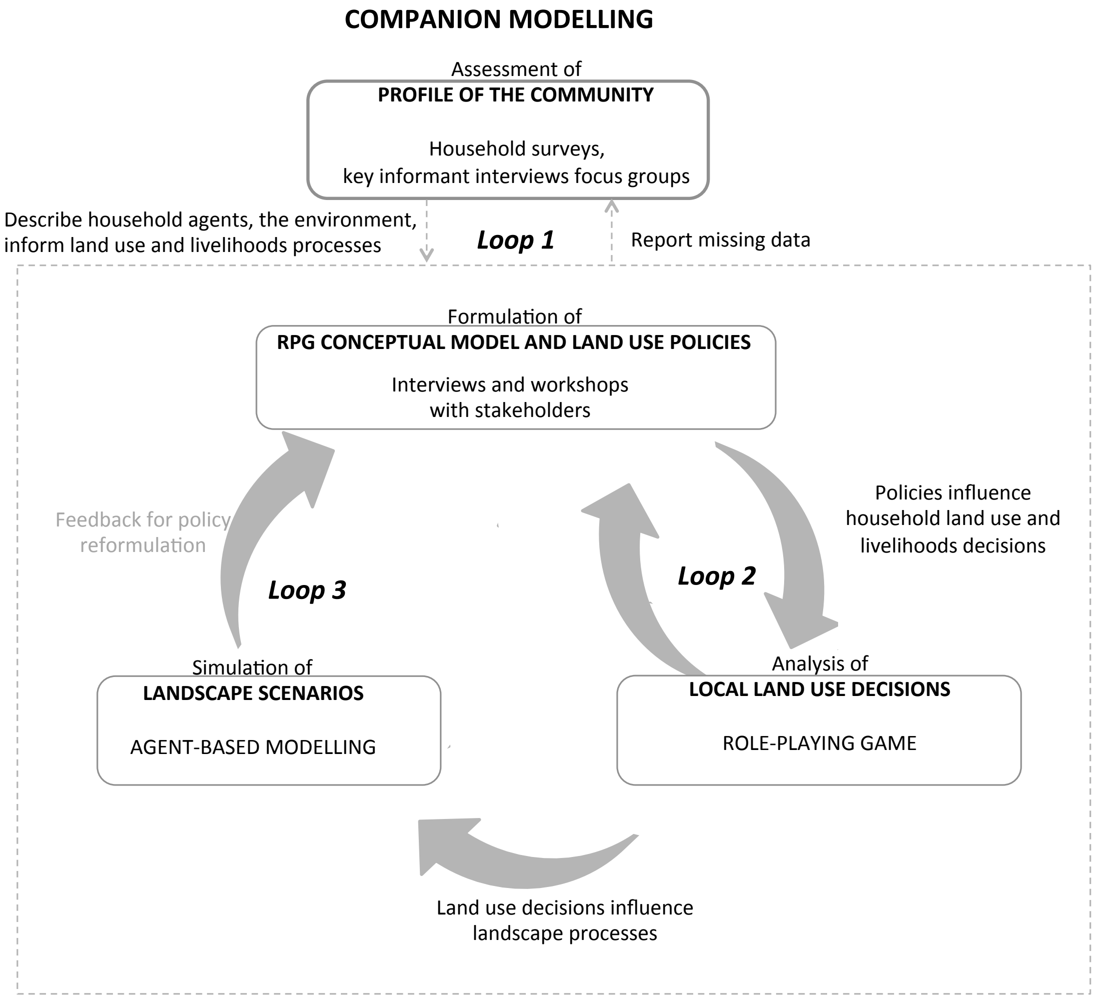


Figure 3.3 The ComMod process utilised in this study with three iterations, also known as loops

Loop 1 of the ComMod process is an investigative phase that consisted of collecting socioeconomic and environmental data about the community under study, including data on land use decision-making and motivations to enrol in land use policies. As the study evolved and data requirements were further identified, the initial data was further complemented.

Loop 2 consisted of a series of steps. Firstly, stakeholders co-constructed a conceptual model of the socio-ecological land use dynamics that occur in the landscape. Secondly, they commonly agreed, via stakeholders' workshops, on plausible land use policies that aim to increase food production and conserve biodiversity. Thirdly, a RPG was developed based on the conceptual model to test the direct beneficiaries' reactions to the proposed land use interventions and further understand the land use decision-making processes that occur in the landscape. In a final step, the feedback from the RPG enabled the improvement of the land use policies proposed by stakeholders. The outcomes of Loop 2 were used as inputs for the final iteration.

Loop 3 entailed the simulation of the effects of the scenarios developed at the landscape level over decades using an agent-based model. The landscape was modelled explicitly and the households surveyed in Loop 1 represented the agents. Other relevant stakeholders (e.g. Forest Department, Tea Board) were also represented in the model. Instead of being autonomous agents, they are represented as external factors influencing the system mainly through the introduction of land use policies in the landscape.

The research aimed to complete the cycle with the communication of the results of the ComMod process to policymakers, allowing them to reformulate policies to tailor them better to the local context, thus rendering them more effective. Due to time and funding limitation this was not possible, as part of the current research, but steps to complete this stage will be sought in future. The design of this study shares important aspects with Salvini et al. (2016), which builds on the understanding that landscape dynamics are driven by the land use decisions made by local stakeholders, and the fact that active participation of local land users is needed to ensure policy effectiveness.

To understand how the research questions connect with the ComMod Loops a summary is presented in Table 3.1. In the table it can be observed that the three communities, presented in detail in *Section 2.4.3*, are not part of all the ComMod loops and that a particular focus is placed on the Badaga communities in Loop 2 and 3. The rationale behind this decision is that they represent the largest caste group, are the main farmers' group and the main landowners with property rights and their fields could be represented in Landsat images. By contrast SC have almost no lands while ST have smaller plots of land, mostly without property rights, that are located within the forest, under the tree canopies. Therefore in Loop 1 all caste groups are included to allow a holistic representation of the landscape and to gain and understanding of the interactions that occur between the SC and ST who represent the main pool of labour for Badagas. Loops 2 and 3 focus on the Badaga communities as the direct landowners that can take decisions regarding land use interventions and that can be feasibly modelled in the ABM.

Table 3.1 The data collected, method of collection and analysis, and the community examined for each research question

Objective or Research questions	Data	Data collection methods	Methods of Analysis	Communities investigated
Understanding the landscape and the communities where land use interventions are going to be tested. Assessment of motivations to enrol in interventions. *ComMod Loop 1*	Quantitative and qualitative data. Socioeconomic, land use and food security data. Motivations to adopt land use interventions.	Primary data from in-depth household survey, *what-if* scenarios, focus groups, key informant interviews, literature review. Secondary data from Landsat images.	Univariate and multivariate statistical analysis. Mixed Effects Models. Qualitative data presented in form of frequency tables and representative quotes.	Badaga, Scheduled Caste and Scheduled Tribes
Q1: Feasibility of interventions: What land use interventions are plausible in a landscape given diverse interests of stakeholders? *ComMod Loop 2*	Qualitative data. Conceptual model of the decision-making processes in the landscape.	Stakeholders mapping, ARDI (details in Chapter 6-Table 6.1), key informant interviews, stakeholders' workshops, RPG.	Stakeholders' analysis. Coding and content analysis.	Badaga
Q2: Social acceptability: What is the social acceptability (uptake) of the interventions to direct land users? *ComMod Loop 2,3*	Qualitative and quantitative. Preference data.	RPG, ABM	Univariate and multivariate statistical analysis. Frequency tables and Coding and content analysis.	Badaga
Q3: Socioeconomic and Environmental outcomes of adoption: What are the implications of adoption for agricultural production, biodiversity, food security and livelihoods? *ComMod Loop 3*	Quantitative data; Socioeconomic, land use, food security, production, landscape connectivity and tree cover data;	ABM	Univariate and multivariate statistical analysis.	Badaga
Q4: What do the results tell us about the relevance of the LS/LS framework to real life? What policy recommendations can be made for the future? *ComMod Loop 3*	Qualitative and synthetic assessment	Based on outcomes of research and literature review		

Sections 3.4 to *3.6* of this document introduce the data collection and analysis undertaken within each of the three ComMod Loops.

3.4 ComMod Loop 1

This loop was designed to collect sufficient information for:

i) An initial characterization of the study site and households

ii) Informing the RPG

iii) To parameterise behaviour models and generate statistical descriptions of the attributes of agents in a population in the ABM

To meet these objectives information was sought, for farmers and their households, on demographic profile, the crops cultivated and associated yields, land ownership and management decisions, sources of income, food security, participation in land use interventions and motivations to adopt interventions on the farm as well as future land use and livelihood scenarios in the area. This information was collected as primary data using an in-depth household survey (*Section 3.4.1*), semi-structured interviews with key informants and village focus groups (*Section 3.4.2*) over a period of five months starting in November 2015.

3.4.1 In-depth household survey

Prior to the formulation of the household survey a scoping trip was conducted in March 2015 during which informal interviews were conducted with farmers, a number of village leaders and local stakeholders to obtain an initial overview of landscape dynamics, the stakeholders driving these dynamics and the interventions that had already been implemented. The aim was to gain insight into the key processes in the landscape that can help guide the formulation of the household survey that is further presented.

3.4.1.1 Survey design and implementation

Survey design

Household surveys were used to capture information on household socioeconomic and land use decision-making processes as well as on motivations to adopt land use interventions on farms. To facilitate the collection of such a diverse set of subjects, the questionnaire was formulated so that it generated a number of different types of variables including continuous, censored, binary, ordinal, nominal and count data.

The household survey (Appendix 3.1) comprised eight sections:

- Section A. Introduction and respondent's consent
- Section B. Household survey general information
- Section C. Household respondent and Type
- Section D. Household Profile
- Section E. Land Assets and Income
- Section F. Agricultural activities
- Section G. Decision-making and scenario testing
- Section H. Food security, consumption and composition

Sections A-D include standard demographic information about the household characteristics such as household head, number of family members, age, gender, level of education and main occupation.

Sections E-H, which refer to household assets, and, land use and livelihoods decision-making processes, focused on five categories necessary for understanding livelihood outcomes: natural, human, physical, social and financial capital. The choice of these categories was influenced by a widely-used framework, the Sustainable Livelihood Framework (SL), which uses the five categories as a platform to understand livelihood strategies (DFID, 1997). The SL framework has been used successfully as a tool to improve conservation practice by analysing the impacts of biodiversity conservation policies on livelihood outcomes and assets (Carney, 1999, Igoe, 2006, Serrat, 2017).

Data on decision-making, motivations and attitudes towards land use policies prior to their implementation were collected in the form of *what-if* scenarios by asking the respondents to either select from a list, or rank-order a set of statements about a topic on the basis of their individual perspective. The advantage of using scenario-based approaches is their capacity to control for contextual complexity to produce meaningful predictions of behaviour (Gordon, 1992). Furthermore they are highly suitable for predicting conservation outcomes under different policy or intervention conditions (e.g. Cinner et al., 2009). They are superior to alternative methods such as quasi-experimental matching approaches or adaptive management in that they could deal with evidence in a pro active rather than reactive manner (see comparison between different methods in Travers et al., 2016).

The survey was designed not to exceed 60 - 75 minutes. To overcome language barrier biases (Gray, 2009) the survey was designed in English and translated in the regional language, Tamil, by a local professional translator. A back translation to check the accuracy of the translated survey was undertaken by a member of Keystone Foundation, a local livelihoods and environmental organisation with a long-term presence in the landscape. The principal community surveyed, the Badagas, communicate more freely in the Badaga language, which is exclusively an oral language. Enumerators were selected and trained so that they could administrate the questions both in Tamil and Badaga to ensure clarity among respondents with different language preferences.

The design of the household survey questions

Some of the strengths of household surveys are that they can be representative of a large area, capture household heterogeneity and can be applied to statistical analysis. However, they only represent a snapshot in time, often have high implementation costs, and neglect intra-household decision-making processes. The questions asked can introduce bias and the data quality depends on design and implementation (Robinson et al., 2007). Here the potential problems that have been reported with household surveys that have collected similar data are discussed and recommendations for addressing these potential issues are described.

Questions about social and financial capital can suffer from issues regarding their definition and measurement. For example, defining the diverse sources of income and quantifying them can often raise difficulties, especially in communities with multiple and inconsistent sources of income that find it difficult to keep track of all revenues. I treated assets systematically, so that both sales and purchases were included for key assets, thus using the disaggregation principle (Angelsen et al., 2011).

Sensitive questions such as those dealing with food security and consumption were introduced after the middle of the interview where they have been shown to elicit better results (Angelsen et al., 2011). To account for both chronic and seasonal hunger two methods were used to collect food security data in the household survey. The first method used questions relating to access to food during the year (Bacon et al, 2014). For example, ‘was there a time in the past year when they could not meet their basic food needs, if so, why not and for how long?’ Secondly, a dietary diversity method was used, which involved creating a list of foods grown and consumed in the landscape. The list was established during prior focus groups. The list was then used to record the frequency with which individuals in the household consumed different foods over the last week. A weighted sum was then calculated based on the types and frequency of foods consumed. This metric can be used to indicate food security as better-off households in developing countries consume a wider variety of foods and it has been correlated with caloric acquisition (Bickel et al., 2000). It should be noted that the dietary diversity method only captures a snapshot in time and should always be correlated with other questions, such as the annual food access questions reported above.

Implementation of the household survey

In implementing the survey the study followed the recommendation of Lund et al., (2011). A list of potential problems for the local study site and how they might be overcome (Table 3.2) was constructed before fieldwork and considered three main areas where systematic errors could occur: enumerators and questionnaire administration, respondents' strategic behaviour and understanding, and bounded knowledge.

Table 3.2 Systematic errors that could occur during data collection, relevant to study area, and ways to avoid or minimise the bias based on Lund et al., (2011) recommendations.

Category	Potential problem	Systematic error bias	Avoiding/minimising the bias
Enumerators and questionnaire administration	Personal characteristics and appearance of the enumerators	Age, sex, ethnic group, caste, attitude and appearance can greatly influence the data generated in a survey	Be selective in choosing the enumerators by training and testing them to observe how they perform.
	Integrity of enumerators	Enumerators might take short cuts, have low quality standards, or even falsify data.	Letting the enumerators know that field checks will occur. Doing spot checks with households to check if enumerators came to ask questions. *Ex post* detection where quick reviews of the questionnaires are done every evening to spot 'odd' data and discuss it with the enumerators.
	Enumerator fatigue	Enumerators can become demotivated and demoralized for conducting the same tedious and monotonous interview for long periods.	Provide constant recognition, support, feedback and motivation for the enumerators so they give their best. Provide trainings, highlight interesting results and organise social events.
	Probing bias	Differences between enumerators regarding interpreting, explaining and exemplifying questions may influence the answers.	The bias can be reduced by spelling out all questions in their entirety, having detailed written guidelines for the questionnaire and thoroughly training the enumerator team.

Category	Potential problem	Systematic error bias	Avoiding/minimising the bias
Respondents' strategic behaviour and understanding	Strategic answering	Three main factors can affect how respondents answer the questions: personal anxieties with particular respondents, questions that can generate fear of social rejection or hope of social acceptance and questions that can generate fear of political or economic sanctions or hope of rewards.	Provide ample information regarding research purposes to avoid spreading false rumours. Include background information to sensitive questions. Spend time in the village and attend social events to gain locals trust. Triangulate answers with observations where possible.
	Vague or imprecise responses	Imprecise responses are common in detailed household surveys, particularly when related to income or accounting.	Ensure that the question can't be formulated more precisely then that. Inform enumerators that specific details are needed.
	Misunderstanding the question	Respondents may easily misunderstand or misinterpret the question.	Keeping questions short and concise, and avoiding difficult wording is essential.
Respondents' strategic behaviour and understanding	Respondent fatigue	Tired respondents may give 'quick' answers in order to finish fast, especially in the later part of the questionnaire.	Selecting areas that are not 'over-researched' provides a context that is less exposed to research fatigue. Interviews should suit the respondents, vis-a vis their daily routines.
Bounded knowledge	Recall	It refers to the inability of the respondent to fully remember past activities and events, thereby creating a bias.	Shorter recall periods should be associated with small and frequent events and longer recall periods should be associated with infrequent, large or rare events. In the later case more general questions could be of help. For example: 'did it happen before marriage? Before the drought season?'
	Differences in perceptions or understanding of definitions	Key definition or perceptions taken for granted can crate biases.	Ensure respondents have a common understanding of definitions. Define key terminology, Beware of meaning, units and perceptions.

It was initially proposed that both male and female enumerators carry out the studies to enable local women to feel more comfortable in engaging in the research. Identifying female enumerators proved problematic due to local customs and safety concerns. Hence, data were collected with the support of 8 male enumerators and a research assistant who also assisted with the translation of the questionnaire. Six of the enumerators were Badagas (and interviewed Badagas and STs communities) and three were from Scheduled Caste (and interviewed the SCs communities). The enumerators were all in their twenties and came from a local University or a company that provided survey and information technology services. Before implementing the survey they participated in workshops, trainings, test sessions and were accompanied in the field to ensure proper data collection protocols were followed. While the first seven sections (A-G) of the survey could be answered by any adult member of the household, the enumerators were asked to fill in the last section (H) about food security with a female member of the family, where possible and appropriate, because they are the ones who prepare food.

3.4.1.2 Sampling: who, how and how many?

The aim was to obtain a representative sample of the population in the study area to inform the ABM. Following in the field practices of ABM studies with similar aims (e.g. Le et al., 2010, Salvini et al., 2016) stratified random sampling was identified as the best sampling strategy to meet this goal (Shively, 2011). On the basis of time constraints and statistical power the data collection was restricted to the Kotagiri Taluk, the most eastern division of the Nilgiris district (see Figure 2.2). The capital of the Taluk is Kotagiri city, the main urban centre of the administrative unit. The Taluk was selected based on the landscape being representative of the agricultural and biodiversity scenarios encountered across the Western Ghats and for the available infrastructure to carry out research with a partner organisation (*Section 3.4.1.3*).

The Census of India (2011) divides the population of Kotagiri into three main categories. Schedule Tribes, of which there are 4,463 inhabitants, Schedule Caste with 18,352 people and the ‘other’ category, which has 41,403 inhabitants. In Kotagiri the ‘other’ group is predominantly comprised of the Badaga community. About 44% (28,207) of the Kotagiri district population lives in the main urban area, Kotagiri town, and the remainder (36,011) lives in rural areas. The latter is the target population of this study.

Typical to the landscape is the spatial distribution of the three different communities (or castes) within separate, caste specific, housing groups. The number of households found together can vary in size from a couple of households to agglomerations of tens and hundreds (the equivalent of hamlets and villages). A list of hamlets and villages was produced using information from the Village Panchayat Offices, Statistical Department, Collector’s Office, Electorate lists and Keystone Foundation. There are more than 360 groups of houses in Kotagiri Taluk. Different strategies had to be applied in selecting the households for the three communities (Table 3.3).

A total of 408 surveys were conducted with the aim of covering at least 10% of the households within each village selected, in order to ensure sufficient statistical power (Crawley, 2012). Stratified sampling was used in establishing the total number of households surveyed by community group. Thus, the number of ST, Badaga and SC households surveyed was: 36, 265 and 105 respectively. Where possible (given the conflicting data sources) the number of households surveyed in each village was established proportionally to the total number of households within the villages surveyed of each community (Table 3.3). All households surveyed were in close proximity (less than 2 km) of native shola forest (Figure 3.4).

Table 3.3 The community and villages selected for the survey, the strategy of village selection and the total number of households surveyed in each village.

Community surveyed	Strategy for village selection	Village Surveyed	Description of the village	Pop. size	HHs	No. of HHs surveyed
Badaga	Due to time constraints in engaging with local village leaders and limited transport budget, larger villages (of circa 100 households or more) were selected for the household survey. To be representative of the area the villages had to have a diversity of land uses and contain both households that are landless and that own land. The village head had to give consent to carry out the survey. Having a mix of villages closer or further away from forest is preferred for observing changes when land use policies are introduced.	Milidhen	One of the largest Badaga villages that relies on tea growing and sparse agricultural fields. It borders a shola forest under protection.	1323	300	75
		Nedugula	Sizeable Badaga village with one of the largest number of agricultural fields. Tea crops are also grown.	1046	240	61
		Kercombai	Similar to Milidhen the village relies on tea growing and sparse agricultural fields.	400	100	25
		Denadu	Characterized by steeper slopes where mainly tea is grown. Surrounded by dense forests.	1097	184	46
		Sundatty	Similar to Milidhen and Kercombai the village relies on tea growing and sparse agricultural fields.	700	140	35
		Kaggula	Medium sized Badaga village that relies on tea growing mainly.	551	93	23

Scheduled Caste	Surveyed households had to come from agglomerations of households of circa 100 households or more and village leaders had to give their consent to carry out the survey with the selected enumerators.	Queensolai	Large SC village built around TANTEA estates with most of the population working in tea plantations.	617	200	47
		Kakasolai	SC village built around agricultural fields with most of the population working in agricultural fields.	634	150	37
		Keradamattam	Most of the population works on tea estates or agricultural fields.	565	230	22
Scheduled Tribe	Villages were selected with members of Keystone Foundation based on accessibility, size and village head consent.	Andthiy-arai	Kurumba village with a tradition for gathering forest products, including wild honey harvesting. The inhabitants work on tea plantations.	46	10	6
		Bangala-padugai	Irula village with most of the households working as labourers on tea plantations.	106	50	9
		Bavyiur	Kurumba village similar to Andthiyarai	84	40	13
		Kothimuku	Irula village similar to Bangalapadugai	128	25	8
Total	-	-				**408**

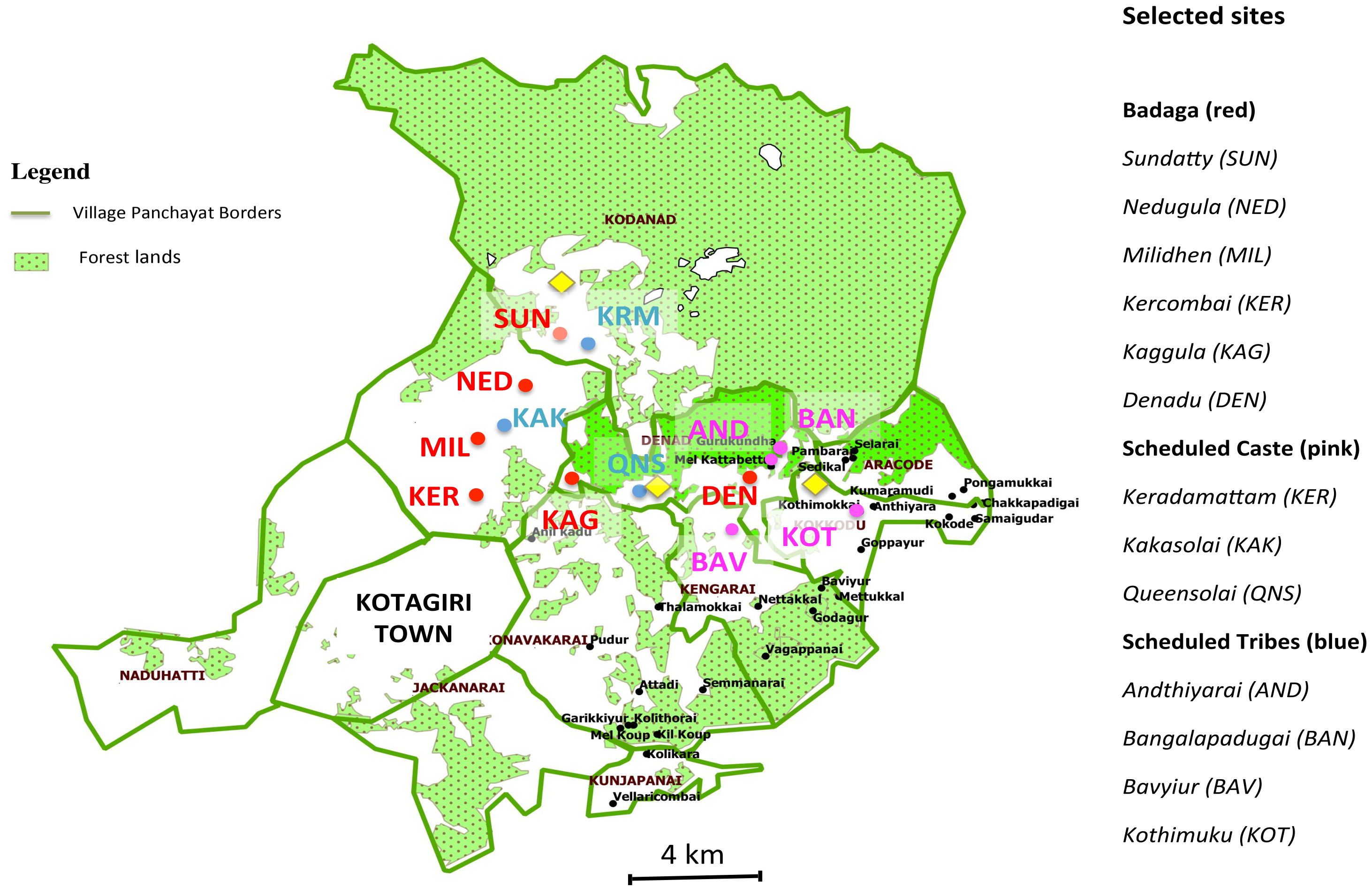


Figure 3.4 Map of Kotagiri Taluk with the selected sites for study. With black dots are represented the Scheduled Tribe settlements. *Source: adapted from Keystone Foundation*

Within each village households were selected at random using a lottery method (Shively, 2011). 110% of the target total of households was selected in each village in order that a reserve list of households was present in case of refusal, non-response or attrition.

3.4.1.3 Fieldwork considerations-Ethical assessment and local collaborator

Before fieldwork data collection, an ethical assessment was undertaken. Details of ethical consideration are provided in Appendix 3.2.

The research was undertaken with the support of a local organisation, Keystone Foundation. Details of the collaboration and reflection on minimising research biases are provided at the end of Appendix 3.2.

3.4.1.4 Survey data analysis

Quantitative data from Sections A-G of the household survey were analysed using descriptive statistics. Univariate and multivariate analysis using standard parametric and non-parametric tests was conducted in the statistical package RStudio Version 0.98.953 (R Core Team, 2016). Where relevant, data was presented by caste group.

Qualitative data was primarily presented in form of frequency tables, which were occasionally accompanied by representative quotes.

Sections H of the household survey that focused on food security was analysed using logistic regressions to understand the factors that determine food security in the landscape. Logistic regression is one of the most commonly used methods in the analysis of food security data (Amaza et al., 2006, Felker-Kantor and Wood, 2012, Abdullah et al., 2017). The study used a type of regression method known as Generalised Linear Mixed Models (GLMMs) to deal with the *random effects* of village and enumerator. This allows conclusions to be drawn about a population at landscape level (necessary for the ABM) from which the observed units ('village') are chosen, and not about the particular units themselves. In the case of 'enumerator' variable the model controls for the variation that occurs in data collection from the different enumerators so that the results are not affected by these differences. Further reasons for selecting GLMMs and the decision tree used in selecting the appropriate model is presented in Appendix 3.3.

The GLMMs were developed using the R statistical package 'lme4' (R Core Team, 2016). To find the best model a Minimum Adequate Modelling (MAM) approach was taken, following the method described by Crawley (2002). To carry out the MAM process, an initial maximal model was generated, which included all the candidate explanatory terms. This model was then repeatedly simplified by removing terms, which did not significantly improve it, until the model with the lowest Akaike Information Criterion (AIC) and the highest overall explanatory power (R^2) was found.

3.4.2 Focus groups and key informant interviews

Focus groups were selected as a tool for data collection because they are flexible social science data collection tools and can bring out information that is difficult to obtain in individual interviews (Wiles et al., 2011). There are a number of disadvantages to the method, including limited reliability and validity, and various forms of moderator and respondent bias (Wilkinson, 1998). Nevertheless, there has been a large number of studies that showed how limitations can be reduced or overcome when careful consideration is given to the design and implementation (e.g. Smithson, 2000, Hydén and Bülow, 2003, Litosseliti, 2003, Parker and Tritter, 2006). This study made use of a practical guide developed on lessons learned in the field that covers topics like focus group set-up, design, question formulation, facilitation and ethical considerations (Breen, 2006). For more sensitive data related to food security, this study drew from previous work of the Food and Agriculture Organisation (FAO, 2013) that provides specific and comprehensive guidance on how to set up focus groups and formulate questions in rural areas of developing countries.

The focus groups and key informant interviews were used for two main purposes:

(a) In an initial exploratory phase to inform the in-depth household survey and the development of a structured and systematic interview schedule

(b) To triangulate and add richness and depth to the food security data. More details are provided in the chapter 6 where they were used.

In the exploratory phase local leaders, landowners and farmers were invited to participate in a focus group of 6 to 8 people aiming to investigate how participants view the landscape, how it has changed over time and how it is likely to change in the future. The focus groups also helped identifying historical time trends, brainstorming on possible future scenarios and identifying possible interventions to be explored. Additionally, questions relating to the factors making households more likely to be food insecure were also asked so that they could be included in the household survey.

In this phase focus groups of about 2 hours were organised in all 13 villages. However, the focus groups and key informant interviews on food security data were only carried on the

Badagas group, since they were the only community that was represented in the RPG and ABM phases of the ComMod process.

3.5 ComMod Loop 2-RPG

The overarching focus of this loop was the selection of land use interventions and the development of a RPG with local stakeholders (*Section 3.5.1*) and the implementation of the RPG with direct land users (*Section 3.5.2*). The information provided in these two sections is complemented by more detailed information in Chapter 6.

The RPG data provide complementary and more in-depth information about farmers' decision-making processes that were observed in the household survey in the first loop of the ComMod process.

3.5.1 Selection of land use interventions and development of the role-playing game

The land use policies and the RPG were co-constructed with the support of stakeholders and followed a step-wise approach (Table 3.4). The RPG was designed for direct land users from the 6 Badaga villages (Denadu, Kercombai, Nedugula, Milidhen, Kaggula and Sundatty) surveyed in the study area in the first ComMod loop.

Table 3.4 Data collection methods used in the selection of interventions and the development of the RPG

Aims of each phase	Method of data collection and analysis
Phase 1. Selection of core stakeholders that will support the development of the RPG	
1. Create a list of the potential stakeholders involved in land use decision-making	An exhaustive list of potential stakeholders driving landscape dynamics was created during the scoping trip following discussion with local land users, village heads and Keystone Foundation. Key informant interviews were conducted with all the stakeholders identified to understand their role in land use dynamics.
2. Map the power and influence of the stakeholders over decision-making	Stakeholder analysis was used to summarise in a diagram the power of the stakeholders and their impact on land use decision-making. Stakeholder analysis is one of the most commonly used and recognized processes of systematically gathering and analysing qualitative information to determine whose interests should be taken into account when developing and/or implementing a policy or program (Schmeer, 2000). This process can help frame issues that are solvable in ways that are technically feasible and politically acceptable and that advance the common good (Bryson, 2004). There have been numerous studies providing best practices in the field (Grimble and Wellard, 1997, Brugha and Varvasovszky, 2000, Bryson, 2004). This study uses the method developed by OGC (2007) that looks at mapping the stakeholders along a power-impact gradient. Impact was devised in three levels: direct, moderate or limited whereas power has four levels: low, intermediate, significant or high. This method is suited for this study because it is more explorative than most of the other tools used in stakeholder analysis. Given there is no predefined policy to be tested in the landscape the mapping is an exercise to understand what the relevant stakeholders might be in an initial stage rather than how to influence stakeholders to achieve a common goal.
3. Selection of relevant stakeholders for co-development of RPG	Details are provided in Chapter 6 (Table 6.1).
Phase 2. Defining the question to be answered by the RPG	
	Details are provided in Chapter 6 (Table 6.1).
Phase 3. Collective construction of the RPG conceptual model	
	Details are provided in Chapter 6 (Table 6.1).
Phase 4. Selection of land use policies to be tested in the RPG	
1. Selection of policy tools and specific land use interventions	Details are provided in Chapter 6 (Table 6.1).
2. Collect data on information necessary to complete the RPG	Where stakeholders needed additional information to finalise the formulation of policies household surveys or key informant interviews were conducted.
Phase 5. Designing the RPG	
Decide components of the RPG	Details are provided in Chapter 6 (Table 6.1).

Aims of each phase	Method of data collection and analysis
Phase 6. Testing and calibration of the RPG	
	Workshops to test and improve the RPG were organised with direct land users in Badaga villages. Each session had three steps: a briefing, a game session and a debriefing (which included feedback forms). Stakeholders were presented with the outcomes to allow feedback and further improvement of policies and RPG.
Phase 1, 2 and 3 were conducted in the field over a two-month period between February and March 2015, Phase 4 was developed between May and October 2015 and was almost entirely desk-based, while Phase 5 and 6 were carried in the field between October 2015 and January 2016.	

When using tools like RPGs, model validation in the context of uncertainties during the process can be even more important than just at the end (Refsgaard et al., 2007). This principle was at the core of the modelling process of the current study and the different sources of information (e.g. household surveys, focus groups) paired with local knowledge and expertise challenged and validated the findings in each phase of the modelling process.

3.5.2 Implementation of the RPG and data analysis

The implementation refers to organising and running the RPG sessions.

In implementing the RPG the study considered the recommendations of ComMod researchers regarding: representation of the games, the selection of players, duration of the game, choosing the location, the spatial setting, selection of team members to assist in conducting the workshop, the information provided to the players and other aspects such as time management during session development (Garcia, 2014). The specific details of the RPG session implementation and their justification are provided in *Section 6.3.1.4*

To allow a better understanding of the effect of proposed policies on land use decisions the RPG explored two situations: the current land use practices, and the impacts of policy scenarios inferred from the stakeholders' workshops. This enabled the investigation of land use decisions and dynamics under different policy scenarios and the exploration of factors that might prompt farmers to adopt different land use practices. The outcomes of the RPG were communicated to the policy makers, allowing them to reformulate policies to tailor them better to the local context, thus rendering them more effective when further tested in the ABM.

Methods of data collection during the RPG session, proposed by ComMod researchers during ComMod Spring School (Garcia, 2014), were also the main inspiration for the design of this research. For example, the indicators of interest measured during the RPG workshops relate to scheme uptake, land use change, production and environmental changes, and livelihoods changes. Data for the indicators measured in the RPG were collected using several paper forms that the players filled at every stage of the game. These documents, presented in Appendix 3.4 were:

a) The RPG Players' Sheet, which traced the processes regarding the choice of food crops grown on the farm every year and the number of seasons selected for cultivation;
b) The Income and Expense Sheet, which recorded the sources of income and spending each year;
c) The Decision-making Form, which contained information about the different land use and livelihood strategies of a household over the years;
d) The Final Evaluation Form.

Along with these data, notes were taken during the RPG workshops (including debriefing sessions) and transcripts of the game sessions recordings, which aided the understanding of the emerging processes and the reasoning behind farmers' decisions.

RPGs are laborious and generally take a long time to set up, run and manage the resulting data. This means that the number of games that can be played during a field season is limited. In some cases ComMod team recommends a one-month gap between sessions to allow proper preparation and facilitation (ComMod Spring School, 2014). A small number of RPGs means a small sample with limited explanatory power. The results should not therefore be over-interpreted; instead they should be used as a way to triangulate the data from other data sources such as the social survey. The results from the RPG were therefore analysed using descriptive statistical methods. Using the data from the RPG in this way filled knowledge gaps about processes that occur in the landscape and provided simple rules that contribute to the construction of the ABM.

The policies negotiated by stakeholders and the outcomes of the RPG were subsequently used to develop the ABM presented in the next and final loop of the ComMod process.

3.6 *ComMod Loop 3- the ABM*

This section will start by giving an overview of agent-based land use models and their suitability to answer the research questions. Examples of the use of ABMs in similar contexts (*Section 3.6.1*) are also described. The section then goes on to give details about the strengths of using an ABM (*Section 3.6.2*), and their limitations (*Section 3.6.3*). The section continues with the steps taken to model an ABM designed to reproduce the landscape dynamics informed by the in-depth household survey (Loop 1) and observed during the RPG (Loop 2), and project them into a long-term (decadal) timeframe (*Section 3.6.4*).

3.6.1 Agent-based land use modelling

LS/LS policies aim to change both micro and macro-level land use and land cover patterns (LULC). These patterns are shaped by the interactions between the anthropogenic and the biophysical environments. Human decisions and actions aggregate to influence land use and land cover patterns, while conversely macro-level policy influences micro-level behaviour and land use (Lambin and Meyfroidt, 2011). Conventional modelling has lacked the capacity to integrate this two-way process (Le et al., 2010). The value of agent-based land use models lies in the fact that it can fill this gap, by being specifically adapted to provide a more realistic representation of these human-environmental interactions (Macal, 2016).

Studies that model land use with ABM techniques have seen a gradual progression from abstract scenarios with only tenuous links to real-world problems (e.g. Lansing and Kremer, 1993; Epstein and Axtell, 1996) to more complex representations of socio-ecological systems based on empirical data that answer specific real-world questions (e.g. Hoffmann et al., 2002; Deadman et al., 2004; Le et al., 2008; 2010). Several comprehensive reviews of agent-based land use models have been published demonstrating the broad range of applications (Parker et al., 2003, Matthews et al., 2007, Sohl and Claggett, 2013, Yu et al., 2013).

Table 3.5 Examples of agent-based land use models based on the categories identified by Matthews et al. (2007)

Model Category	Model description	Studies
Policy analysis and planning	Considers heterogeneity in cultural values and interests of an agri-environmental schemes proposed beneficiaries	Weisbuch and Boudjema, 1999
	AgriPolis: Assesses the effect of reducing price support and introducing compensation payments in EU farms	Happe et al., 2006
	BIOCAPARO: Explores the outcome of three governmental policies (hands-off, pro-forestry and agro-forestry) on the local environment	Moreno et al., 2007
Participatory Modelling	CORMAS: A platform developed to solve specific problems, it can also be used as a tool in assisting RPGs. Allows the engagement of stakeholders during model development, model conceptualisation, model building and running	Le Page et al., 2010
	A bottom-up participatory modelling process for a multi-level agreement on environmental uncertainty management in West Africa	D'Aquino and Bah, 2013
Explaining spatial patterns of land use or settlement	LUCITA: investigates the factors involved in deforestation and subsequent reforestation	Deadman et al., 2004
Testing social and economic science concepts	FERALUS: A model investigating strategies of land use selection and associated impacts at landscape level	Polhill et al., 2008, Gotts and Polhill, 2010
	LUDAS: Developed to support the design of land use policies which enhance long-term environmental and socioeconomic benefits.	Le et al., 2010
Explaining land use functions	PALM: to explore the impacts of human decisions on soil nutrient dynamics in Nepal	Matthews, 2006

3.6.2 Strengths of an Agent-Based Approach

Aside from being one of the most advanced tools to capture human-environment interactions, ABMs are capable of representing complex behaviour and detecting emergent trends (Parker et al., 2003, Brady et al., 2012, Sun et al., 2016). They are flexible, in that multiple components can be altered fairly easily, and in that they can be applied to many different systems at multiple scales (Crooks and Heppenstall, 2012).

ABMs are equipped to capture heterogeneity by representing, for example; individuals, households, farms, markets or institutions as autonomous agents (Macal, 2016). ABMs create environments that allow the exploration of an agents' role in system dynamics over time (Kennedy, 2012) and when linked to physical space with a graphic interface, they can act as 'virtual social laboratories' allowing the exploration of future policies and their impact on LULC *ex ante* to their implementation (Lee et al., 2014). Thus, they can produce information that is useful for policymakers, such as what interventions may be most suitable in a particular local context.

When compared to other modelling approaches used in socioeconomic policy-making, ABMs scored best in terms of relative fitness; they were the top option for realism, have important interdisciplinary potential and capture bottom-up and stochastic dynamics (Boulanger and Bréchet, 2005). Finally, with ABM, landscape dynamics can be projected forward in time, over longer timeframes when compared to other methods such as RPGs.

3.6.3 Limitations of Agent-Based Modelling

ABMs aim to capture human behaviour and dynamics, which rarely operate along rational lines (An, 2012). As such, inputs may be difficult to quantify and calibrate meaning that outputs of the model shouldn't be taken as facts, especially since relatively small variations in initial conditions and agent rules could greatly skew the outputs (Crooks and Heppenstall, 2012). This is also emphasized by the lack of a standardized approach to measuring and modelling behaviour, defining agents and selecting scale (Bousquet and Le Page, 2004).

Because ABMs are not able to capture all the socio-ecological interactions, agents have reduced abilities with regards to their knowledge, memory, processing and learning (Schreinemachers and Berger, 2011). Furthermore, it has been recommended for ABMs to be used as research tools rather than decision support tools, because they can explore a range of management choices in terms of robustness and resilience but neither the models nor the landscapes lend themselves to seeking optimal outcomes or to making predictions (Matthews et al., 2007).

Finally, data requirements for ABMs are typically large, and when applied to complex systems these models can demand high computational power and most importantly they can become difficult to validate and verify (Crooks and Heppenstall, 2012).

For some of the limitations highlighted in this section solutions have started to come forward and there are ABMs that are seen as good-practice (Table 3.6).

Table 3.6 Challenges in agent-based modelling based on Filatova et al. (2013)

Type of challenge	Description of challenge	Good-practice ABMs
Modelling agent's behaviour	Balancing competing decision-making theories in social sciences and empirical observations when parameterizing the agent's behaviour	Sun and Müller (2013) introduce an innovative hybrid approach combining Bayesian belief networks and opinion dynamics models
Sensitivity analysis, verification and validation (especially important in policy contexts to inform management challenges)	Addressing the soundness of their construction and their success in replicating real-world trends and patterns	Balbi et al. (2013) validated the model through a social experiment where local stakeholders tried to anticipate the outcomes of the model after they were briefed about the assumptions.
Coupling socio-demographic, ecological and biophysical models	Integration of various modeling components is strenuous	Robinson et al. (2013) used loose coupling to provide the new land-change modeling framework with flexibility to enable the authors to link in other ecosystem models at a later stage.
Spatial representation	Defining the spatial scale of analysis and combining multiple scales of analysis in the same model	Barnaud et al., 2013 combined different spatial scales in a step-wise process that started with abstract representations to realistic ones. In this process they observed the limits and advantages of these representations.

3.6.4 Modelling approach

The rationale and the process of modelling the landscape and the agents (households) are explained in detail in Chapter 7.

The purpose of the ABM was to provide *ex ante* information to policy-makers on key processes that could emerge in the landscape and it is not meant to indicate exact outcomes for the scenarios tested.

3.6.5 The role of the researcher in the modelling process

In this study I had to alternate between the role of modeller in the RPG and facilitator. As modeller, I had to make sure that the scientific components of the model adhered to standard scientific practice and objectivity in order to warrant the credibility of the model among decision-makers, stakeholders, scientists and the public. Thus, while participants determined the questions that the model had to answer and supplied key parameters and processes, consulting specialized literature constantly challenged the structure of the model. Nevertheless, in order to allow the stream of ideas and achievement of results the scientific accuracy and rigor were sometimes loosened, a practice that is not uncommon in this type of modelling, provided the assumptions and uncertainties are acknowledged (Voinov and Bousquet, 2010).

In terms of facilitating the RPG modelling process I position myself as a neutral party. It is recognized however that this is difficult to be achieved. Scientists develop their own understanding and viewpoints about the system and its future trends, which can result in incorporation of biases into the scientific components of the model. Nevertheless, the alternatives can offer even less control over the facilitation outcomes. If governmental or non-governmental agencies act as facilitators of a collective process, they might push their own agendas. External facilitation can be a good alternative but raises problems of delegitimisation and overlegitimisation (Korfmacher, 2001).

3.6.6 Dealing with power relations

Who is empowered and who is disempowered in the participatory modelling process, is the collaboration mutually beneficial or are there winners and losers (Chambers, 2006, Reed, 2008)? These are questions relevant to any process where different institutions or hierarchical levels are involved (Kok et al., 2007). Following recommended practices in this field, the study alternated between group and one-to-one exercises offering stakeholders the option to work together and separately (e.g. Olsson et al., 2004). In this way stakeholders were given the chance to deal with power relations and provide individual insight. Nonetheless I acknowledge that while this method can help minimise the power imbalance, the problems cannot be fully overcome.

3.7 Conclusions

To date the impact of agriculture on the environment has largely been dealt with reactively and advocates of the LS/LS framework have promoted policies in a top-down approach overlooking local stakeholders' objectives. The use of methodological approaches like ComMod allows engaging stakeholders in bottom-up participatory modelling processes and assessing *ex ante* the impact of LS/LS policies on agriculture, biodiversity and local livelihoods. In doing so it determines the effectiveness of such policies from an early stage. ComMod is versatile in that it allows for a combination of methods such as RPGs and ABMs to create an exploration space that facilitates collective information sharing and learning that often results in models better fitted to local context and stakeholders' needs.

I now go on to present the results of this method in Chapters 4-10.

PART II
Socioeconomic and environmental profile of the study community

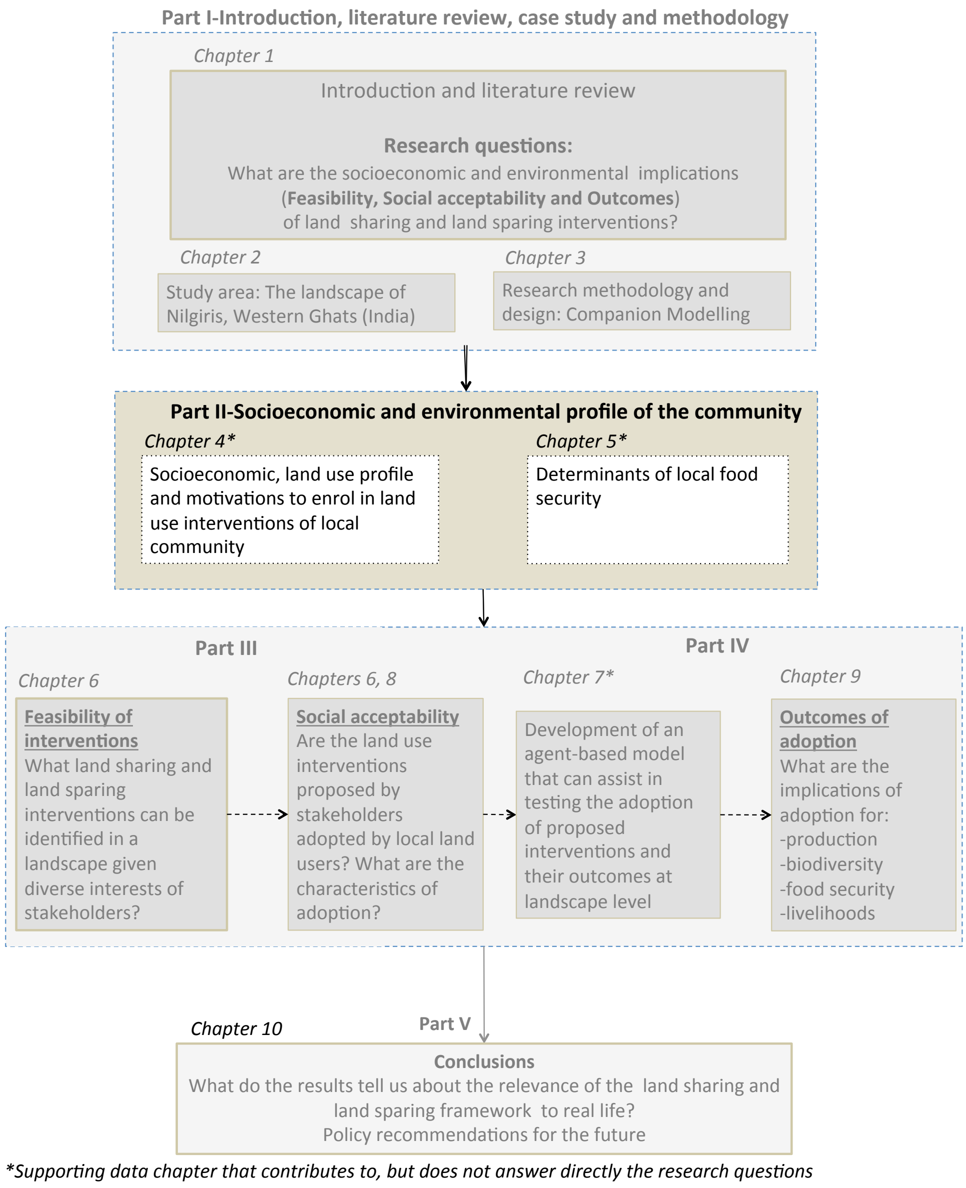


Diagram 1 Summary of research highlighting the focus of research in Part II of the study

Part II (Diagram 1) offers insight into the socioeconomic characteristics, land use profile and motivations to enrol in potential land use policies, of the communities under study (Chapter 4). Furthermore, it aims to understand what determines food security in the Nilgiris communities (Chapter 5). This part of the study provides empirical evidence for the construction of the RPG (Part III) and the characterization of the agent population and the environment represented in the ABM (Part IV).

Chapter 4

Socioeconomic and land use profile of the study area

4.1 Introduction

Achieving conservation objectives in agricultural landscapes is conditioned by our understanding of the characteristics that define a landscape, the communities that inhabit them and their motivations in engaging in biodiversity conservation (Greiner and Gregg, 2011, Greiner, 2015, Jóhannesdóttir et al., 2017). In the LS/LS context, knowledge of the local context and the likely aspects that prompt communities to accept or not land use approaches on their farms has proved essential in formulating successful management strategies grounded in local realities (Jóhannesdóttir et al., 2017).

Constructing the social, economic and land use profile of a community could provide better context for scrutinizing and justifying the emergence of anticipated or unanticipated events when land use policies are tested or implemented (Lee et al., 2014). In the context of current research, in which the Nilgiris landscape is confronted with a period of economic turmoil prompted by the crisis of the tea plantation sector, there is little understanding of where the future of the landscape and its communities are heading. Nor is there evidence of how farmers might respond to policies like LS/LS and what motivations for adoption there might be.

This chapter proposes to fill this knowledge gap, by portraying an image of the current landscape, its communities and land use practices, and investigating how the communities might respond to future socioeconomic and land use scenarios. Additionally, farmers' response to hypothetical land use policies, which aim to aid biodiversity conservation and food production, are analysed by looking at both the benefits that farmers associate with them and their actual willingness to engage with such interventions and their motivations to do so. These results then contribute to the RPG and ABM described in chapters 6 and 7.

4.2 Data source and methods

This chapter makes use of primary quantitative and qualitative data collected during fieldwork using the in-depth household survey described in detail in Chapter 3 *(Section 3.4.1)*. Secondary data obtained from official sources are used to support the findings of the study.

The quantitative data is analysed using descriptive statistics. Univariate and bivariate analysis using standard parametric and non-parametric tests were conducted in R (see *Section 3.4.1.4*). Where relevant for comparison, data was presented by caste group (Badaga, Scheduled Tribes and Scheduled Caste) or at population level. Qualitative data is primarily presented in the form of frequency tables or diagrams.

The metrics analysed are mostly presented in the order of data collection based on the first seven sections of the survey, A-G (Table 4.1). Sections A and B provide an overview of how the survey was conducted and who the respondents were. Section C focuses on aspects of migration in and out of the landscape, while Section D centres on the social profile of the households with comparisons between the three communities. Section E focuses on the economic profile of households, followed by land use characteristics, with comparisons between castes, where relevant. Finally, Section G encompasses *what-if* scenarios and looks at how households would reportedly respond to different future scenarios and their motivations to engage with land use policies. The scenarios selected for testing in the household survey result from the most frequent themes that were identified by the communities during the initial exploratory phase in the landscape (see *Section 3.4.2*). Additionally, scenarios that were considered relevant for understanding the conditions under which farmers are willing to participate in land use policies were included. To answer the *what-if* questions respondents could select from a pre-defined list, provide an open answer or both. The pre-defined lists were created based on the most frequent answers provided in the exploratory phase.

The last section does not differentiate between castes and it applies to all households in the landscape regardless of whether they own land or not. Since future conditions of the household might change (e.g. those that do not own land could become landowners) it was considered more relevant to have universal questions for all respondents.

Table 4.1 Metrics selected to characterize the landscape of Nilgiris, its community and motivations to enrol in LS/LS interventions based on the in-depth household survey

Results section	Survey Section	Metric description
General outcomes	Section A. Introduction and consent by main respondent	Number of households that consented to take part in the household survey (quantitative)
	Section B. Data Handlers	Mean time per interview (quantitative)
		Language of interview (quantitative)
		Proportion of households interviewed by gender of respondent (quantitative)
		Household type by household head (quantitative)
In and out migration	Section C. Household profile	Migration to the area (quantitative)
		Period of migration (quantitative)
		Main reason for moving in the area (quantitative)
		Members moved away (quantitative)
		Reasons for moving away (quantitative)
Social profile of household	Section D. Family details	Mean family size (quantitative)
		Religion and association membership (quantitative)
		Gender of household members, global and by caste group (quantitative)
		Education level, global and by caste level (quantitative)
		Main occupation of household members, global and by caste group (quantitative)
		Percentage of time working on own farm (quantitative)
		Percentage of time working on others farm (quantitative)
Economic profile and land ownership	Section E. Land ownership and income	Income by source and mean annual income (quantitative)
		Income per capita and income distribution by caste group (quantitative)
		Households below poverty line (see definition in Box 4.1), where the poverty line is 1081.94 INR per capita per month (quantitative)
		Land ownership by land size broken down by caste group (quantitative) and land tenure by caste group (quantitative)
Land use profile	Combines data from Section E and F	Land use at landscape level (quantitative)
		Land use by caste group (quantitative)
Farm practices, farm spending and returns	Section F. Agricultural activities	Tea farms (quantitative)
		Vegetable farms (quantitative)
		Farm spending and returns, global and by caste group (quantitative)
What-if scenarios	Section G. Decision-making and scenario testing	Decisions related to labour shortages (quantitative and qualitative)
		Decisions related to tea crisis (quantitative and qualitative)
		Policies and interventions-benefits of participation (quantitative and qualitative)
		Participation in hypothetical land use interventions (quantitative and qualitative)
		Land use practices that could influence participation in land use interventions (quantitative and qualitative)

Box 4.1 Poverty line threshold calculation in India

There are different measures for the poverty line threshold in India, all of which have different strengths and weaknesses (Government of India, 2009, Government of India, 2014, Reserve Bank of India, 2015, World Bank, 2017). Given different metrics, statistics estimate that between 21.29-50% of Indian live below poverty line. This study uses India's current official poverty rates based on its Planning Commission's data derived from Rangarajan methodology (Government of India, 2014). In line with the long practiced method, the Committee recommended the use of absolute poverty measures based on monthly per capita consumption expenditure. It defines poverty in terms of consumption or spending per individual over a certain period for a basket of essential goods. The methodology sets different poverty lines for each state, and within the state for rural and urban areas. The poverty line threshold in the Nilgiris is based on the rural value established for the state of Tamil Nadu (1081.94 INR per capita per month).

Where relevant, results are presented at either household level (*n*=408) or for all members of the households surveyed (*n*=1602). Data about the household members were obtained from the survey respondent.

In the results I am going to refer to the vegetable land as agricultural land to match the Horticulture Department classification. Tea land is classified under plantation land.

The next section presents the results and interpretation of the metrics (*Section 4.3*). The chapter then concludes with the main findings about the socioeconomic and environmental characteristics of the study community (*Section 4.4*)

4.3 Results and discussion of the socioeconomic and environmental characteristics of the study area

4.3.1 General outcomes

All 408 households asked to take part in the survey gave their consent. One respondent withdrew from the survey and another household from the reserve list replaced it. The average time per interview was 26 minutes. 31% (126) of the interviews were carried in the Tamil language and 69% (282) in Badaga. Gender ratios were balanced with 52% (212) male respondents and 48% (196) female respondents. The respondents' gender ratios can be considered representative of the area, with the most recent census showing that the proportion of females in the rural population is 49% (Census of India, 2011).

Of the 408 households, 78.2% (319) had married male heads and 2 were divorced, widowed or single (0.5%). Only 1.9% (8) of households had a married woman heading the households. The remaining households, 19.4% (79), had a female head that was single, widowed or divorced.

4.3.2 In and out migration

Out of the 408 households 14% (57 households) declared that they migrated into the area. Of these 57 households, 81% (46) arrived between 1970 and 1990. A large majority of the 57 households that migrated into the area are Scheduled Caste (55). The main reason given for moving into the area is related to work in 92% (53) of cases, the remaining 8% (4) was related to other aspects such as marriage, education, better housing or land access. The arrival of SC corresponds with the Indian-Sri Lankan agreements of 1964 and 1974 for the repatriation of Sri Lankan Tamils (Hockings, 2012; see *Section 2.4.3.2*). The findings are also supported by the decennial population growth which shows high rates of population growth in that period (Census of India, 2011; see *Section 2.4.2*). Given that TANTEA was created for the rehabilitation of Sri Lankan Tamils in the work sector, around 1960s and 1970s (see *Section 2.4.3.2*), it is not surprising that the majority of households declared their move has been motivated by work opportunities.

40% (163) of households declared that they have at least one family member (on average 1.74 members per family) that moved away to a nearby village or outside the Nilgiris district. Of these 163 households, 25% (41) had at least one member that moved outside the Nilgiris district for better work opportunities with the majority (37) leaving after the year 2000. 75% (122) had one or several members moving out after getting married and joining or setting up a new household in a nearby village or outside the Nilgiris district. 10% (16) of the 163 households had at least one member pursuing secondary or higher education outside the district. Marriage, education are common, traditional reasons for the out migration of family members. The survey revealed a large number of family members have left the area for better work opportunities since the year 2000, potentially as a result of the tea crisis. This recent out migration is reflected in the depopulation of the area with 2001-2011 being the first decade since the beginning of 20th century when the area experienced a negative population growth

(Census of India, 2011). A decline in coffee prices, led to an associated 17% population decrease in the Nilgiri district of Gudalur between 1891 and 1901 (Raman, 2010). If the severe tea crisis affecting a large proportion of the households in the Nilgiris persists, and no alternative economic opportunity arises imminently, the area could experience a similar population decline.

4.3.3 Social profile of the household

4.3.3.1 Average family size

The average household in the sampled population has 3.73 (SD 1.57) members close to the 3.5 person average of Tamil Nadu state (IIPS, 2006). The observed difference is probably related to the rural profile of the study area, with rural areas usually experiencing a higher average family size than urban areas.

4.3.3.2 Religion and association membership

All the households except one (407) identified themselves as being Hindu. The non-Hindu household identified as Christian. The proportion of Hindus is higher than the district average of 77% (Department of Economics and Statistics, 2017). The variation is partially due to regional demographic differences. For example the Gudalur sub-district, which is at lower altitudes and boarders the state of Kerala, has a higher proportion of Muslims compared to higher altitudes regions, like the Kotagiri sub-district (Department of Economics and Statistics, 2017). The variation is also due to village traditions and customs (Hockings, 2012). Those that convert to a different religion are excluded from the villages and live in separate agglomerations of households. Only Hindu villages occurred in the village selection process meaning non-Hindus were unlikely to be encountered as respondents within the survey area.
Religious homogeneity has implications for diet and food security. Different religions and caste affiliations dictate the type of products that can be consumed in a household. For example Christian households consume meat, while most Hindus in the Nilgiris do not. Consequently the results of the survey are most representative for the Hindu households of the Nilgiris.

Of the total population sample 59% (242) have no membership to an association. 33.8% (138) are part of a financial self-help group (loans or savings), 5.1% (21) are members of a village association and 1.7% (7) is part of a farmers' association.

The high proportion of households belonging to financial self-help groups (SHGs) is likely due to high levels of indebtedness with 75% of rural India households believed to be indebted as a result of marginal returns from farming (Narayanamoorthy, 2006). The SHGs play an important role in communities. They are the main form of loan access and have a strong repayment record because they are grounded in the theme of collective community responsibility with a strong moral undercurrent that acts to enforce loan repayment (Pritchard and Neilson, 2009). Nevertheless, these groups only offer temporary support in periods of critical financial insecurity. SHGs can rarely support farmers to increase productivity or switch to more profitable crops or alternatives, which means that farmers continue to be trapped in deteriorating livelihoods.

In terms of the households declared to be part of farmers' association it is believed the number is underreported. It might be that the question design led farmers into thinking they should report only the agricultural association membership and not that of tea growers. Based on communication with Tea Board tea growers are part of either Nilgiris Small Tea Growers Association or the Nilgiris Small and Tiny Tea Growers Association.

4.3.3.3 Gender of sampled population

Of the 1602 people in the 408 households surveyed 49.5 % (793) were male and 50.5% (809) were female. The ratio between male and female is balanced in the sampled households in all of the three castes surveyed (Figure 4.1).

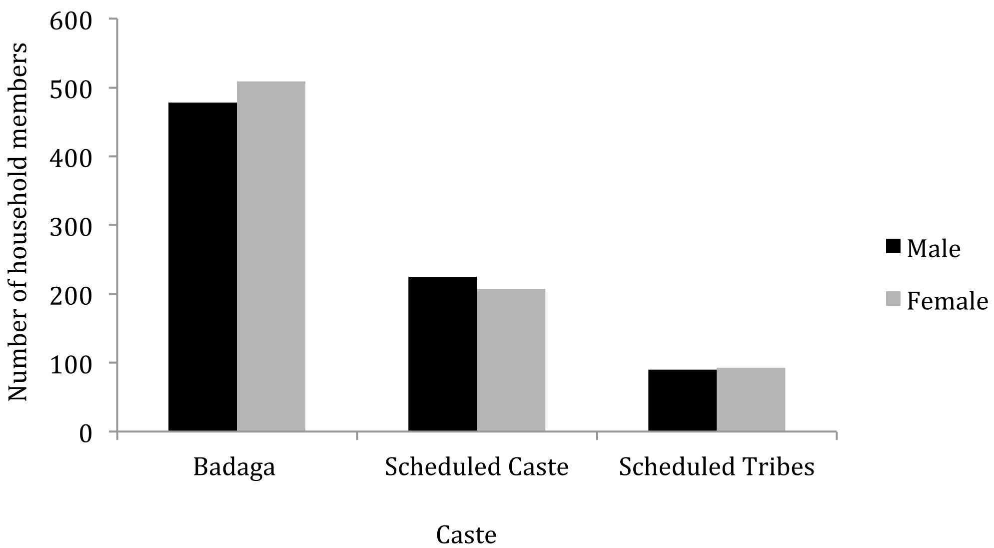


Figure 4.1 Frequency bar chart showing the number of individuals in each caste by gender (*n*=1602).

Official data available on SCs and STs suggest that the survey is also representative of gender ratios by caste group with 49.2% of the SC population and 49.6% of the ST population estimated to be male according to the last census (Census of India, 2011).

4.3.3.4 Education

81% (933) of the population living in the sampled households is literate. By gender, 70.3% (428) of the sampled female population is currently in education or has attended school compared to 91% (505) of the male population. The literacy rate of the sampled population falls between that of Tamil Nadu State, 80.1%, and that of the Nilgiris district, 85.2%, (Census of India, 2011). A lower proportion of literate women was observed in the study area than is reported at the district level (78%). The ST population may influence the difference in the proportion of literate women. STs have a lower level of education among women and live predominantly in the survey area. A higher proportion of STs in the sample population may therefore be pulling down the female literacy rate in comparison with the Nilgiris as a whole. The proportions of literate men in the survey was the same as the district level, 91% (Census of India, 2011).

All three communities are represented in primary, secondary and tertiary education (Figure 4.2). Badagas are the group with the smallest number of people with no education (0 years) and the largest proportion of individuals attending higher education (over 12 years). STs show the reverse trend with a low number of people with higher education and a high number of individuals with no years of education. As the number of years spent in education increases, the proportion of Scheduled Tribes in education decreases. SCs have higher proportions of individuals with 5 years of education or more than STs.

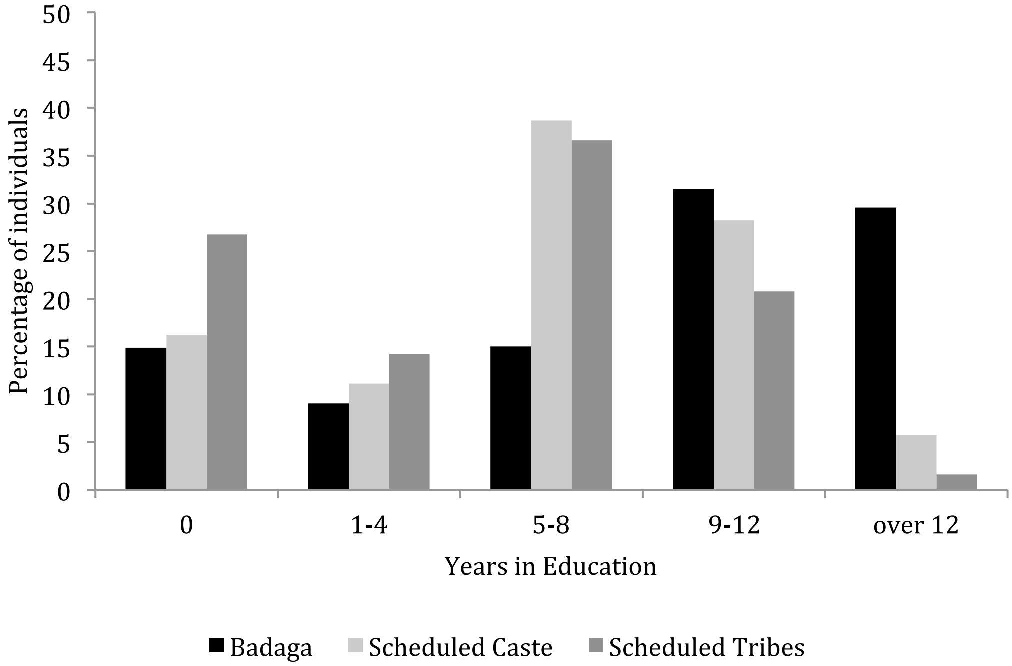


Figure 4.2 Chart showing the percentage of individuals from each caste by number of years in education (*n*= 1602).

There are no official data available for literacy rate by caste, but the results show expected outcomes based on observations of the area and its historical context. Badagas were the first group to have access to education, whereas STs, who live primarily in forests and have limited financial resources, have only begun to engage with education more recently. SCs have access to primary and secondary education, but only a small fraction has the means to pursue tertiary education.

4.3.3.5 Main occupation and time worked on the farm

Of the total population sampled (1602), 48% (767) qualified as non-workers and the rest worked on their own farms, as labourers or had other off-farm jobs.

More specifically, 9.7% (155) of the total population stayed at home and looked after the household (only women were reported), 23.7% (380) were still in education at the time of the survey, 232 (14.5%) stayed home as a result of being a child or retired or having a handicap or disease, 31.6% (506) were employed as labourers on the local farms, 11.6% (186) were practicing farming on their own lands and 8.9% (143) had off-farm jobs (Figure 4.3).

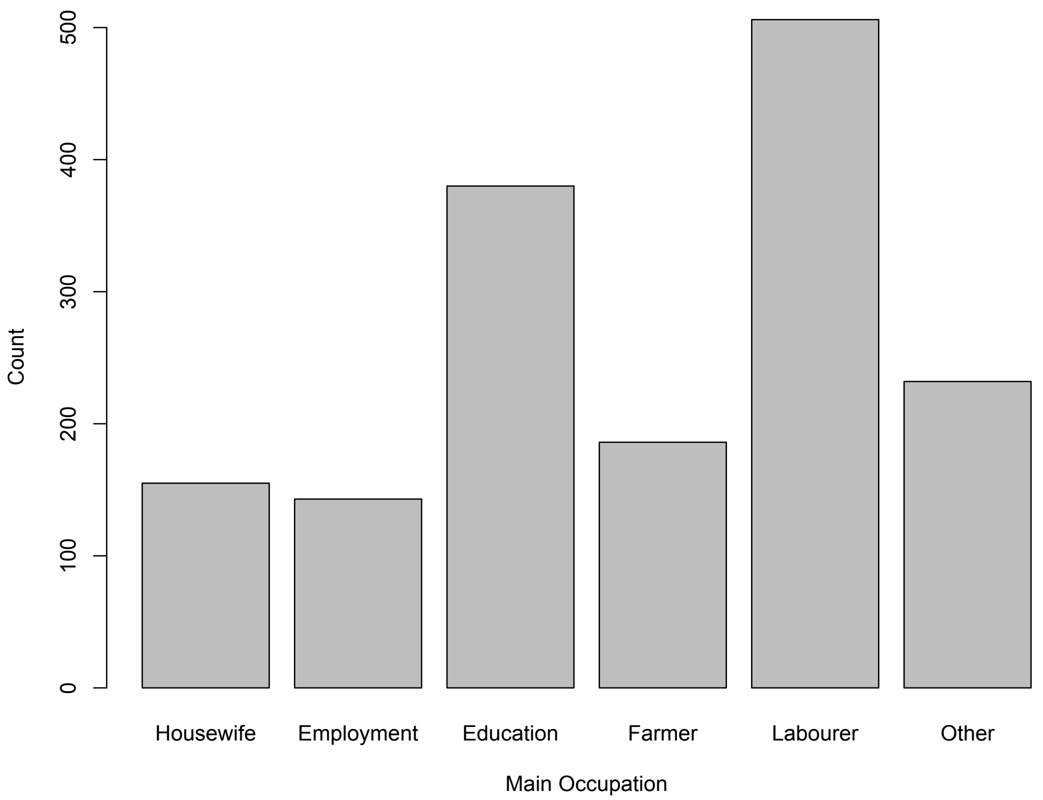


Figure 4.3 A bar chart showing the number of individuals by category of occupation (*n*= 1602)

Census data shows a small difference in the number of individuals that qualify as non-workers, 52.5% (Census of India, 2011) compared to the sampled population (48%). Larger differences are observed in terms of the working population, when broken down by different activities. For example, the census identifies that 34% of the Nilgiris population works off-farm (Census of India, 2011), almost 4 times the proportion identified by the household survey. Furthermore, the census found that only 10.7% of the population is working as labourers on the farm, whereas the survey found three times as many. These disparities occur as the census data includes urban centres and is therefore expected to have a higher proportion of off-farm activities compared to the rural survey population. The results of the study should thus be discussed in the rural context and not the whole of the Nilgiris.

The survey observed a ratio of labourers to farmers of almost 3:1 and unlike many other states of India this is expected to increase (Government of Tamil Nadu, 2017). In the last decades there has been a continuing decline in the share of farmers in Tamil Nadu state. Between 2001 and 2011, the number of farmers decreased by 0.86 million, whereas the absolute numbers of agricultural workers rose by 0.94 million. This has been attributed to two main factors: the inability of the modern sector to absorb the growing workforce and proletarianisation of the peasantry in the State. Farmers that once used to employ a workforce have had to go back to working their own land or have sold their land and now work as labourers on others' land (Government of Tamil Nadu, 2017). If the work force is not absorbed at a faster pace then the state could be faced with increasing poverty and food insecurity, or a rural exodus.

When the main occupations for each caste group are explored Badagas have the highest proportions of housewives, employed individuals and farmers than SCs and STs (Figure 4.4). SCs and STs have a higher proportion of individuals in education at the time of the survey or as labourers in comparison to the Badaga group (Figure 4.4).

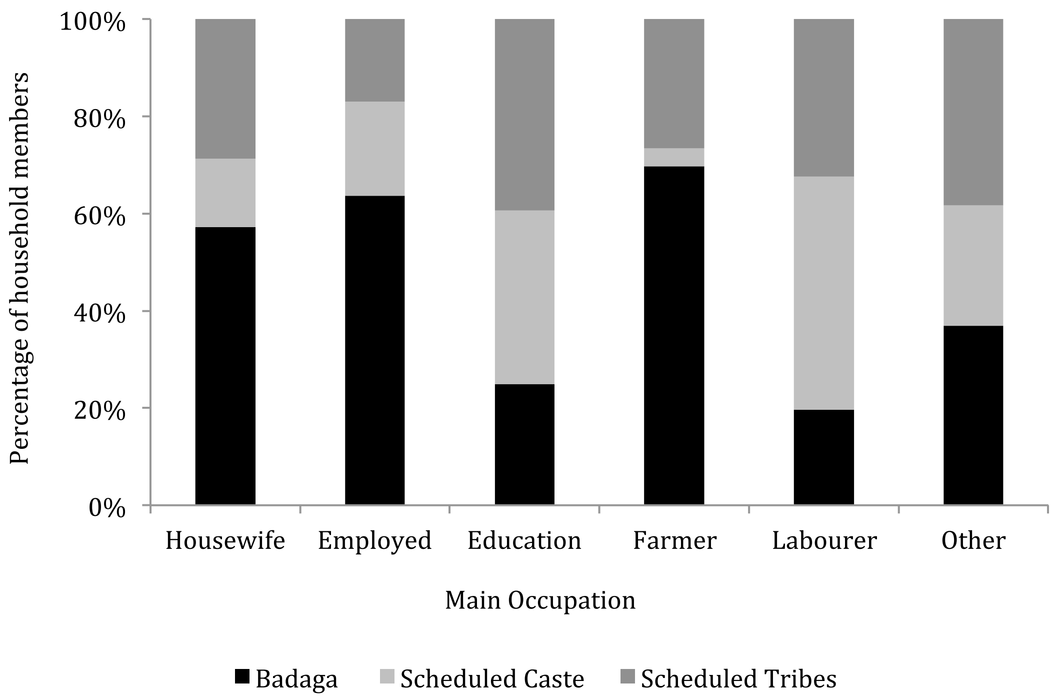


Figure 4.4 Stacked columns chart showing the proportion in each occupation of the caste groups (n= 1602)

These patterns were expected, as it is more common in the Badaga caste for women to stay home and look after the household. In SCs and STs both men and women have to get employment in order to meet living costs. It was also expected for Badagas to have the highest proportion of farmers given they are the main landowners whereas SCs are the main labour force in the Nilgiris.

Farmers that work on their farm work between 10 to 165 hours per month, with an average of 35.8 hours per month. Labourers work 6 days a week, 26 days per month for a total of 164.14 hours per month or 6.31 hours on average per working day. Srinivasan (2015) reported that labourers work, on average, between 7-9 hours per day. This difference may arise from

Srinivasan's focus on labourers employed by company estates in the Nilgiris. Estate labourers have to comply with working hours or are given bonuses for plucking more tea so they are incentivised to work longer hours. This study did not discriminate between company plantation workers and labourers working on private plantations, so the results can be seen as an average or somewhere between the two categories.

4.3.4 Economic profile and landownership

4.3.4.1 Income by source, mean annual income and mean annual income per capita

Salaries are the main source of income for 68% (277) of households (Table 4.2). Three quarters of these salaries being labourers' wages. This high proportion was anticipated given that the largest proportion of working force is engaged in off-farm activities or they work as labourers (see *Section 4.3.3.5*).

Table 4.2 Proportion of households classified by their main source of income (*n*=408)

Sources of income*	Percentage of households (%)
Farming (vegetables and plantation)	22
Salary (off-farm work and labourers)	68
Other sources (e.g. relatives send money)	7
Non-timber Forest Products, Public/Environmental allowances	3

** Households can have one or several sources of income. This table classifies the households only by their primary source of income*

The mean annual income per household is calculated as 114,700 Indian Rupees (INR) or 1170 US Dollars ($). Data on the mean annual income of a household provided in the literature shows great variation. A survey across India showed that the mean annual income for a farming household was 25,380 INR ($395) in 2003 and that relatively developed states like Tamil Nadu and West Bengal were below the national average, which was attributed to low agricultural productivity and market constraints (Narayanamoorthy, 2006). A more recent study found that in 2013 Tamil Nadu annual average income of a farming household was 85,030 INR or $1,326 (Ranganathan, 2014). In both cases this is lower than the average annual income identified in the survey and the difference could be the result of the survey averaging the result not only across farming households but also across those that have off-farm incomes.

According to the survey the average annual income per capita is 30,750 INR ($313). The Human Development Report provides a state value of 57,131 INR or $831 (Government of

Tamil Nadu, 2017), almost double the value reported in the sampled population. This difference in averages could manifest due to the Nilgiris district relying on a plantation crop that is highly unprofitable, compared to other districts of the state that are predominantly supported by more profitable forms of agriculture. The difference could also be the result of the Government of Tamil Nadu (2017) accounting for both urban and rural areas as opposed to the household survey that focuses on rural areas, which have lower incomes. These widespread differences indicate the difficulty of measuring income, and the importance of having more conservative interpretations of the results that are related to revenue (Angelsen et al., 2011).

4.3.4.2 Mean annual income per capita and annual income distribution by caste

Mean income per capita varies significantly between the different castes (Kruskal-Wallis chi-squared = 35.905, df = 2, $p < 0.001$) with SC having the highest income, followed by Badagas and then STs (Figure 4.5).

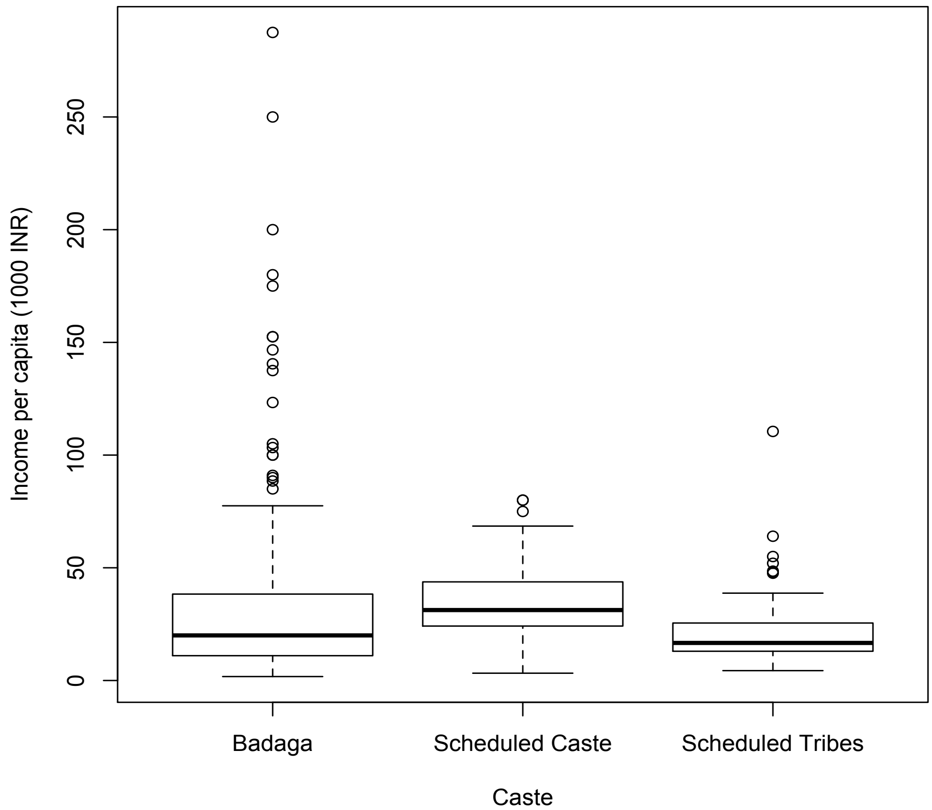


Figure 4.5 Boxplots showing the annual per capita income of respondents by caste group (*n*=408)

The income categories of households across the three castes show that Badaga households are represented proportionally between different income groups. SCs have more households in the upper income groups (over 100,000 INR/year) and the STs in the lower income groups (under 100,000 INR/year; Figure 4.6).

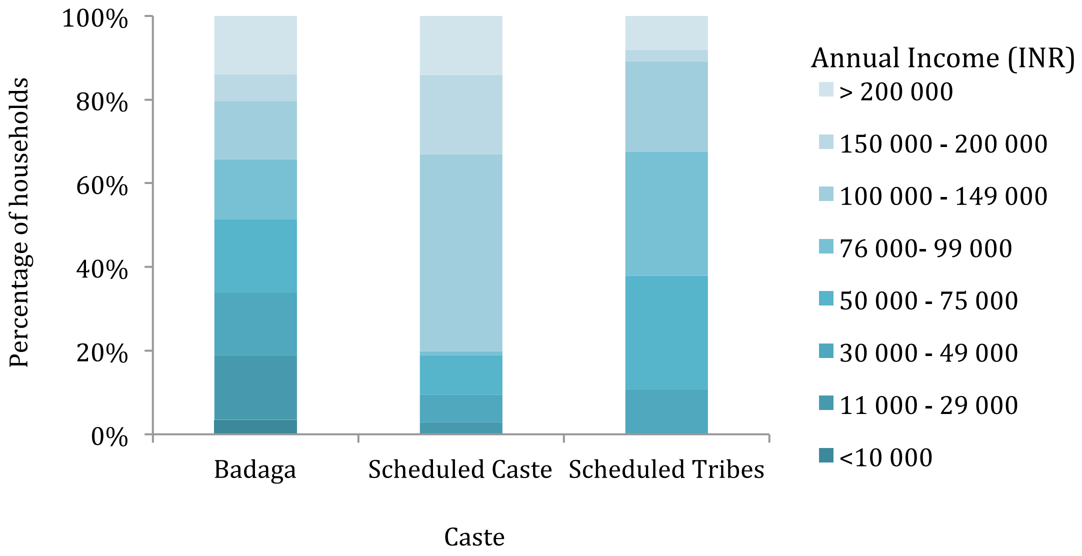


Figure 4.6 Stacked columns chart showing the proportion of households in different annual income categories by caste (*n*=408)

Looking at the differences that occur between castes, in terms of income per capita (

Figure 4.5) and total income distribution (Figure 4.6), the most surprising observation is that SCs have the highest income per capita and the largest proportion of households with earnings greater than 100,000 INR. It is believed that this figure is overestimated as a result of the sampling method, which asks workers what their daily wage is and how many days they work on average per month. Some marginal workers who work between 0-6 months per year might overestimate the amount of work they can obtain in a year or find it difficult to calculate a value when they live on daily jobs. To a lesser extent this applies to STs as well. Under these circumstances it is considered that the incomes of the SCs and STs are likely to be inflated and almost certainly in reality they are lower than those of Badagas, which are closer to official values. It is believed that the RPG and the ABM will not be affected because only data about Badagas is used.

4.3.4.3 Households below poverty line

There is a large difference in the proportion of households below the poverty line between SC and the other two communities sampled. While only 4.7% (5) of SC households are below poverty line, 25.2% (66) of the Badaga and 27% (10) of ST households are categorised as below the poverty line.

These results differ from the official data, which shows a significantly higher number of SC households below poverty line. The Human Development Report estimated that in 2011-2012 there were 24% of SC below the poverty line (Government of Tamil Nadu, 2017), which is six times higher than the survey results. Given that incomes are likely to be overestimated in the current study (see *Section 4.3.4.2*) state data are expected to be more representative of the local realities. Variation between the survey findings and those of the official data did not vary to the same extent for STs where official data again report that 24% of households are below the poverty line (Government of Tamil Nadu, 2017).

Comparing observed and reported results is more difficult for the Badaga community. Households belonging to Badagas that are below the poverty line fall under a broader caste category referred to as Other Backward Communities of whom 13% are estimated to be below the poverty line (Government of Tamil Nadu, 2017). This is about half of the estimation of the household survey. Furthermore the estimates of the Human Development Report are based on Tendulkar committee recommendations (Government of India, 2009) that offer more conservative estimates of the number of households below poverty line, with 10 percentage points less for the national average, compared to the Rangarajan committee recommendations (Government of India, 2014) on which this study was based.

4.3.4.4 Land ownership by land size and land tenure

48% (196) of the sampled households own land. ST is the group with the highest proportion of landowners (76% or 28) followed by the Badaga (60% or 160). SC is the community with the largest number of households that are landless (98% or 104; Figure 4.7). Most of those households that own land in all three castes have farms that are smaller than 5 acres (2 hectares) in size (Figure 4.7). The average land size across all landowners is 2.03 acres (0.8 hectares). Only STs and Badagas have land over 5 acres in size. Between these two communities Badagas have the largest proportion of households with landownership greater than 5 acres.

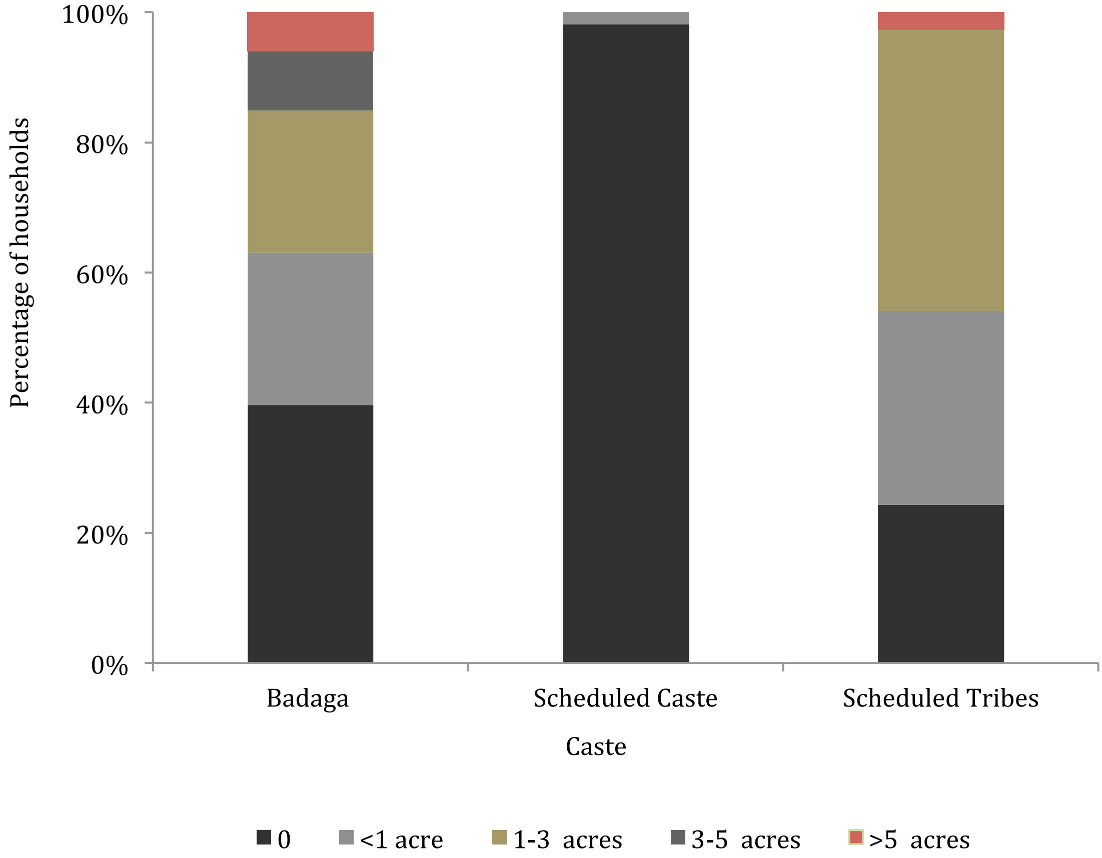


Figure 4.7 Stacked column chart showing the proportion of households from each caste that own land of different sizes (*n*=408)

As only two Scheduled Caste households own land, land tenure results are presented for Badagas and Scheduled Tribes only. Most Badagas own land with rights, *patta*, (87% or 136) and a smaller proportion have leased their land (13% or 20; Figure 4.8). In contrast Scheduled Tribes mostly own forestland without state rights (69% or 20) or *patta* land (31% or 9). Land ownership and tenure represent central reasons why the research has focused on Badaga community in the RPG and ABM.

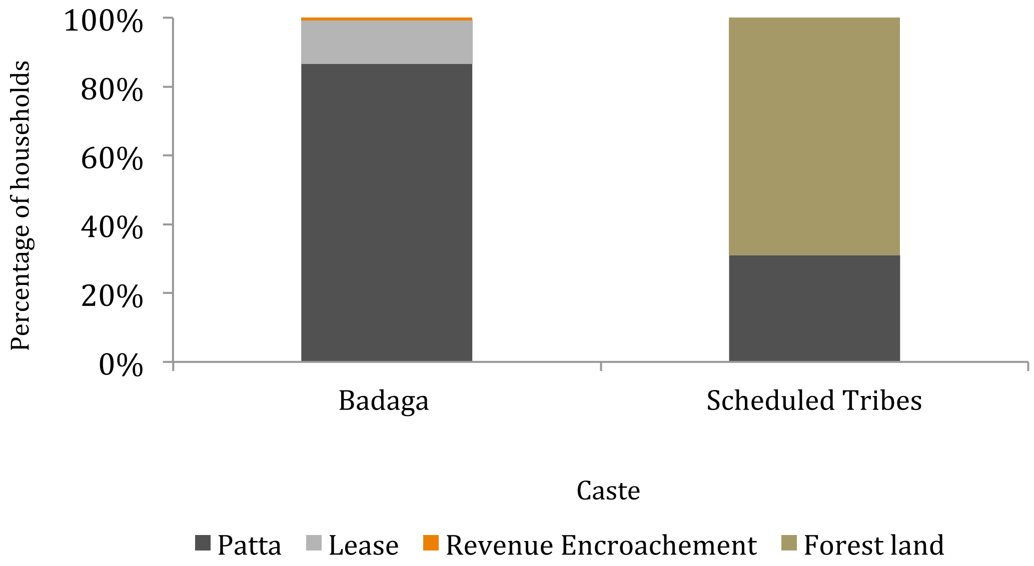


Figure 4.8 Stacked column chart showing the proportion of households in the Badaga and Scheduled Tribe Castes by type of land tenure (*n*=186, *n* refers to landowners)

Land ownership, farm size and land tenure results show large discrepancies between the three communities, but they fall within the characteristics of the caste groups in the study area where SCs and STs are among the most vulnerable groups in terms of land ownership and property rights (see *Section 2.4.3*).

The average land size in the sampled population is considerably lower than that at national level of 1.37 ha (Chand et al., 2011) but matches the state average of 0.83 ha and is only 0.06 ha lower than that of the Nilgiris district average (National Informatics Centre, 2011). The small average land size of the households within the district is probably the result of rapid population growth in the previous century (see *Section 2.4.2*), which led to widespread land division. Average land size is not expected to reduce further in the immediate future given the current negative population trend. On the contrary land abandonment, as a result of unprofitable agriculture, may lead to land aggregation in the hands of moneylenders or real estate companies.

4.3.5 Land use profile

4.3.5.1 Land use at landscape level

The type of land owned in the landscape is predominantly plantation land followed by agricultural land (Table 4.3). There is no pastureland owned by farmers (although it exists in the landscape) and a trivial proportion of households own land where native or secondary vegetation is growing.

Table 4.3 Percentage of households that own different land of different use types (*n*=408)

Land type	Number of households	Percentage of households (%)
Pastureland	0	0
Agricultural land	57	14
Plantation land (tea, coffee, fruit trees)	179	44
Native vegetation (natural grassland or shola)	8	2
Secondary vegetation	3	1

On agricultural land, farmers plant between 1 and 5 main crops annually (Table 4.4). The types of crops grown in the area are: carrot, cabbage, potato, bean, pea, pepper, brinjal (aubergine), radish and beetroot. One household reported growing maize; there were no other households that cultivated cereals.

Table 4.4 Number of crops grown by agricultural landowners in one year (*n*=56)

Number of crops grown that year	Number of households growing crops	Percentage of households growing crops (%)
1	8	15
2	11	19
3	29	51
4	7	12
5	1	3

Data regarding land use conversions shows that 27% (109) households had converted land in 121 separate instances. 84% (102) of all conversions (121) occurred between 1960 and 1990. The two main reasons for conversion were 'unprofitable land use' (65% or 71 households) and for 'cash crops' (26% or 28 households). The remaining 9% (10) converted for other reasons (labour shortage, natural disaster, logging restrictions, changes in land rights). With the exception of three households, all land was converted into tea land (Table 4.5).

Table 4.5 The number and proportions of households undertaking different types of land conversions

Previous land use	Current land use	Number of households that converted land	Percentage of households that converted land (%)
Agricultural land	Plantation	71	65
Forest	Plantation	35	32
Pasture	Plantation	0	0
Plantation	Forest	1	1
Other	Vegetables	2	1

The land use profile of the area shows some anticipated outcomes. In the last century the Nilgiris district had experienced a significant decline in grassland (see *Section 2.4.4)* at the expanse of more lucrative crops. In this context it should not be seen as surprising that households that once owned pastureland, have converted their lands and have a trivial number of livestock. The findings are also reflected in the district's governmental data (Department of Economics and Statistics, 2017).

The widespread land conversion observed in the sampled population is also supported by the historical changes in the area. Agricultural area was gradually lost to tea plantations after 1960 up until the tea crisis in 2000. Since then the crisis has persisted, with no end in sight (Venugopal, 2004). Future prospects show that land use changes are likely to be observed with farmers either abandoning their land (Chetan et al., 2012) or converting to a more profitable crop. While land abandonment can have undesired livelihood implications, there is a lot of potential for ecological restoration in the abandoned plantations (Chetana, 2013).

4.3.5.2 Land use at community level

Badaga

58% (156) of Badagas grow tea. Of these 77% (120) grow tea on farms smaller than 3 acres. 20% (53) of Badagas grow vegetables and out of them 62% (32) have less than 1 acre of agricultural land and 38% (20) between 1-3 acres. Of the Badagas that own land (160), 26% (41) grow both vegetables and tea. There are very few fruit trees and coffee plants grown on Badagas' land. The small numbers cultivated are for household consumption only.

Scheduled Tribes

56% (21) Scheduled Tribes households grow tea, 48% (18) grow coffee and 15% (9) grow vegetables with almost all households owning less than 3 acres of land. Similar to Badagas, fruit trees are grown in small numbers, intercropped and only for household consumption.

The main difference in land use between the STs and the Badagas is related to land size (which has already been addressed in *Section 4.3.4.4*) and coffee growing. Historically, the Scheduled Tribes took to the cultivation of coffee under forest cover whilst Badagas switched from vegetable growing to tea and kept only a few coffee plants for household consumption.

4.3.6 Farm practices and farm spending and returns

The data regarding livestock show that few households continue to own animals around their farm. Only 3% (13) of the households interviewed own cattle with less than 5 animals each, while another 3% (14) and 2% (9) respectively own poultry and goats.

4.3.6.1 *Tea farms*

The mean tea yield in the landscape is 3,424 kg of green leaves per acre (1st Quartile: 2,350 kg, 3rd Quartile: 4,000 kg). The number of plants grown in an acre gives a measure of tea farming intensity. This varied widely in the area: between 750-6500 plants per acre (Table 4.6). Within tea plantations farmers intercropped jungle wood, from 0-100 trees per acre, and exotic trees, from 0-150 trees per acre (Table 4.7). 44% (80) of the tea growers declared they make income from timber sale. In terms of fertilizers and pesticides, 98% (176) of all tea growers (179) declared that they use chemical inputs and 6% (11) use organic inputs. Most of the tea growers 97% (173) apply fertilizers 'when funds are available' or once a year.

Table 4.6 The number and proportion of households by category of tea plant density

No of plants per acre	Number of households	Percentage of households (%)
< 3000 plants per acre	38	21
3000-3500 plants per acre	68	38
>3500 plants per acre	73	41

Table 4.7 The number and proportion of households by density of intercropped wood category

Type of trees intercropped	Number of households	Percentage of households (%)
Jungle wood		
0	130	73%
< 10 trees/acre	37	20%
11-30 trees/acre	9	5%
>30	3	2%
Exotic trees (Silver Oak)		
0	89	49%
< 10 trees/acre	35	19%
11-30 trees/acre	26	15%
>30	29	17%

The majority of tea plantations in the study area have a suboptimal number of tea plants per acre when compared to UPASI recommendations of 5,263 plants per acre or 13,000 plants per ha (UPASI, 2015a). The mean annual yield is slightly under the one estimated by the Tea

Board at 3,582 kg of green leaves per acre. The number of trees intercropped and the quantity of pesticides and fertilizers used is also considered suboptimal, with UPASI recommending 100 trees per acre and at least 2-3 sprays a year, compared to once a year most of the farmers in the Nilgiris perform (UPASI, 2015b). The net income obtained from tea plantations is in line with previous findings and it represents less than half of the net income obtained by large growers, estimated at about 45,000 INR (Viswanathan, 2012). Large growers are considered those that have 10 ha of plantation land or more.

In this context it can be appreciated that there is considerable potential to increase production on the farm and close the yield gaps by increasing the density of plants per acre, applying fertilizers and pesticides in a timely manner and increasing intercropping with trees. However, closing the yield gaps is challenging, in some regards, given the impediments that small tea growers face across India. Goswami (2006) provides a comprehensive list of these major challenges. First, the majority of the tea bushes are 50 years or older and have passed the most productive age. Uprooting of these bushes and replantation is required to increase productivity. Given the low tea prices small tea growers do not have enough funds to maintain the plantations properly or 'revitalise' them. Nor do they have the motivation to do so when they are faced with high costs of production (wages, inputs, pruning etc.) and marginal returns. In addition, declining soil fertility, resulting from high chemical inputs, becomes a major impediment in increasing productivity.

The usual response of Indian policy makers to rural hardship has been to implement price floors or direct subsidy payments, with the objective of securing farmers' livelihoods in tough times. These measures have been taken in the Nilgiris in the past, but they do not represent a sustainable approach in the long term. A more far-sighted strategy would be to focus on auto sustainable alternatives such as quality improvements in tea plantations. By instigating 'cultural change' within the smallholder sector that focuses on improved field maintenance and increased plucking of fine leaf grades, higher tea prices and consequently improved livelihoods could be attained (Pritchard and Neilson, 2009). Such measures have been promoted following the start of the tea crisis and so far the results are encouraging. UPASI has implemented the Quality Upgradation Programme sponsored by the Tea Board of India in collaboration with a number of Government and Non-Government agencies. In some cases the price per kg have increased from 8 INR to 14 INR and on average participating households have obtained 3 INR per kg more (Pritchard and Neilson, 2009).

4.3.6.2 Vegetable farms

There were four main vegetable crops (cabbage, potato, beans and carrot) grown by farmers out of the nine types reported in the household survey. The crops have different yields, costs of production and cost-benefit ratios (Table 4.8).

In one agricultural year farmers declared that they chose to plant either for two or three seasons of cultivation. The choice to cultivate a third season or not is based on the success of previous years, current climatic conditions, available capital and market prices.

Table 4.8 Comparison between the cost-benefit ratios, production costs and yields of the four main crops grown in the study area according to secondary data from UPASI and primary data from the household survey (*n*=62, *n* refers to vegetable growers) and farmers' workshop.

Source	Indicator	Cabbage	Carrot	Beans	Potatoes
UPASI	Cost-benefit ratio	1:1.50	1:1.60	1:1.9	1:1.3
UPASI	Mean yield (kg per acre)	30,360	11,000	4,641	4,858
Household survey	Mean yield (kg per acre)	20,537	5,300	4,575	8,685
Household survey	First quartile (Q1)	12,500	2,425	2,300	7,804
Household survey	Third quartile (Q3)	28,500	5,000	6,000	9,353
Farmers' workshop	Mean cost of production (INR per kg)	3,07	12	13	15
Household survey	Min. production on farm (kg per acre)	600	1,000	600	6684
Household survey	Minimum budget spent on crop production (INR per acre)	1,842	12,000	7,800	100,263
Household survey	Maximum production on farm (kg per acre)	40,000	20,000	14,000	10,457
Household survey	Maximum budget spent on crop production (INR per acre)	184,200	220,000	173,000	150,000

4.3.6.3 Farm spending and returns

On average the cost of vegetable cultivation is six times higher than the costs with tea, while the return is nine times higher for vegetable crops in comparison with tea. 84% of the farmers declared that the current price they are selling tea for is below 10 INR per kg and the remaining 16% obtain between 10-15 INR per kg. The mean net income from tea is 18,000 INR per acre while for agriculture is 84,000 INR per acre.

On average a Badaga households spends 23,206 INR per acre per year in farming costs. This figure is almost three times as high as the average spending per acre per year for ST households, 8,630 INR.

The household survey's key finding with regards to vegetable agriculture is that regionally vegetable cultivation is more profitable than tea. While conversion from tea to vegetable agriculture could considerably improve the livelihoods of farmers, there are numerous impediments in pursuing this transition. The cost of uprooting tea plants and preparing the land is very high and farmers need to invest more money in vegetable cultivation at the beginning of the agricultural year. There are also more risks associated with agriculture based on climatic conditions, which affect the number of successful cultivation seasons in a year. Furthermore, vegetable agriculture is more labour intensive. By contrast once the tea plantations are set up they are easier to manage, have lower maintenance costs and their incomes are spread throughout the year.

Finally, the differences that occur between the STs and the Badagas in terms of farm spending and profits are expected. STs do not have a history of practicing agriculture to the same extent as Badagas do (Hockings, 2012). For STs agriculture has been undertaken as part of more diversified livelihoods but may represent an opportunity in adapting to a new lifestyle (Keystone Foundation, 2007).

4.3.7 What if scenarios-future land use policies

4.3.7.1 Labour shortage

Local communities ranked labour shortage as an important *what-if* scenario to be tested. 81% (330) of the respondents declared that if faced with labour shortages they would compensate by having members of their family help with work, whereas 13% (55) said they would help their neighbours so their neighbours could help them in return. The remaining 6% (23) declared they would take one of the following actions: abandon land, move to the city, convert their land to another use, reduce the area under cropping or rely more on money from children or relatives.

At the state level there is evidence of an increasing labour work force (see *Section 4.3.3.5*). However, the Nilgiris farmers have already joined forces in harvesting each others' plantations in periods of labour shortages (Radhakrishnan, 2016) and nearby coffee plantations have also reported labour shortages (Robbins, 2015). The true extent of the labour shortage and how it manifests locally requires further assessment before definite conclusions can be drawn.

If the labour shortage persists or accentuates in the future the majority of respondents will aim to find solutions within their household or social network before decreasing production or abandoning their lands. Given farmers' willingness to find adaptive mechanisms to labour shortages any analysis of future scenarios in the area must pay attention to the lags that occur from when the true labour shortage manifests and when land abandonment occurs.

4.3.7.2 Tea crisis

100% (408) of the sampled households declared that the current price of tea is too low to meet livelihood needs. 31% (128) considered that a fair price should be between 10-15 INR per kg, whereas 60% (244) considered that it should be somewhere between 16-20 INR per kg. When asked if they would still grow tea if the tea price continued to stay below 10 INR per kg, 46% said they would not. Furthermore, two thirds of the households (272) declared that young family members are not interested to practice or engage in agriculture in the future.

Many farmers are unsatisfied with current prices, and consider leaving tea cultivation. The minimal income from tea and high levels of debt mean that there are limited options for local communities to adapt to the challenge of the tea crisis. A failure to identify new agricultural policies that could boost the local productivity and provide more sustainable livelihoods, coupled with a disinterested young generation means there is a risk of widespread land abandonment.

4.3.7.3 Policies and interventions: benefits of participation in future interventions and willingness to participate

Interventions found in the landscape and benefits of participation in future interventions

When asked about the benefits, subsides interventions or programmes available in the landscape to support both the environment and agricultural production only 7% (28) respondents were able to name any. There were 10 interventions mentioned, 5 related to tea cultivation, 2 related to agriculture, 2 are common for both agriculture and tea and one is related to non-timber forest products (Figure 4.9).

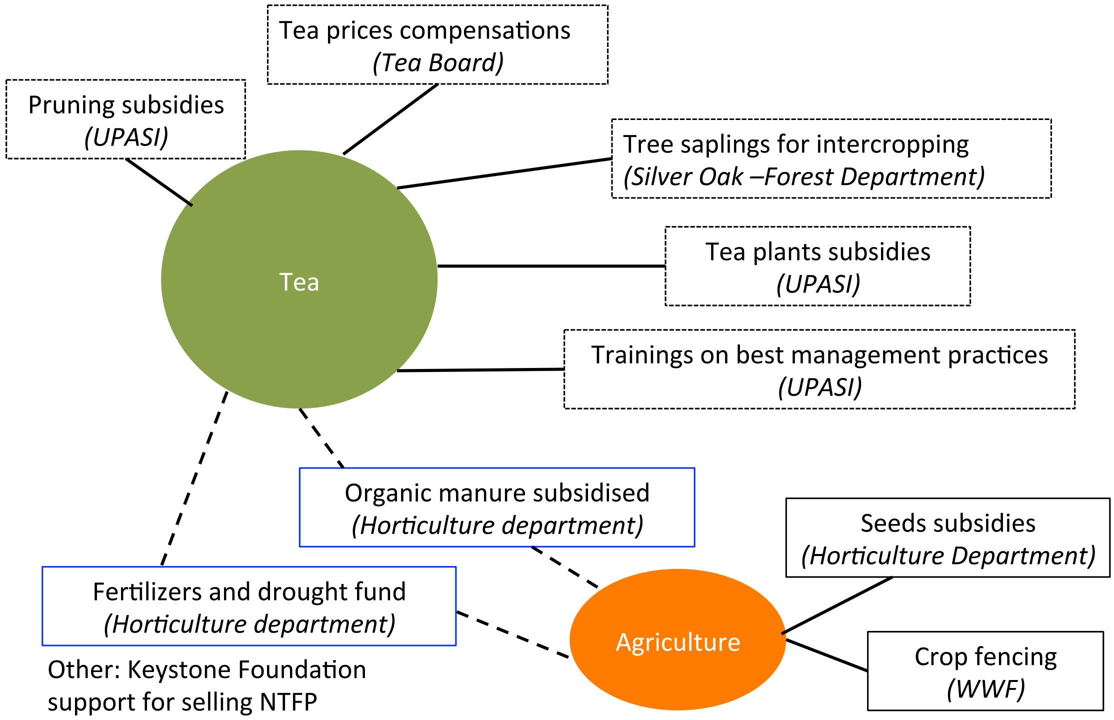


Figure 4.9 Policies and interventions available in the landscape mentioned by households in the survey (*n*=28)

Most of the accessed agro-environmental programmes have been in the form of extension services directed by four main state and research institutions: Tea Board, UPASI, Horticulture Department and the Forest Department. Only two NGO programmes, WWF and Keystone Foundation, were mentioned. Interviews carried out with all these institutions (except WWF) suggest more farmers have been exposed to these programmes and services than was reported, along with additional programmes that weren't mentioned, such as The Quality Upgradation Programme (see *Section 4.3.6.1*). Nevertheless, the results suggest there is still space to increase awareness, access and participation among the surveyed communities.

Furthermore, the study area appears to have been exposed to a considerably smaller number of interventions than many other parts of Western Ghats landscape (see interventions list in ATREE and CEPF, 2013). Moreover, the types of programmes mentioned appear to focus more on increasing productivity and improving livelihoods with a limited environmental dimension with the exception of the programs run by WWF and Keystone Foundation. Thus, future programmes could benefit more from an environmental element and most importantly from a combined livelihoods and biodiversity conservation approach.

When asked about whether there is a value in introducing interventions that benefit both the environment and agriculture 99% (407) of the respondents answered positively. Their support for such interventions stems from different motivations that are grouped into three main dimensions: **social dimension** (8% of households), **productivity dimension** (47% of households) and **environmental dimension** (21% of households; Table 4.9). A fourth class refers to those that could not provide an answer, **hesitant dimension** (24%).

Table 4.9 The frequency with which farmers associate different benefits with the introduction of land use interventions aiming to improve production and the state of the environment (*n*=407)

Benefits of participation	Number of households
Community benefits (SOCIAL DIMENSION)	**33**
Good for farmers	1
People will engage in agriculture again	7
More young people will be attracted by agricultural sector	4
Allows increases in labour income	1
It benefits community at large	19
More support for all farmers	1
Productivity benefits (PRODUCTIVITY DIMENSION)	**192**
Food productivity will increase and that means higher incomes	119
Agriculture will develop	71
Without long term planning agriculture cannot bring benefits	1
Enhances vegetable production	1
Environmental benefits (ENVIRONMENTAL DIMENSION)	**84**
Better management of chemicals	2
Prevents the environment from degrading	14
Water sources will increase	27
Better environmental quality	35
Because of aesthetic value of the landscape	1
Prevents deforestation	4
Good for soil fertility	1
Could not provide an answer (HESITANT DIMENSION)	**98**
No answer	47
Cannot say exactly why	51

Participation in land use interventions

Aside from the benefits of participation in future interventions, the farmers were asked if they would participate in interventions that benefit both the environment and agriculture if they own or will own land in the future. Out of the 407 households that were interested in the interventions, 18% (73) of the respondents do not want to enrol in land use interventions with their farms. The rest (334) would enrol based on different conditions: 56.5% (230) would enrol in a land use intervention if it carried a **financial incentive** higher than the farm profitability, 6% (25) would enrol only if their **neighbours** had already enrolled, 17% (69)

would enrol because of **pro-environmental motivations** and 2.5% (10) would enrol as a result of a **mix of factors** or other reasons.

Accounting for these different motivational profiles could be of significant value to the design and success of proposed interventions (Karali et al., 2014, Greiner, 2015). The fact that financial incentives are the most common reason for wanting to join land use policies is not surprising (Darnhofer and Walder, 2014). But there is also abundant evidence that shows policy design that considers 'soft values', like farmers' altruistic behaviour is more effective than policy that ignores these factors and solely focuses on monetary rewards (Ryan et al., 2003, Ahnström et al., 2009, Manner and Gowdy, 2010). Furthermore there is growing literature that highlights the importance of accounting for conservation-oriented motivations in agro-environmental interventions which in some cases are even more important than monetary rewards (e.g. Wilson and Hart, 2000, Ryan et al., 2003, Manner and Gowdy, 2010, Karali et al., 2014, Darragh and Emery, 2017, Jóhannesdóttir et al., 2017).

An important and central observation is that the benefits farmers associate with these interventions do not always translate into their motivations for participation. When asked about the conditions under which they would take part in such interventions the same four dimensions manifested, but with slight differences. The first difference is that the social dimension observed under the benefits of participation has reduced. Furthermore, when asked about participation in interventions, households have translated it into a form of social condition, which could be expressed as: 'if my neighbours benefit then and only then I would enrol'. Interestingly there is a significant overlap (in 86% of the cases) between those that saw the societal benefits of the interventions (social dimension) and the households that required the neighbouring condition. This means that what initially appears to be an altruistic dimension (the greater good of the community) is actually a masked form of individual consideration based on the societal response to the intervention.

The second dimension, productivity, remains similar, with farmers wanting to take part in interventions for monetary gains dictated by productivity improvements. The third dimension, those motivated by pro-environmental beliefs has also maintained its core supporters but its dimension has reduced when it comes to actual participation.

Finally a large proportion of the households that were interested to engage in the interventions but could not explain why (the hesitant dimension), have rejected taking part in the interventions. This can probably be the case of those households that have no previous experience with programmes or are landless and have no expectation of acquiring land in the future. In this case, more targeted interventions should first understand what hindrances there are to participation given that households perceive the interventions as being beneficial but refuse to join (Greiner and Gregg, 2011).

To conclude, the results align with findings from other continents, the Americas, Australia and Europe, which show incentives are only one consideration influencing the participation decision (Sorice et al., 2013, Bremer et al., 2014, Greiner, 2015). The findings thus demonstrate the importance of accounting for different motivations that stimulate farmers' participation in land use interventions in order to ensure participation by farmers across a landscape (Merckx et al., 2009). Knowledge of these motivations could maximise farmer participation as well as the intervention's efficiency (Falconer and Saunders, 2002).

4.3.7.4 Land use practices

In order to determine the feasibility of potential land use interventions to be tested in the landscape, farmers were asked a series of questions about their land use practices. Although more questions were asked in the survey, in this section only those practices that were found relevant for the development of the ABM are included.

The first question refers to farmers accepting an integrated or separated nature and farming type of management on their farms or a combination of both. 37% (151) of the households answered that they would only accept farming and nature separated on their land (land sparing) with more than half of the participants (102) motivated by beliefs that such segregation will minimise human-wildlife conflict and enable higher rates of productivity. The rest of 63% (256) prefer integration of nature and farming (land sharing). 195 respondents preferred this option because it is the normal way to practice farming in the Nilgiris and because it is important for the fertility of the soils and water availability in the fields.

The second question relates to whether farmers accept having native trees on their farms or not. 62% (252) would not accept native trees on their farms, whereas 38% (155) would allow native trees (jungle wood or fruit trees) on their land. Those that do not want trees on their land are motivated by three beliefs:

i) That productivity will decrease if tree roots affect the tea plants (153);

ii) That they will attract more wildlife (34);

iii) That they will need special permits from the Forest Department to cut down the trees and they fear losing their rights over the trees (68).

This section draws attention to the aspects that need to be considered in the design of local policies. It is not surprising that the type of farming practices, whether integrated or separated from nature, are a reflection of farmers' experiences in the field. Farmers have to balance between the different economic and social gains and losses that they consider most important to them. The fact that most of the farms have planation crops or are working in plantation crops where trees are intercropped with tea plants explains why most farms have a vision of farming that is closer to a form of land sharing. Other landscapes where farming practices favour separation from nature might find the opposite, a preference towards land sparing strategies.

An important outcome is the high number of farmers that are averse to having native trees on their farms with tree rights playing a major role in their decision. Recent studies show the importance of understating farmers past experience with tree rights, along with other factors, in order to ensure successful tree planting policies (Garcia et al., 2013, Kakuru et al., 2014, Ashraf et al., 2015).

4.4 Conclusions

This chapter portrays an image of the Nilgiris landscape with its local communities and land use practices, and investigates how the communities might respond to future socioeconomic and land use scenarios. Farmers' response to hypothetical land use policies that aim to aid biodiversity conservation and food production are analysed by looking at both the benefits that farmers associate with them and their actual willingness to engage with such interventions and their motivations to do so.

The main findings reveal an agricultural economy on which the livelihoods of all three main community groups rely directly or indirectly on the success of a single crop, tea cultivation. The crisis brought by low tea prices has resulted in a decaying economy with low crop productivity and a community with high levels of poverty. There is little interest and motivation in the future generation to continue agricultural practices, and land abandonment and labour shortages are foreseen if the crisis is to persist.

Policies that aim to revitalize agriculture and increase biodiversity are seen with interest by local communities. The land users are willing to engage them on their farms provided they meet their motivations and aspirations. An interesting observation is that the benefits land users associate with these interventions are not the main reasons for which they are willing to trial them on their farms. The main reasons that would stimulate participation are monetary rewards, social norms and pro-environmental beliefs. Along with understanding the motivations for participation, knowledge of the local land use practices, such as preference of integration or separation of farming and nature, or accepting native trees on the farm or not, are essential in formulating successful management strategies grounded in local realities.
Achieving conservation objectives in Nilgiris agricultural landscapes needs to account for the characteristics that define the landscape, the communities that inhabit them, their land use practices and motivations in engaging in biodiversity conservation interventions.

The next chapter adds more information to the social profile of the community by looking into aspects of food security.

Chapter 5

Food security dynamics and determinants of food security

5.1 Introduction

Many scientists have argued that food production must increase substantially to meet the needs of a growing human population, and that this poses a threat to biodiversity conservation (Adams, 2012, Dudley and Alexander, 2017). This widespread framing of the food–biodiversity challenge, best known through the debate on LS/LS, has been criticized for its limited focus, primarily on food production (Kremen, 2015). Food production is only a means to an end; the implied societal goal is to ensure food security (Fischer et al., 2017). Understanding how local food security is impacted by policies such as LS/LS is key to the success and sustainability of interventions on the long-term (Glamann et al., 2017, Delzeit et al., 2017). But so far, debates about food security in the context of the LS/LS framework have been ideological in nature, and there is a lack of empirical evidence to inform decisions grounded in local realities (Fischer et al., 2014). In the context of current research, where it was revealed that the Nilgiris farmers are interested to participate in future LS/LS policies, assessing the potential impacts of the interventions on food security offers a good research opportunity. However, there is little information on what factors affect the food security of the local households, especially in a landscape that has seen dynamic economic and land use changes in the last 50 years.

Previous studies in different regions of the world have identified a complex range of factors that can influence household food security. These include: household assets (Guo, 2011), household savings and monthly income (Frongillo et al., 1997, Bashir and Schilizzi, 2013), financial constraints (Chang et al., 2014), access to credit (Gundersen and Gruber, 2001), ownership of livestock (Ali and Khan, 2013), jobs loss and low level of income (Loopstra and Tarasuk, 2013), education (Keenan et al., 2001), knowledge of the household about food storage, processing, nutrition and management of illness (Riely et al., 1999), corruption, fiscal imprudence, debts and policy inconsistency (Akpan, 2009), non-farm work (Owusu et al., 2011), gender of the household head (Kassie et al., 2014), cultivated land size, fertility of soil, irrigation access, number of extension visits, fertilizer use and improved seed (Bogale, 2012), remittances and access to market information, and age of the household head (Mango et al., 2014), structure of the family and dependency ratio (Asghar and Muhammad, 2013, Bashir and Schilizzi, 2013) and infrastructural availability (Gill and Khan, 2010).

This chapter proposes to build on the previous food security literature to fill in the gap identified in the Nilgiris landscape by:

(1) Describing the food security changes in the landscape, and

(2) Assessing the current determinants of the food security at household level.

5.2 Data and methodology

The metrics selected to assess food security at the landscape level use primary data from focus groups and key informant interviews (see *Section 3.4.2*), whereas the determinants of food security at household level are determined based on primary data from the in-depth household survey (see *Section 3.4.1*). The 'landscape' is defined as the area that was selected for representation in the ABM (see *Section 7.4.2*). The outcomes of the food security metrics measured are triangulated with secondary data (beyond the 'landscape') from district or state level, based on relevant literature.

This section will start by introducing the rationale behind the selection of food security metrics (*Section 5.2.1*). It will then continue with introducing the metrics used in measuring food security at landscape level (*Section 5.2.1.2*) and at household level (*Section 5.2.1.3*), before moving to introducing the methods used in analysing the household level data (*Section 5.2.2*).

5.2.1 Measuring food security

Food security is a multi-faceted concept, open to interpretation, leading to numerous ways of measuring it. Since the concept of food security was first proposed under food balance sheet (post World-War I) and broadly agreed as being a human right in the Universal Declaration of Human Rights (1948), the definition of food security has constantly evolved conceptually, often broadening its meaning by adding considerations of supply and availability, access and entitlement, utilization and nutrition to more recently incorporating discussions about food sovereignty and sustainable livelihoods (FAO, 2001, Simmons and Saundry, 2012). To date, the most widely used definition states that food security is achieved 'when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life' (FAO, 1996) while the World Summit on Food Security stated that the 'four pillars of food security are availability, access, utilization, and stability' (FAO, 2009).

Food availability relates to enough food supply being available through production, distribution, and exchange (Gregory et al., 2005). Food access refers to the affordability and allocation of food, as well as the preferences of individuals and households. Access depends on whether the household has enough income to purchase food at prevailing prices or has sufficient land and other resources to grow its own food (Gregory et al., 2005). Utilization refers to the metabolism of food by individuals, the quantity and quality of food that reaches members of the household (Tweeten, 1999). The last pillar of food security, stability, refers to the ability to obtain food over time. Food insecurity can be transitory, seasonal, or chronic (FAO, 1997).

There are many factors that can act as barriers or promoters of food security and they are often interlinked or have complex relationships, demonstrating the challenges of defining and measuring food security (Hendriks, 2005, Webb et al., 2006, Coates, 2013). A compendium and review of the current metrics shows the complexity, diversity and differences that occur by measuring aspects of food security in different ways; the field is awash in measurement tools that have 'many measures, many constructs and many uses' (Jones et al., 2013). The Jones et al. (2013) review concludes that until metrics are standardized and the field of food security becomes more homogenized, deciding on an appropriate approach will depend on the conceptualization of the construct to be measured and the intended use of the data to be collected. It proposes a step-wise approach that acts as guidance in enabling researchers to select the appropriate metrics to measure food security. In doing so it considers a range of aspects that are essential in determining the right metrics to be used by a study, such as the component of food security measured (access, utilization, stability, availability), the geographical scale of interest (food security at individual, household, regional or national level), time scale (e.g. food security in the past year, in the last week), the use of data and the resources available to collect the data (Jones et al., 2013).

In the context of the current research it was considered important to measure all four pillars of food security. The Human Development Report highlights that all food security pillars were found to have a significant influence in the level of food security in the Nilgiris district

(Government of Tamil Nadu, 2017). The variables measured at landscape level were not predefined. The aim was to understand the general trends and themes that occur in the landscape. Thus the variables were selected in an exploratory phase (see *Sections 3.4.1 and 3.4.2*), prior to conducting the focus groups. The exploratory phase also helped define the metrics under the four pillars that were important to measure food security at household level. Out of them, one needed special consideration: food utilization.

5.2.1.1 Food utilization: Food Consumption Score

Food utilization at household level can be measured using a number of instruments including: Food Security and Vulnerability Analysis (FSVA), Household Food Insecurity Access Scale (HFIAS), Food Consumption Score (FCS) and Household Dietary Diversity Score (HDDS) (VAM, 2003, 2008, Coates et al., 2007, Kennedy et al., 2013). These instruments have been developed by various international agencies, at different times and with different objectives, rendering it difficult to compare them. This study propose to use the FCS (Box 5.1) given that it has been one of the most widely used instruments, tested in over thirty countries including Indonesia, Peru, Bolivia, Ecuador, Rwanda and Gambia (Dibba et al., 2017, Habyarimana and Nkunzimana, 2017, Hasanah et al., 2017, Limon et al., 2017).

One of the main advantages of the FCS is that it focuses on both dietary diversity and food frequency, and therefore might be preferred to indicators that exclusively focus on food diversity (Jones et al., 2013). Compared to other instruments, such as HDDS, that requires higher-level technical skills in data collection, FCS data are relatively easy to collect (Hoddinott and Yohannes, 2002).

Box 5.1 Calculation of Food Consumption Score

FCS is developed by the World Food Programme and is a proxy indicator of household food security, based on the weighted frequency (number of days per week) of intake of eight different food groups (VAM, 2008). It is measured as:

$$FCS= a_{staple}x_{staple} + a_{pulse}x_{pulse} + a_{vegetables}x_{vegetables} + a_{fruit}x_{fruit} + a_{animal}x_{animal} + a_{sugar}x_{sugar} + a_{dairy} x_{dairy} + a_{oil}x_{oil}$$

where 'x' is the frequency of food consumption (number of days during the past 7 days on which each food group was consumed) and 'a' is the weight of each food group.

The weights of the food groups set by the World Food Programme are as follows: cereals and tubers (2), pulses (3), vegetables (1), fruits (1), meat and fish (4), milk (4), sugar (0.5) and oil (0.5).

The FCS is computed for each household as a measure of household food consumption. FCS helps to classify households in three categories of food consumption based on their core (VAM, 2008):

- Poor food consumption: 0-21
- Borderline food consumption: 21.5-35
- Acceptable food consumption: 35 or more

The indicator itself is simple to calculate, the information on which its based can be accessed from a household survey and it allows classifying households who are food insecure by categorising food consumption groups: poor, borderline, and acceptable (Jones et al., 2013). This allows for comparisons to be made from local all the way to national and international levels. However, due to dietary differences between regions, the World Food Programme recommends for the thresholds between the different consumption groups to be adjusted to reflect local realities (VAM, 2008).

Like all metrics the FCS has a number of limitations. It only captures a snap-shot in time, it does not capture seasonal change, nor does it quantify the food gap or capture variation in intra-household food consumption (Vhurumuku, 2014). The food group weights and food consumption group thresholds, although standardized, are based on certain inherently subjective choices and the analysis can mask important differing dietary patterns (for example, rice vs. millets consumption) that have an equal FCS (VAM, 2008). These limitations can be overcome when paired with other complementary metrics of food security including periods of food shortages and coping strategies during these periods as well as a qualitative assessment of the local context (Limon et al., 2017).

For the study area, specific alterations were made to the Food Consumption Score to better reflect the local context, for a variety of reasons (Table 5.1).

Table 5.1 Changes made to the Food Consumption Score data collection methodology and calculation

Difference from FCS methodology	Implications and Alternatives
(1) Previous research shows that the thresholds for the FCS groups (poor, borderline and acceptable) may need to be adjusted upwards in situations where nearly all households consume sugar and oil regularly, effectively establishing a minimum FCS of 7 for all households (VAM, 2008, Wiesmann et al., 2009)	Sugar and oil consumption was reported in nearly all households. As a result the FCS thresholds were increased to reflect local realities.
(2) The thresholds set for the FCS groups are based on diets where meat consumption is an integral part of the locals diet. This however does not apply to the study area, where caste groups such as Badagas have mainly vegetarian diets.	Because 'meat and fish', receives a high weight it is expected for the local FCS to be smaller than those on which the thresholds between the groups were established by the WFP. In establishing the new thresholds consideration should be given to such customary diet choices and not penalise the non-consumption of meat. Thus, it is proposed to reduce the thresholds between groups to accommodate for the local dietary differences.
(3) Although it is increasingly being used across different regions of the world, the FCS has been mainly tested in African countries. No studies using this indicator have been carried in India. This study will be the first to do so. While this is an exciting prospect, there are no indicative thresholds for the food groups to be used as a country guideline. As such this study proposes new thresholds between the food groups that are meant to take into account the observations made in points (1) and (2). New thresholds proposed: Poor diet: 7-23 Borderline diet: 23.5-42 Acceptable: over 42	This study did not use the same thresholds as proposed by the WFP and the choice of new thresholds is somewhat arbitrary. Because of that in the analysis of the determinants of FCS the variable was maintained as continuous and not as categorical (poor, borderline and acceptable) as proposed by WFP. This way fewer assumptions were made about whether a household is food secure or not and the analysis was more targeted on understanding the direction and magnitude of the different factors impacting FCS.

5.2.1.2 Assessing food security at landscape level

The changes in food security at landscape level (Table 5.2) used key informant interviews and focus group data, carried only in one of the caste groups, the Badagas (see justification in *Section 3.3*). Twelve focus groups were organised with a total of 120 participants.

Table 5.2 Measures of the four pillars of food security at landscape level –comparison before and after 1990

Variable measured	Type of data	Method
Food availability		
Food being produced, distributed in the area or available in the local markets before and after 1990	Qualitative and quantitative	The focus groups *(focus groups= 12; individuals =120)* were asked to establish whether sufficient food is available in the area to all households either through own production, distribution or local markets.
Food access		
Proportions of food consumed in the household coming from the farm and bought foods before and after 1990	Quantitative	The focus groups *(focus groups= 12; individuals =120)* were asked to establish the percentage of food consumed in the household from their own production vs. bought food, in the past and at present. Only average results of all the focus groups were reported for the two time periods (before and after 1990).
Budget available to buy food	Qualitative	The focus groups *(focus groups= 12; individuals =120)* were asked to establish whether the available budget to buy food was considered sufficient and stable to secure sufficient food for the household before and after 1990.
Food utilization		
Proportion of different food groups consumed as part of a household's diet before and after 1990	Qualitative and quantitative	The participants that cook or assist with cooking (*focus groups= 12; individuals= 48)* were asked about the type of foods cooked before 1990 and the type of foods cooked after 1990 and the proportions of different foods in a household's' diet? For each village it was reported the rough mean value estimated per food type.
Diversity and frequency of food groups consumption and whether the foods were produced on the farm before and after 1990	Quantitative	20 members over 70 years old that took part in the focus groups *(n=12)* were given a list of 11 food groups (cereals, roots and tubers, nuts, pulses, vegetables, meat, fruits, milk, fats, sugars, spices) for which they had to agree on the reported frequency of consumption (*rarely, occasionally, frequently, most of the days, every day*).
Sugar and fat intake in and after 1990	Quantitative	The participants that cook or assist with cooking (*focus groups= 12; individuals= 48)* measured the sugar intake by thinking of the rough number of sweetened tea/coffee cups they used to consume in the past compared to more recent years. For fat intake, they were asked to compare the amount of fat that went in the preparation of the main meal of the day in 1990 and after 1990.
Perception of diet and conditions associated with dietary changes	Qualitative and quantitative	Focus group members *(focus groups= 12; individuals =120)* were asked whether they consider the diet in 2015 to be more diverse, nutritious and healthier than before 1990. They were also asked about any health issues associated with dietary changes that they have perceived. Lastly the focus group members had to state what they consider to be the most important component of food security (availability, access, utilization, stability or stability).
Food stability		
Seasonal food shortages	Qualitative	The focus groups *(focus groups= 12; individuals =120)* were asked to establish whether food security is impacted by seasonal food shortages and if so what are the causes.

The focus groups were formed of both young and elderly community members that cook or assist with cooking, farmers that work or used to work the land in the past and people that are responsible of family shopping. Key informant interviews were carried out with 8 local women who assist in cooking for community functions and events. The data were used to triangulate the results of the focus groups.

In understanding the changes in food security in the landscape comparisons were made before and after year 1990, which represents the year of transition between two economic periods. The first one, between 1960-1990 is defined by a fast expansion of plantation agriculture with high rates of land conversion and economic development. The second period after 1990 is characterized by a deceleration of land conversion and transition into an economic crisis.

5.2.1.3 Determinants of food security at household level

The present status of food security used data only from the in-depth household survey (*n*=408) on the three caste groups: Badagas, Scheduled Caste and Scheduled Tribes.

Descriptive statistics was used to look at some key food security related aspects:

- Proportion of foods produced on the farm retained for household consumption;
- Food availability:
  - Proportion of households that consider food accessibility to be a problem
  - Proportion of households that are part of the Public Distribution System (a government-sponsored chain of shops entrusted with the work of distributing basic food and non-food commodities to the needy sections of the society at subsidised prices).

Mixed Effects Models (*Section 5.2.2*), were used to assess the relationship between different economic, social and land factors and three pillars of food security (Table 5.3):

- Food access: Food Budget
- Food utilization and access: Food Consumption Score
- Food stability: Food Shortage

Table 5.3 Fixed and random explanatory variables used for assessing the food security under three of its pillars (access, utilization and stability)

Variable	Data type	Description
Response variables		
FCS	Continuous	See *Section 5.2.1.1*
Food Budget	Continuous	A composite of two variables measured in the household survey: the average food monthly budget declared by the household, and the monetary value of the proportion of production retained for household consumption.
Food shortage	Categorical 2 levels: Yes/No	A variable that measured if the household did not have sufficient food to satisfy the household demand in the last month, and as a result at least one member of the family went to bed feeling hungry.
Fixed Effects		
Economic factors (INR)		
Income (total)	Continuous	A measure of all sources of revenue of all household members in a year. It is composed of income generated through farming activities (agricultural income), labour and off-farm income (salary) and other sources.
Agricultural Income	Continuous	The amount of money that a family obtains from selling all or a part of the crop.
Salary (Labour and off-farm Income)	Continuous	The amount of money a household obtains from paid work, either as farm labourer or off-farm work.
Land Assets (acres)		
Landholding Agriculture	Continuous	The total amount of agricultural land a household owns. It only refers to land for vegetable growing.
Landholding Tea	Continuous	The total amount of plantation land owned.
Social Factors		
Family size	Integer	-
Education level	Integer	Represents the number of years in education of the most educated household member.
Caste	Categorical 3 levels: ST, Badaga, SC	Refers to the three communities analysed.
Household type	Categorical 2 levels: Female/Male headed	Refers to the gender and marital status of the household head.
Farm Production		
Number of trees grown	Continuous	Refers to the total number of trees a family has on both tea and agricultural land combined.
Cost of farming	Continuous	Refers to the cumulative cost of fertilizers, seeds, irrigation, clearing the land, transport to the market and labour costs that a household enquires over an agricultural year.
Number of crops grown on farm	Categorical	9 levels
Other		
Distance to Market	Categorical 3 levels: 2 km, 2-10 km; >10 km	Refers to the distance the family members have to travel to the market were they regularly shop.
Random effects		
Village	Categorical	13 levels
Enumerator	Categorical	9 levels

Two of the variables, 'Landholding size' and 'Annual crop productivity', were removed from the analysis because of the high correlation (spearman's rank correlation test > 0.7, p <0.001) with 'Landholding tea' and 'Agricultural Income' respectively. Because most of the farmers own tea it was expected for the correlation to occur. The case of the 'Annual crop productivity' was also anticipated given that most of the households sell the crop, which is reflected in the income obtained from the crop. The explanatory variables and relevant interactions were fitted as fixed effects, whilst 'village' and 'enumerator' were fitted as random effects (see *Section 3.4.1.4*).

5.2.2 Analysis of food security determinants- Mixed Effects Models

The degree to which the explanatory variables explain the three components of food security: 'FCS, 'Food Budget' and 'Food Shortage' were tested using Generalised Linear Mixed Models (GLMMs) to generate Minimal Adequate Models (MAMs) in the statistical package R (see details *Section 3.4.1.4*). The selection of the appropriate GLMM for each of the three components of the food security followed the decision tree for GLMM fitting and inference proposed in the review by Bolker et al. (2009) (see Appendix 3.3).

Following this approach the 'FCS' and 'Food Budget' variables were found to be appropriate for analysis using the penalized quasilikelihood (PQL) method. Both variables have log-normal distribution, which is not a discretized distribution, and they meet all the other PQL assumptions (mean > 5 and non-binary variables). Therefore in the analysis of 'FCS' and 'Food Budget' the 'glmmPQL' (package 'lme4') function was selected for analysis. For 'Food Shortage' because it is treated as a yes/no binary variable the appropriate approach was the Laplace approximation, which can handle up to 3 random effects. The analysis requires two random effects 'village' and 'enumerator' (analogous to 'FCS' and 'Food Budget' analysis) so Laplace approximation method is suitable for the current study (function 'glmer', package 'lme4').

To find the best model in each case a Minimum Adequate Modelling (MAM) approach was taken. For 'Food Shortage' the selection of the model was done using the lowest Akaike Information Criterion (AIC) as recommended in the literature (Bolker et al., 2009). The 'glmmPQL' models are not able to return AIC results (nor other test such as BIC or the coefficient of determination) so the model simplification looked at the p values of all the independent variables (R-help, 2005). If any term in a model had a p value greater than 0.05, the term with the highest *p* value was removed and the process repeated until the model with all variables significant was obtained.

In terms of random effects, if their variance in the model was essentially 0 (it did not explain additional variance) then they would be removed from the GLMM and instead a linear regression would be performed (Bolker et al., 2009). In this case the MAM would be established based on the AIC and the coefficient of determination, R^2.

For every model, coefficients showing the direction and the effect are reported for each variable. In each case the respondents were included in the analysis only if data were available for them in every variable tested. Full details of the sample size are given with each analysis in the results section.

The next section (*Section 5.3*) will present the results of food security at landscape level (*Section 5.3.1*) and will discuss the changes observed in relation to secondary data at local and national level (*Section 5.3.2*).

5.3 Changes in food security at landscape level

5.3.1 Food security at landscape level based on focus group results

Table 5.4 presents a summary of food security metrics measured at landscape level before and after 1990 and indicates whether their overall change (the sum of positive and negative changes) had improved food security (➚) reduced it (➘) or it affected food security in both ways (➚➘).

Table 5.4 Summary of results at landscape level by food security pillars and their overall impact on food security

Indicator	Results before 1990	Results after 1990	Overall outcome
Food availability			
Food being produced, distributed in the area or available in the local markets	Available most of the times (more difficult to source if stochastic events like drought or heavy monsoon). More food produced on the farm and less food sourced from outside the farm.	Available at all times (+), however most food sourced from local shops, markets, through the Public Distribution System and a small proportion from own farm.	↗
Food access			
Proportion of food consumed in the household coming from the farm v bought foods	Between 20-45% of food consumed produced on the farm	Between 0-10% of food consumed produced on the farm (-)	↘
Budget available to buy food	More households determined the food budget based on the success of the agricultural year. However, more diversified agriculture made the budget less prone to shocks.	Fewer households dependent on agriculture only (+). For households with diversified sources of income, the budget allocated to food is more stable (+). For households reliant on monocrops (e.g. tea) food budget is dependent on the price of the crop on the market (-). Households are more vulnerable when dependent on a single cash crop (-).	↗ ↘
Food utilization			
Proportion of different food groups consumed as part of a household's diet	Compared to the period before 1990, the period after 1990 shows that: Cereal consumption increased (-), milk consumption decreased (-), vegetable consumption increased (+), while all the other food groups experienced small changes. The cereal diversity decreased with rice replacing many local varieties of millets (-).		↘
Diversity and frequency of food groups consumption and whether the foods were produced on the farm or bought	11 out of 11 food groups were produced on the farm or harvested from forest. The table with frequency of food consumption per food group before and after 1990 is presented in Appendix 5.1.	4 out of 11 food groups were produced on the farm (-)	↘
Sugar and fat intake	The change after 1990 shows that: Sugar intake increased between 2-4 times (-); Fat intake increased between 4-9 times (-).		↘
Perception of diet and conditions associated with dietary changes	74% (89) of the 120 people that took part in the focus groups concluded that the diet in the past was more diverse, nutritious and healthy (-); About 10% of the households declared they have members with a diagnosed from of diabetes (-);		↘

Indicator	Results before 1990	Results after 1990	Overall outcome
Food stability			
Seasonal food shortages	Triggered by market and environmental shocks. Resilience to seasonal shortage was determined by factors within the community (family support, self-help groups, charity).	Triggered by market and environmental shocks. Resilience is determined by external factors (public distribution system, access to loans etc.) that are independent of the regional conditions, therefore affecting fewer households (+). Seasonal shortages have a higher impact on households reliant on monocrops (-)	↗ ↘
Food security narrative	Communities found it difficult to agree whether the changes brought by cash crop agriculture had an overall positive or negative impact. The extra income generated from converting their lands to high return cash crops improved welfare, wellbeing and aspects of food security (+). On the other hand loss of diversification made the communities less food secure, in terms of quality and diversity of foods more vulnerable to economic shocks (such was the case of the tea crisis that started in mid 1990s) and ultimately facilitated land abandonment and outmigration (-). Out of all the metrics measured under food security during the focus groups the respondents consider that the budget available to buy food (food access) is the defining measure of food security in the present.		↘ ↗

5.3.2 Understanding food security at landscape level

The changes observed in food security at landscape level follow the historical patterns and trends observed in the earlier chapters (see *Section 2.4*). The food security changes within the four pillars of availability, access, utilization and stability, reveal the importance of focusing on all dimensions of food security in the Nilgiris and understanding both the barriers or promoters of food security and their direction of influence (Limon et al., 2017).

Food availability has improved as a result of more products being available at all times in the study area, through local markets, shops and public policies (the Public Distribution System). State data also show significant improvement in indices of food availability and they similarly attributed the improvement to the introduction of the universal PDS as well as to maintaining sufficient buffer stocks (Government of Tamil Nadu, 2017).

Food access has experienced both positive and negative changes closely interrelated with the agricultural sector. There was a significant reduction in the average quantity of foods consumed in the household that are coming from the farm as a result of land conversion to more profitable crops, a change that has been previously documented in the area (FAO, 2014). This means that households without secure sources of income are more vulnerable to food scarcity because they can't rely on their own crops. At the same time the number of households dependent on agriculture only, has decreased and for those families the food budget is considered to be more stable and adequate for a food secure household.

Food utilization had an overall downward trend. Foods consumed are less nutritious and diets are unhealthier and less diverse. These outcomes are representative of wider trends at the country level (Khera, 2011), with diabetes representing one of the main health related problems affcting 5% of the population (IFP, 2017), which is half the level reported in the focus groups.

Food stability has a mixed outcome. The magnitude of the seasonal shortages is affecting households in a different way than in the past (more vulnerable because of monocrops agriculture), but now farmers employ different coping strategies (more options and more independent of the local context) in periods with food shortages. Reliance on sources independent of the local context is beneficial, but it has led to high levels of debt in rural communities (Narayanamoorthy, 2006). This means that food stability is only postponed and its true extent might be difficult to quantify.

The next section (*Section 5.4*) will present general findings on food security (*Sections 5.4.1*) and the determinants of food security at household level (*Section 5.4.2*). The section will be followed by a general discussion on the factors that affect the three pillars of food security (*Section 5.5*).

5.4 Food security at household level based on in-depth household survey results

5.4.1 General findings

Food produced on the farm

There is no household that lives exclusively on food produced on the farm. Some households produce a higher percentage of their food on their own farms whereas most of the farms supplement their diet with foods produced on the farm. Out of the total production farmers retain from 0 up to 30% of the crop. The average percentage retained from each crop per household is 13.25 % for beans, 14.09% for carrot and 11.53% for cabbage.

Food availability

Food availability results show that out of all households (*n*=408) only 3% (12) considered there is not enough food being produced, distributed in the area or available in the local markets. 96% (391) of the household declared they are taking part in the Public Distribution System.

5.4.2 Mixed Effects Models-Determinants of food security

5.4.2.1 Food stability -Food shortage

Food stability results show that 9.8% (39) of the households (*n*=408) declared they had food shortages in the last year (2014-2015).

January and December were reported as being the most food insecure months, followed by February to May (Figure 5.1).

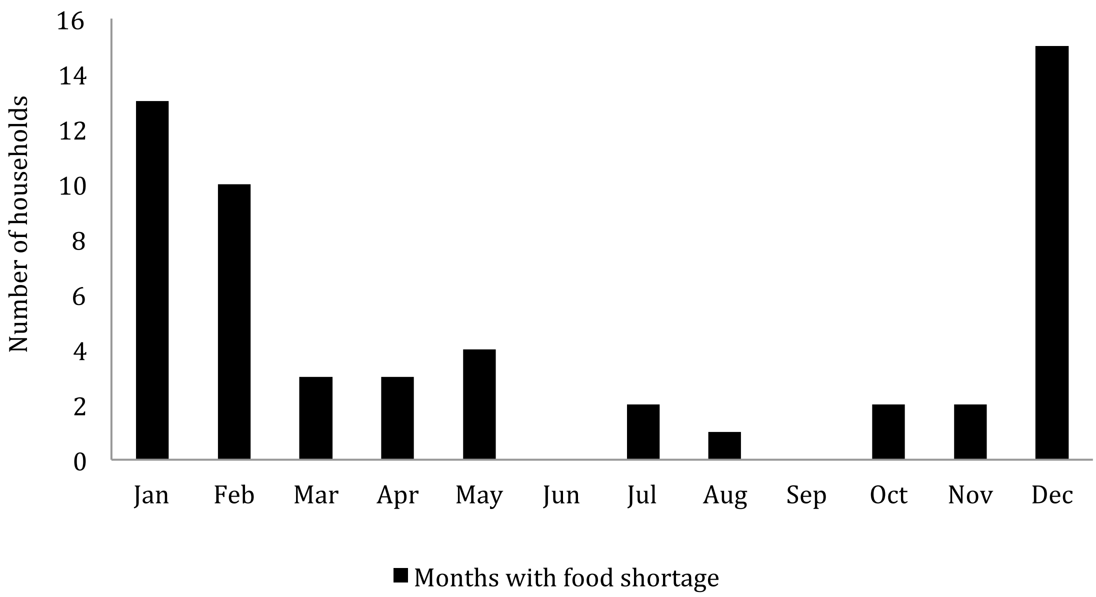


Figure 5.1 Number of times households reported food shortage by month for year 2014-2015. *n* =39, where n refers to the number of households.

At the time of the survey (November-April) the households stated that in the last month the number of days with food shortage ranged between 2-12 days, with an average of 4 days/month.

Determinants of 'Food Shortage'

The best model that explained 'Food Shortage' included three fixed effects variables: income from agriculture, education level and household type, and two random effects variables: 'village' and 'enumerator' (Table 5.5). The model selected based on MAM produced an AIC 245.3 (-13.1 from the original model).

Table 5.5 Generalised Mixed Effects Model of fixed effects variables and two random effects (village and enumerator) explaining food shortage with *n* households=408, *n* village = 13, *n* enumerator = 9. Only explanatory variables found to be significant in the minimal model are reported.

Term	Coefficient	*SE*	*F*	*p*
Intercept	2.495475	0.002032		
Agricultural Income	-1.1177	0.002031	4.917	<0.001
Household type (female v male)	0.737615	0.002031	4.677	<0.001
Education	-0.0656	0.002039	2.540	<0.001
σ^2 *intercept (village)*	0.6184			
σ^2 *intercept (enumerator)*	0.4374			

The results of the model show households with higher agricultural income and a greater number of years in education experience less 'Food Shortage'. The median agricultural income for households with food shortages is 0 INR per year (mean value is 7,725 INR per year) whereas for households with no food shortage the median agricultural income is 800 INR per year (average agricultural income 30,403 INR per year). The median number of years spent in education for households without food shortage is 12, whereas for households that experienced food shortages it is 10. In terms of household type, the model shows that female-headed households tend to be more food insecure than male-headed ones. 8% (24, *n*=297) of the male-headed households reported a food shortage compared to 20% (15, *n*=72) of female-headed households.

The model also shows that the two random effects were statistically significant in explaining a part of the variance. When the two random effects were plotted against 'Food Shortage' it was observed that the difference occurs from having 2 out of 9 enumerators that reported no food shortage and 5 out of 13 villages where no food shortages were reported. There is an overlap between the villages where no food shortage was reported and the 2 enumerators that did not report food shortages. This means there is a chance that 'Food Shortage' was either underreported or it does not occur in all villages.

When asked about the primary causes of food shortage in the household the most common response (*n*=39) was that insufficient money to buy food is the main reason (69.2% or 27 households), followed by incapacity to access loan (12.8 % or 5) and no family members to offer support (12.8 % or 5). Two households provided no answer. The strategies employed to cope with food shortage ranged from accessing loans (71.7%, n=28), decreasing costs or amount of food consumed (12.8%, n=5), relying on relatives' support (5.1%, n=2) and other strategies.

5.4.2.2 Food access - Food monthly budget of household

Out of the 408 households, there were 8 households that had missing data on the food monthly budget and 4 households that were removed from the analysis because their budgets were considered overestimated (over 6,600 INR per person per month) for the type of livelihood reported by the households.

The 'Food Monthly Budget' of a household varied between 500 INR per month and 22,870 INR per month with the median 5,000 INR while the monthly budget per capita varied between 250 INR per month to 6,472 INR per month with a median of 1500 INR. Compared to the minimum food security poverty line set at 441.69 INR per person per month for rural Tamil Nadu (Government of India, 2014), 20.4% (81 households) are food insecure.

Determinants of 'Food Monthly Budget'

The best model that explained 'Food Monthly Budget' included five variables: the size of agricultural and tea land, family size and caste group (Table 5.6). The MAM had an AIC = 514 or – 5 from original model and $R^2 = 0.44$.

Because the variance explained by the random effects ('village' and 'enumerator') are indistinguishable from zero a regular linear model was performed instead. In the model the log of 'Food Monthly Budget' was used given that it follows a log distribution.

Table 5.6 Linear Model of socioeconomic variables explaining the budget allocated monthly to food by households (*n* = 396). Only explanatory variables found to be significant in the minimal model are reported.

	Coefficient	SE	*p*
(Intercept)	8.422	0.092	< 0.001
Landholding Agriculture	0.069	0.025	< 0.01
Landholding Tea	0.089	0.026	< 0.001
Education	0.014	0.006	0.02
Family size	0.070	0.015	< 0.001
Caste (Scheduled Caste v Badaga)	-0.661	0.057	< 0.001
Caste (Scheduled Tribes v Badaga)	-0.548	0.089	< 0.001

The results show that there is a positive relationship between the amount of money spent on food and several of the indicators: the size of tea and agricultural land (Figure 5.2), as well as the number of years spent in education (Figure 5.3).

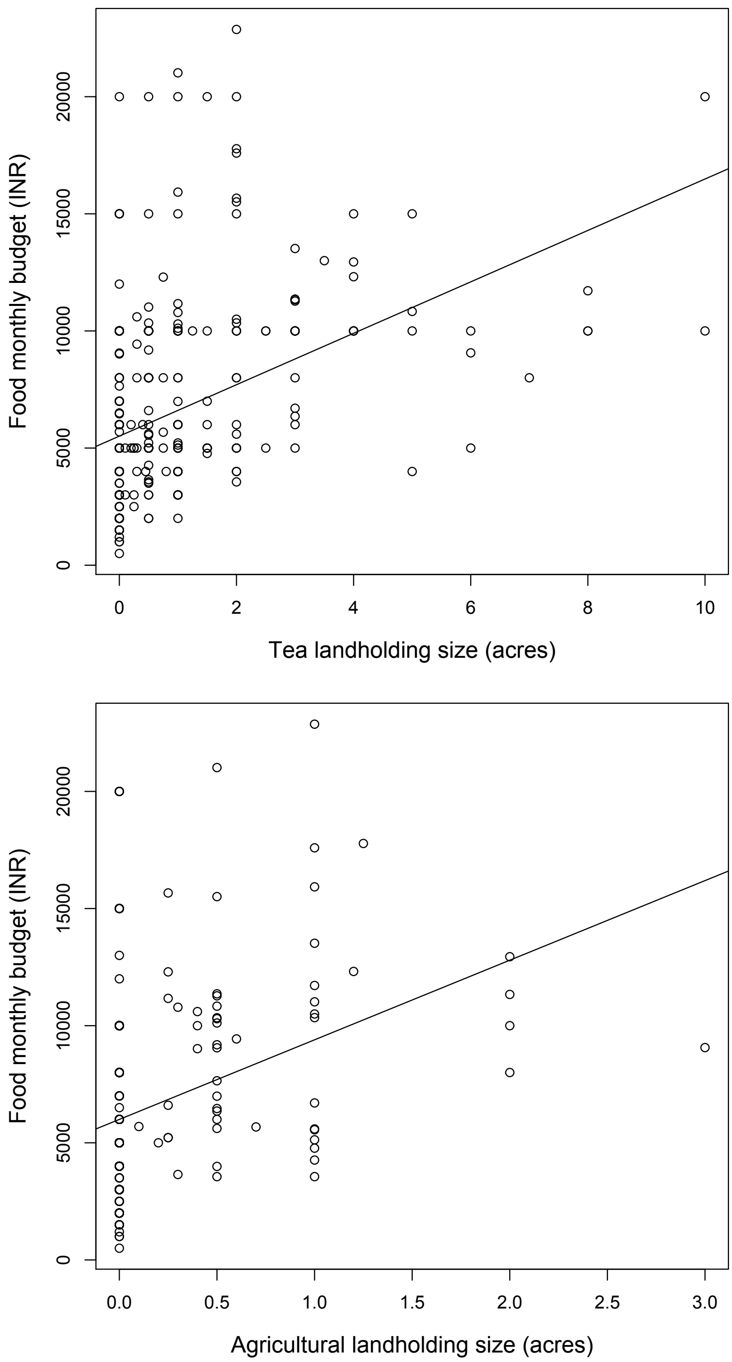


Figure 5.2 Scatterplot showing the relationship between the food monthly budget and landholding size (tea and agriculture); *n* tea landholdings = 186; *n* agriculture landholdings= 56

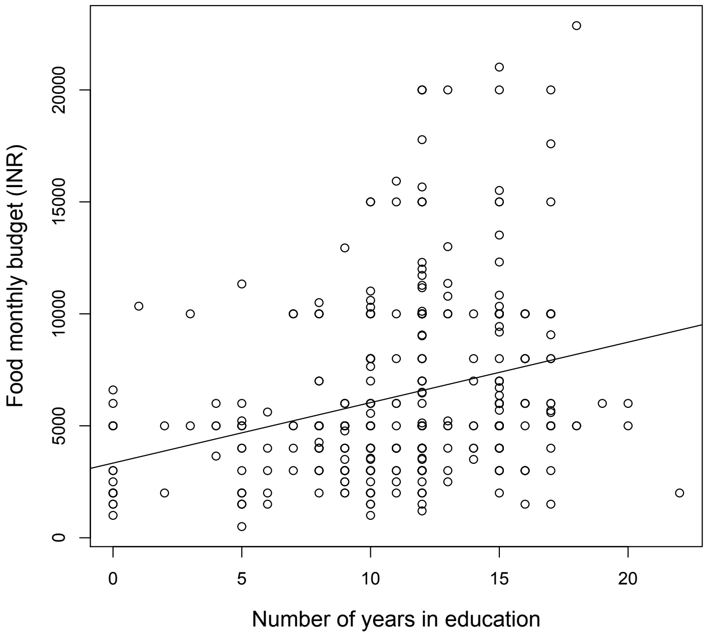


Figure 5.3 Scatterplot showing the relationship between the food monthly budget of the households and education level (*n*= 396).

There is also a positive relationship between the 'Food Monthly Budget' and the family size. However, as family size increases the 'Food Monthly Budget per Capita' decreases (Figure 5.4).

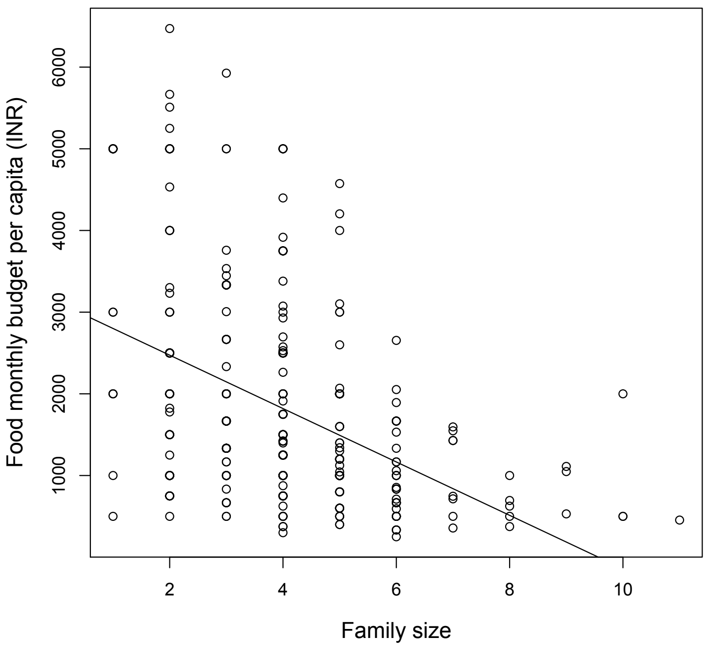


Figure 5.4 Scatterplot of food monthly budget allocated per capita by family size (*n*=396)

Finally, the model shows that both Scheduled Caste (median food budget 3,500 INR per month) and Scheduled Tribes (median food budget 4,000 INR per month) have a smaller budget allocated to food when compared to Badaga group (median 6,000 INR per month).

5.4.2.3 Food utilization: Food Consumption Score

The FCS household results varied between a score of 21 and a maximum of 99, with the first quartile at 39, the median value of 46 and the third quartile at 57.

The household with the lowest score had a diet that consisted mainly of carbohydrates/cereals (7 times per week), sugars (7 times per week) and fats (7 times per week). The household with the highest score declared that they eat from all food groups (including meat) almost every day. Households that were around the mean (with a score between 47-48) had a mixed diet consisting of all food groups (apart from meat). The most common foods consumed by these households were cereals (7 times per week), vegetables (almost all reported 7 times per week), spices, fats and sugars (7 times per week), milk and pulses consumption varied widely between households (between 1-5 times per week), whereas fruit consumption was very low in all households (predominantly less than 2 times per week).

Based on the FCS thresholds, households can be classified as having diets that are:

- Poor diet (≤23): 4 (0.9 %)
- Borderline diet (23.5-42): 112 (27.5%)
- Acceptable diet (> 42): 292 (71.6%)

The best model that explained 'FCS' (continuous variable) included four fixed effects variables: household type, caste group, distance to market and education and one random effect variable, 'enumerator' (Table 5.7).

Table 5.7 Generalised Mixed Effects Model of fixed effects variables and one random effect (enumerator) explaining Food Consumption Score with *n* households =408, *n* enumerator = 9. Only explanatory variables found to be significant in the minimal adequate model are reported.

	Coefficient	SE	*p*
(Intercept)	5.065	0.103	< 0.001
Household type (female v male)	-0.068	0.024	0.005
Caste (Scheduled Tribes v Badaga)	-0.134	0.046	0.003
Distance to market (between 2-10 km compared to > 10 km)	0.074	0.027	0.006
Education	0.005	0.002	0.01
Random effects			
σ^2 *intercept (enumerator)*	0.2140		

Results of the model show female-headed households have smaller FCS (median score = 43) than male-headed households (median score = 47). In terms of differences between castes, the model shows that the FCS is lower for STs than Badagas (median score = 43 and 52 respectively). Additionally, it shows there is no statistically significant difference in terms of FCS between other pairs of castes.

The FCS varies with the 'distance to market' variable and statistically significant differences occur between those that have a market within a 2-10 km range and those that travel over 10 km to get to a market. It appears that the further a household is to a market the larger the FCS. The median FCS value for households that are within 2-10 km is 44 and households that have to travel over 10 km have a median score of 55.

In terms of 'education' there is a positive relationship between the number of years spent in education and the food consumption score obtained by a household.

5.5 Understanding food security at household level

5.5.1 General findings

The total number of households that were found food insecure based on food access is slightly higher than the state average of 24.3% (Government of India, 2014-Rangarajan Committee). The households that take part in the PDS were found to exceed marginally the state average level, 91% (Government of Tamil Nadu, 2017). In both cases it can be concluded that the survey data is representative of the wide state.

5.5.2 Determinants of food security

The food security at the household level was shown to be influenced by capital, land assets, social factors and other variables (Table 5.8). The three components that measured food security: food stability, access and utilization were influenced by common variables or by variables that were unique to each component.

Table 5.8 Summary of the determinants of food security measured for three of its pillars (stability, access and utilization). Variables with a positive influence on food security are marked with '+' and those with a negative influence are marked with '-'. Categorical variables that influence food security are marked with '✓'. The total number of variables that influence one or several of the food security pillars is presented in the last column.

Variable	Food Shortage (food stability)	Food Budget (food access)	FCS (food utilization)	Combined
Economic factors (INR)				
Income (total)				-
Agricultural Income	(+)			1
Salary (off-farm Income)				-
Land Assets (acres)				
Landholding Agriculture		(+)		1
Landholding Tea		(+)		1
Social Factors				
Family size		(+)*		1
Education level	(+)	(+)	(+)	3
Caste		✓	✓	2
Household type	✓	✓	✓	3
Farm Production				
Number of trees grown				-
Cost of farming				-
Other				
Distance to Market			✓	1
Random Effects				
Village	✓			1
Enumerator	✓		✓	2

** As family size increases the amount spent on food increases but the spending per family member decreases.*

The two factors that affect food security across all three components are education and household type. The first variable, education, shows that the more the educated a household is the more food secure the household will be and vice versa. The results of this study are consistent with findings across India and other rural communities from around the world (Kaiser et al., 2003, Amaza et al., 2006, Idrisa et al., 2008, Makombe et al., 2010, Kumar et al., 2012, Bashir and Schilizzi, 2013, Asghar and Muhammad, 2013, Abdullah et al., 2017). The abnormality that occurs in the Nilgiris is that although it ranks as one of the most literate districts (see *Section 4.3.3.4*) it has the lowest Food Security Index (FSI) among the districts of Tamil Nadu (Government of Tamil Nadu, 2017). According to official data, the district has problems with respect to all components of the FSI: availability, access and absorption (utilization), but the first component is thought to weight the most in reducing the FSI. The

Human Development Report rationalizes that low availability comes from the Nilgiris having a hilly terrain and a cultivation regime mostly based on tea plantation cultivation and high value horticultural crops (Government of Tamil Nadu, 2017). These findings contradict the results of this study. Both at community and household level farmers reported food access to be the main problem, while food availability represented a barrier only for a small proportion of the households. As this study found contradictory evidence to official data a closer appraisal of the factors affecting food security across the Nilgiris may be justified.

The second variable, household type, manifests similarly in all three dimensions of food security. Female-headed households are less food secure compared to male-headed households. A lower FCS score could be explained by the difference in education. The level of education of women in the study population is significantly lower compared to that of men. Female education was previously found to be specifically important because food preparation and serving is done by women (Ramachandran, 2007, Asghar and Muhammad, 2013, Kassie et al., 2014). A lower food budget and a higher risk of food shortages in female-headed households could be explained by characteristics of the households resulting from civil status. Most of the female heads are widows, which have been associated with higher levels of poverty and food insecurity due to e.g. limited land rights or work opportunities (Drèze, 1990, Rao, 2006, Ramachandran, 2007, WFP, 2012). In better understanding food security in the Nilgiris, studies could thus benefit not only from incorporating aspects of education and household type, but also the civil status of the household head.

Caste affects two of the food security dimensions: food access and food utilization. Under food access Badagas have higher budgets allocated for food compared to Scheduled Tribes and Scheduled Caste. This is not unexpected given that Badaga communities are generally better-off than the other two caste groups (Government of Tamil Nadu, 2017). In terms of food utilization they have higher scores than Scheduled Tribes, but similar results to Scheduled Caste. Scheduled Caste have smaller budgets to purchase food than Badagas however as their diet includes meat consumption and Badagas doesn’t (for cultural reasons), the difference in the FCS is negligible. The outcomes demonstrate the importance of measuring the different dimensions of food security in the Nilgiris when comparing between the different communities, as underlying differences could be masked if only one of the food components was measured. Similar findings were reported in Eastern India where it was shown affiliation to ST or SC influences the food diversity scores (Parappurathu et al., 2015).

All the other variables, agricultural income, landholding agriculture, landholding tea, family size and distance to market affect only one of the dimensions of food security.

Agricultural returns influence food shortages. As the agriculture income increases the food shortage in the landscape decreases. The importance of agricultural income in explaining food shortages is probably linked to most vulnerable households relying more on farm revenues. Similar findings can be observed both in Asian and African countries where food shoratges have been linked to the success of agricultural years in farming households (e.g. Asghar and Muhammad, 2013, Muche et al., 2014).

Landholding size and family size influence food access. The budget spent on food increases with the landholding size, whereas the food budget per household member decreases with an increase in family size. These factors were found to be one of the most commonly identified determinants of food security across studies around the world (Feleke et al., 2005, Amaza et al., 2006, Kumar et al., 2012, Bashir and Schilizzi, 2013, Jones et al., 2014, Mango et al., 2014, Frelat et al., 2016, Abdullah et al., 2017).

The last variable, distance to market, was found to influence the FCS. Surprisingly, those households that are further away from markets have a higher FCS, which is opposed to findings of previous studies that looked at the implication of market access on aspects of food security (Ahmed et al., 2014, Mango et al., 2014). STs, living in forests are the furthest away from the markets. Those STs that own land have a higher food diversity given by reliance on diverse small subsistence farms and access to NTFPs. Previous findings report that one of the tribes surveyed (Kurumbas) do cultivate a diversity of food crops and wild fruits (FAO, 2014) which might explain this unexpected result.

5.6 Conclusions

This chapter illustrated the food security transition in the landscape of the Nilgiris and set the context for assessing the current determinants of food security at household level, measured as food availability, access, utilization, and stability.

Three pillars of food security (availability, utilization and stability) investigated using regression models, revealed that education and household type are common determinants of food security. Female-headed households are more food insecure in all measures of food security and education positively affects food security. Other factors that affect either one or two of the pillars are landholding size, agricultural income, family size and caste. In all cases they show expected outcomes that align with previous findings.

Distance to market was also found to influence food security, but this time in an unexpected way. The further the household is to a market the more diverse its diet is and vice versa. A possible explanation is the distinct farming practices and diets of tribal communities living in the forests.

Aspects of food security will be further analysed in the next chapters in the RPG (Chapter 6) and the ABM (Chapter 9).

PART III

Land use policies selection and testing

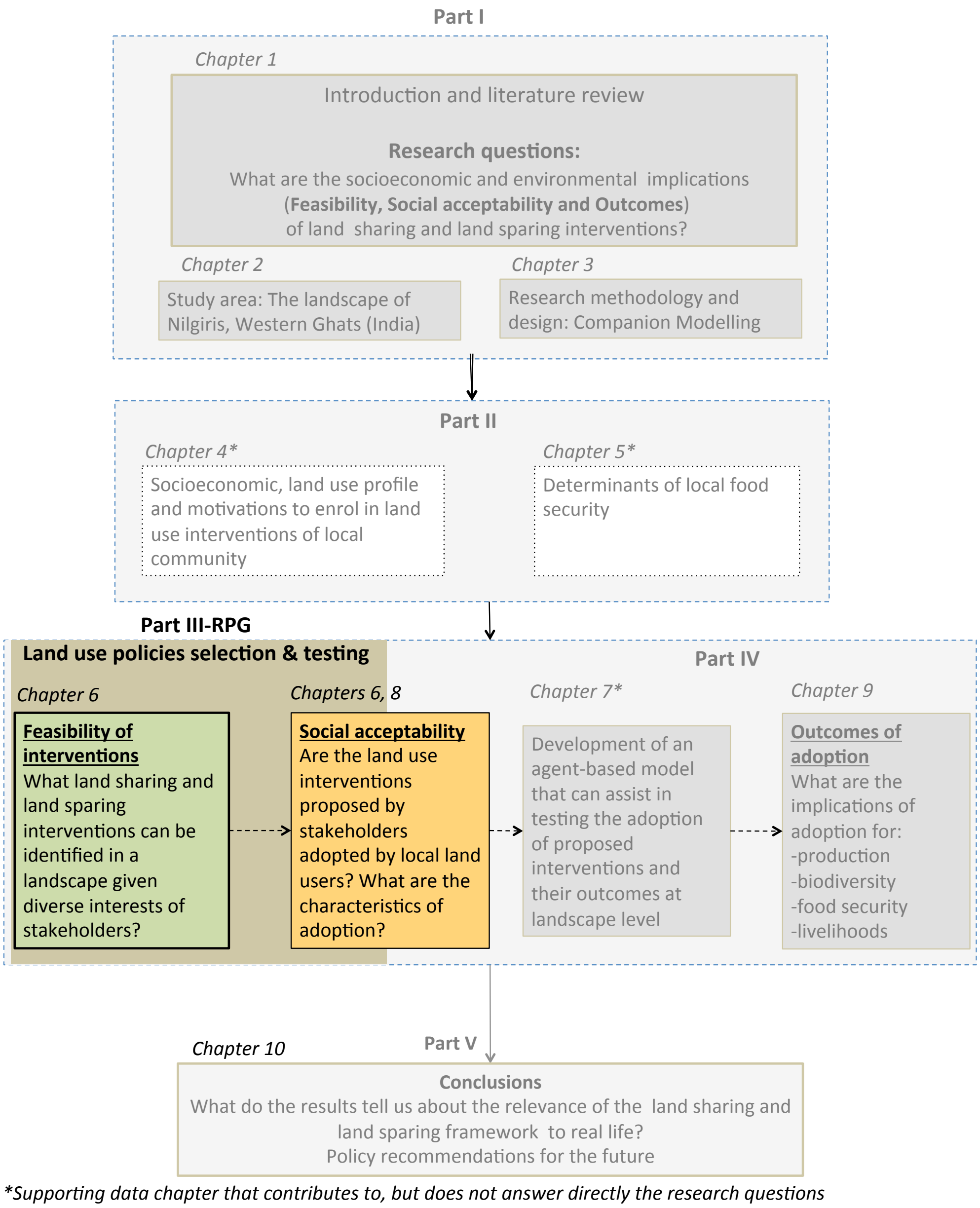


Diagram 1 Summary of research highlighting the questions addressed in Part III

Part II (Chapter 4 and 5) of the thesis set out the current socioeconomic, food security and land use profile of the study area using in-depth household survey and focus group data. The chapters further investigated farmers' land use decision-making processes and motivations to enrol in agricultural and conservation land use interventions. Chapter 6 of Part III uses a bottom-up participatory approach that looks at the structures and institutions, referred to as stakeholders, which can advance and implement such interventions.

The hypothetical uptake of the proposed interventions by direct land users is tested using a reality-grounded RPG developed with the stakeholders group. This allows for new insight into farmers' land use decision-making processes that can occur in the landscape as well as observing the socioeconomic and environmental implications of the policies tested. While Part II addressed the first loop of the ComMod process, this part addresses the second loop. The decision-making processes observed in the RPG are further used to inform the development of the ABM in the last ComMod loop presented in Part IV. While the RPG provides insight at micro level (household level) over a 10-year period the ABM allows the scaling up of results at macro level (landscape level) over decades.

Chapter 6

The elaboration of land use policies grounded in local realities and their *ex ante* assessment using a role-playing game

6.1 Introduction

In areas of research where policy decisions can greatly impact biodiversity conservation outcomes, testing and observing their consequences before they are implemented enables decisions to be grounded in local realities (e.g. Washington-Ottombre et al., 2010, Gourmelon et al., 2013, Garcia et al., 2013, Salvini et al., 2016, Travers et al., 2016). In the debate around balancing food production and biodiversity conservation such an approach is very promising and is particularly relevant for the LS/LS framework. Proponents of the framework have endorsed multiple possible implementation mechanisms of the land use strategies (see *Section 1.4.1*). Yet, there is a lack of evidence regarding their feasibility on the ground, given the diverse interests of local stakeholders (Mertz and Mertens, 2017). Nor is there evidence about the socioeconomic implications of implementing them (Fischer et al., 2014). Advancing such policies without considering the local realities, the social acceptability of the interventions or the implications for local livelihoods could act eventually in the detriment of biodiversity and people (Kremen, 2015, Robbins et al., 2015).

A key challenge in linking the scientific outcomes, including those of the LS/LS debate, and policy is allowing stakeholders to interact directly with analytical and conceptual representations of human and natural systems (CGIAR, n.d.). RPGs are equipped to fill that need and to allow building on collective exploration of possible policies in a participatory and inclusive manner. A RPG is an exercise that directly engages participants in working to solve a realistic but fabricated challenge with the intent that they learn new material or approaches (Rumore et al., 2016). RPGs have been shown to be effective for conveying complex information, teaching skills and fostering mutual understanding and creativity in the context of policy-making (Dolin and Susskind, 1992, DeNeve and Heppner, 1997, Mayer, 2009). They have the ability to: immerse people in realistic situations that they have not yet confronted, to help people handle unprecedented and complex situations, and provide people with an opportunity to experiment in a low-cost environment (de Suarez et al., 2012, Jones et al., 2013).

In the context of the current research the RPGs are not only important for creating this negotiation space for stakeholders. Identifying land use policies interventions deemed viable by stakeholders does not necessarily or automatically lead to legitimacy and support of policies (e.g. Korfmacher, 2001). *Ex ante* assessment of how potential adopters might respond to them is valuable to understand if the policies are going to be accepted and under what conditions. By using RPGs such assessments could be conducted and decision-making processes that arise from testing of polices could be observed and documented (Travers et al., 2016). Therefore, this chapter describes the co-development, with the local stakeholders, of a RPG that acts as a platform for collective exploration of possible land use policies and then enables the pre assessment of these policies with direct land users. In doing so, the chapter aims to answer the following questions:

> **Q1:** What are the plausible mechanisms through which the land use policies could be instituted in the landscape given diverse interests of stakeholders?
>
> **Q2:** Are the land use policies adopted by direct land users? If, so what land use and livelihoods decision-making processes emerge in the RPG?

6.2 Data and Methods

The overarching methodology of this chapter follows the Companion Modelling approach detailed in *Section 3.5*.

The RPG was designed to be played on a table-top that represented the local environment and the farms. It was played by real farmers who take decisions on how to manage their farms and livelihoods under two scenarios: business-as-usual and with land use policies implemented in the landscape (further details are provided in *Section 6.3.1.4*). This section introduces the methods of data collection used in the selection of feasible land use interventions that meet stakeholders' interests, and the co-development of the role-playing game with the stakeholders (*Section 6.2.1*). It then describes the methods used in the implementation of the RPG (*Section 6.2.2*).

6.2.1 Selection of land use interventions and development of the RPG

The land use polices and the RPG were co-constructed with the support of stakeholders and followed a step-wise approach (Table 6.1; see *Section 3.5.1* for justification of methods choice). The RPG was designed for direct land users from the 6 Badaga villages (Denadu, Kercombai, Nedugula, Milidhen, Kaggula and Sundatty). The role of stakeholders was central because they provided expertise, local insight and validated basic assumptions about the dynamics, about the history and patterns of both the natural and socioeconomic systems, central to the development of the RPG conceptual model.

Table 6.1 Data collection methods used in the selection of interventions and the development of the RPG

Phases/Aim	Type of data	Method of collection
Phase 1. Selection of core stakeholders that will support the development of the RPG		
1. Create a list of the potential stakeholders involved in land use decision-making	Qualitative	23 key informant interviews: Horticulture Department (2 officials), United Planters Association of South Indian –UPASI (2 officials), Forest Department (2 officials), Tea Board (1 official), Hill Area Development Programme-HADP (2 officials), Village Panchayat (6), Collector's Office (1 official), Auction Centre Conoor (1 broker), Farmers from Badaga Villages (6 community leaders)
2. Map the power and influence of the stakeholders over decision-making	Qualitative	Six community leaders that interacted with all the stakeholders listed above took part in a one-day workshop during which they had to classify the stakeholders based on two criteria: impact and power. The first criterion refers to the impact of their action on the way the land is used by farming communities and it has three levels: direct/moderate/limited. Power refers to how much they can influence the way in which land is used in the landscape and it has four levels: low/intermediate/significant/high. For example, an institution can have a direct impact through its land use policies but a low enforcement power leading to an insignificant change in the way people take decisions about land-use. Once the institutions were mapped, 9 key informant interviews were carried with representatives from all institutions/stakeholder groups to validate the results.
3. Selection of relevant stakeholders for co-development of RPG	Qualitative	Due to time, financial and management constraints it would have been difficult to engage in the RPG exercise all the stakeholder groups. Hence, it was decided to work only with those stakeholder groups that ranked as having a significant/high power and a direct/moderate impact on decision-making. For clarity and simplification, in this chapter, I will refer to the stakeholders' group as the Working Group (WG). The specific members of the WG were selected based on the suitability and fit within the project as per the guidance of the heads of relevant departments.
Phase 2. Defining the question to be answered by the RPG		
	Qualitative	Two one-day workshops were organised with the selected stakeholder groups to discuss the aim of the research and the main research questions that need to be answered through the RPG.
Phase 3. Collective construction of the RPG conceptual model		
	Qualitative	4 preliminary meetings (with Tea Board, UPASI, Horticulture Department and Farmers' group) and 1 one-day workshop during which the WG worked collectively to build the conceptual model of the RPG based on the ARDI method (Etienne et al., 2008). ARDI is a method to elaborate a domain model of socio-ecological interactions at work, in a given human ecosystem (ComMod School, 2014). It aims at facilitating stakeholders' involvement in the designing stage of the modelling process by asking them to discuss and debate around four main questions: i) who are the

		actors involved in the matter, ii) what are the key resources involved, iii) what are the main processes involved, and iv) what are the interactions between the actors and the resources. The expected outcome is a diagram showing all this information.
Phase 4. Selection of land use policies to be tested in the RPG		
1. Selection of policy tools and specific land use interventions *(Continues on next page)*	Qualitative	During this phase proposals were made by the WG regarding policy tools and specific interventions/agri-environmental schemes to be tested. The policy tools and interventions proposed by the WG had to fulfil a set of criteria: • Enhance agriculture (e.g. soil fertility/yields) • Improve on-farm/protected areas' biodiversity • Be feasible for the landscape considering social, economical, environmental and political realities including the capacity of the institutions to deliver the interventions • Provide technical or financial support • Have the support of the relevant stakeholders The selection method followed consecutive steps: a. The researcher first proposed a list of different policy tools that was sent to the WG members to further expand it and to provide feedback. The list was based on policy tools that resemble those proposed by Balmford et al., 2015 and Phalan et al., 2016. b. The WG deliberated the policy typologies and those found unfeasible were eliminated; c. For each of the selected policy typology the WG proposed a set of specific interventions referred to as schemes. During this process the WG considered preliminary results from the individual household surveys in which farmers were asked under what conditions would they take part in such schemes (results presented in *Sections 4.3.7.3 and 4.3.7.4*). d. The WG eliminated some of the proposals considered unfeasible e. Final schemes were selected during a one-day workshop
2. Collect data on information necessary to complete the RPG	Quantitative	48 household surveys with community representatives assessing the minimum levels of incentives that will motivate farmers to enrol in agri-environmental schemes. 8 surveys in each of the following Badaga villages: Denadu, Kercombai, Nedugula, Milidhen, Kaggula, Sundatty
Phase 5. Designing the RPG		
Decide components of the RPG	Qualitative and quantitative	RPG developed using data from 265 Badaga in-depth household surveys (first ComMod loop), conceptual model developed with stakeholders (Phase 3) and land use policies selected (Phase 4). More details about the sources of data are given in the results section. One-day workshop with WG to deliberate the draft version of the RPG and agree on final version.
Phase 6. Testing and calibration of the RPG		
	Qualitative	3 workshops to test the RPG followed by feedback forms and debriefing sessions to discuss if the RPG is realistic and how it can be improved. Six different players were invited to each session. They were all farmers and belong to Badaga caste. Stakeholders belonging to the WG participated in these sessions to allow for feedback and input. Each session had three steps: a briefing, a game session and a debriefing. Workshop Villages: Denadu, Kercombai, Sundatty

It is important to note that ideally the participatory modelling exercise would have been carried with the same stakeholder representatives at all times and institutions would have attended all the group meetings. However, this was challenging to implement when dealing with so many institutions from distinct townships. Thus the project had to accommodate that by either allowing stakeholders to express their point of view in an individual meeting if they couldn't attend the group session or by asking the institution to find a temporary substitute if that was possible.

6.2.2 Implementation of the RPG

Implementation of the RPG refers to organising and running the RPG sessions with the local farmers. The aim was to organise the RPG in all 6 Badaga villages surveyed in the first ComMod loop. Ultimately five RPG workshops were carried with Kaggula village not being included due to issues with the availability of farmers, venue facilities and time management limitations. The workshops were organised in village community halls and lasted between one and two days. More details about the game setup are given in *Section 6.3.1.4*. Data for the indicators measured in the RPG (Table 6.2) were collected using several forms that the players filled at every stage of the game (see *Section 3.5.2*).

Table 6.2 Data collection methods used in analysing the RPG results

Indicators	Type of data	Indicator/method of collection
A. Social indicators		
Scheme uptake	Quantitative	Number of players measured by: a) the total number of schemes they enrolled in (e.g. no scheme, all schemes) and b) scheme type; Total area enrolled in schemes: a) by scheme type, and b) over time;
B. Land use change		
Land use change	Quantitative	Land use change over time by land use type at landscape level; Land use size by land use type in absolute and percentage values in the first and the last year of the RPG.
C. Environmental changes		
Number of trees in the landscape	Quantitative	Total number of trees by scheme type at the end of the game;
Connectivity of patches spared for conservation	Quantitative	Size of clustered patches spared for conservation resulting from scheme uptake, measured at the end of the game;
D. Production		
Production	Quantitative	Total numbers of farms that experienced an increase or decrease in production as a result of scheme enrolment
E. Economic processes and indicators		
Financial shortages and adaptive livelihoods strategies	Qualitative and quantitative	Total number of players (absolute number and percentage) that experienced financial shortages throughout the RPG. Processes that occurred in the RPG to overcome financial shortages.
Land use and livelihood strategies for years with positive balance	Qualitative and quantitative	Processes that occurred in the RPG when farmers finished the year with a positive balance
F. Food security		
Proportion of food retained for HH consumption	Quantitative	Distribution of food retained for household consumption
Food budget	Quantitative	Changes in food budget over time.
G. Other processes of interest		
Decision-making mechanisms on the farm	Qualitative and quantitative	Processes that occurred in the RPG regarding how many seasons crops were grown for
H. Feedback forms	Qualitative	Using multiple-choice questions farmers were asked about the complexity of the game, the level of entertainment and if they felt that the type of land use decision-making in the RPG was similar to the practices employed on their own farms.

Most of the indicators in Table 6.2 were analysed using descriptive statistical methods (see *Section 3.5.2*).

The next section (*Section 6.3*) presents the outcomes of selecting plausible interventions that meet stakeholders' objectives and the development of the RPG (*Section 6.3.1*) following the six phases presented in Table 6.1. It then goes on to present the outcomes of the RPG sessions (*Section 6.3.2*) based on the metrics in Table 6.2. The sections are then followed by the interpretation of results (*Section 6.4*).

6.3 Results

6.3.1 Selection of land use interventions and development of the RPG

6.3.1.1 Phase 1. Results of core stakeholders selection

The nine stakeholder groups, that can directly or indirectly influence land use decision-making and are relevant for the development of plausible land use intervention and of the RPG, are:

- The Horticulture Department regional office (state institution)
- The Forest Department (state institution)
- UPASI (association founded in 1893 that supports planters by providing scientific research on e.g. crops, pests, soil or market intelligence)
- The Tea Board (regulatory body for cultivation and promotion of tea with an experience of over 100 years)
- The Hill Area Development Programme (institution regulated by India's Union Planning Commission that offers supplementary financial assistance for preservation, protection and enrichment of bio-diversity in Nilgiris)
- The Village Panchayat (local council)
- The Collector's Office (regional council)
- The Auction Centre Conoor (brokers' regulated market for tea)
- The Farmers from Badaga villages

The stakeholders map of power and influence over decision-making (Figure 6.1), as per the vision of community members and then validated by stakeholders, shows that in almost all instances the two groups agreed with the classification. The exceptions are the Horticulture

Department and the Collector's office, which considered that they have a higher power in influencing decisions, while the Forest Department considered the opposite.

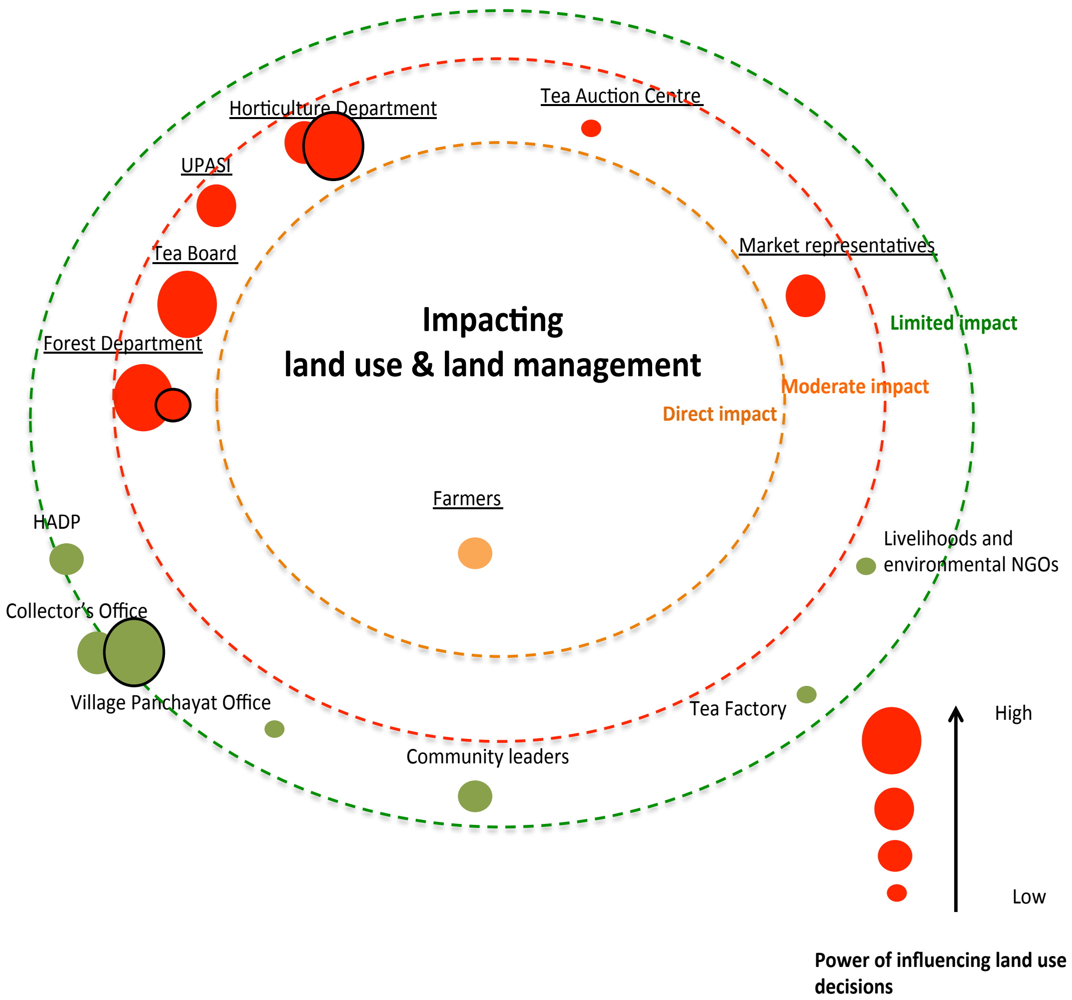
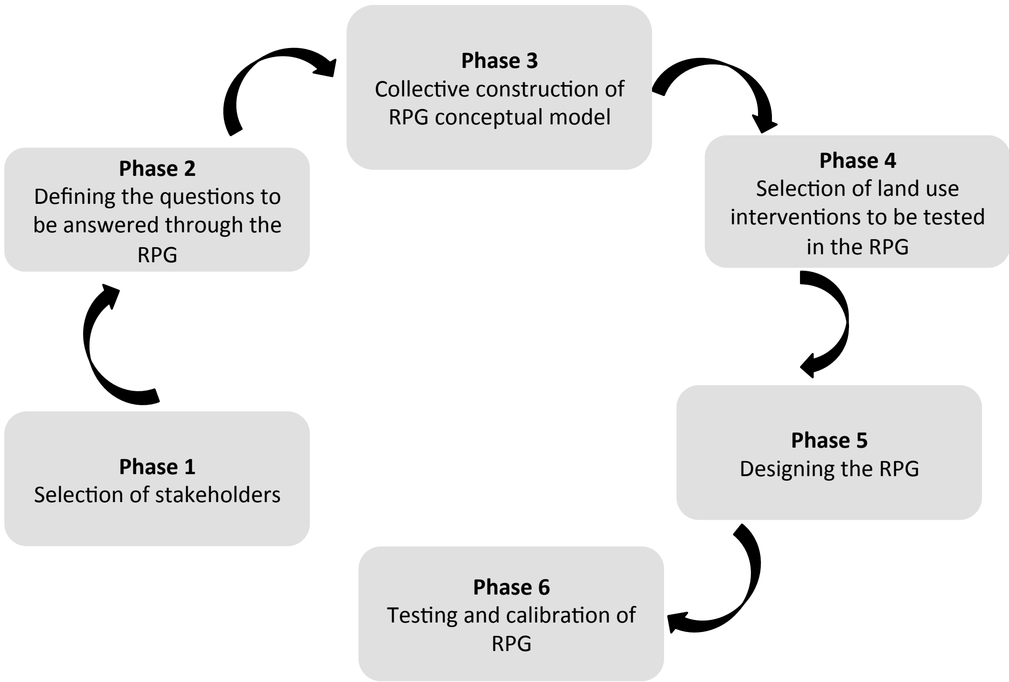


Figure 6.1 Mapping stakeholders' power and impact on land use and land management.
Dashed ovals represent the limits between the three levels of impact a stakeholder can have on the way the land is used and managed (direct/moderate/limited). The solid circles show where the stakeholders are placed within these categories. The variation in size represents the power of each stakeholder in influencing land use decisions with the level of power proportional to the size of the circles. In three instances the same institution was perceived as having different levels of power, the circles without a border represent the community members' perception, whereas the ones with a border represent the view of the stakeholder itself.

The five stakeholder groups selected to take part in the RPG project based on their power and impact results, were: the farming community (direct land users), UPASI, Horticulture Department, Tea Board and the Forest Department. Though Auction Centres and the market representatives have a moderate impact on land use decision processes, they respond to the wider national and international market. As a result they were not included in the central stakeholders' working group. The study relied instead on statistical data about the trends and changes on the market.

The final Working Group (WG) was formed of 11 members: myself, one member from each of the four institutions: UPASI, Horticulture Department, Tea Board and Forest Department and 6 representatives of the farmers' group. It was important to have more farmers represented because they are the players and the main beneficiaries of the land use interventions tested in the RPG. The involvement of stakeholders in each phase of the RPG development is presented in Figure 6.2.



Stakeholders	Engagement of stakeholders in the development phases					
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Researcher						
Farmers						
UPASI						
Horticulture Department						
Tea Board						
Forest Department						

Figure 6.2 RPG participatory modelling phases and the engagement of stakeholders in their development

6.3.1.2 Phase 3. Collective construction of the RPG conceptual model

The conceptual model that resulted from the workshop and independent meetings with members of the WG is represented as a diagram. Throughout the research project the conceptual model was constantly updated and in most instances optimized to include only the most essential information. Below it is presented the final version that supported the development of the RPG (Figure 6.3).

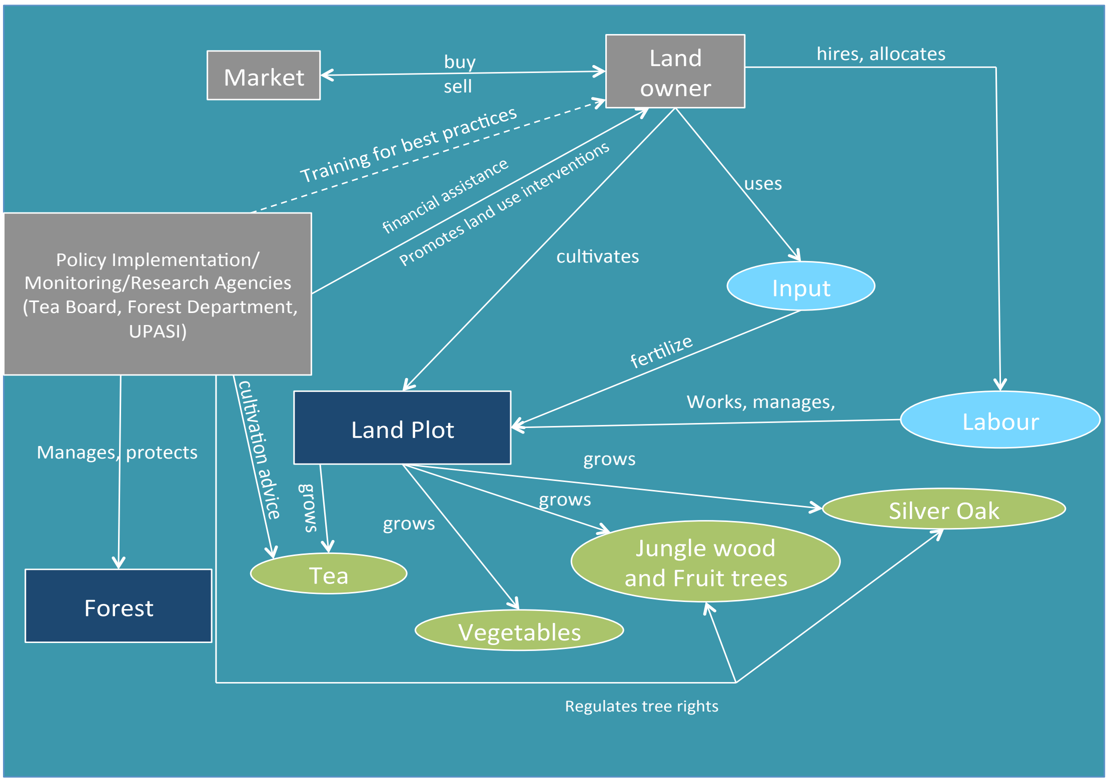


Figure 6.3 Conceptual model diagram showing the main stakeholders in the landscape, represented in grey. Arrows are associated with verbs that describe the type of action or symbolize the interactions between stakeholders and different resources (in dark blue, light blue and green), or among stakeholders. This diagram served as a support for the design of the RPG and was inspired by the work of Garcia (2014).

There are three main agents that can take or influence decisions: Land Owners (farmers), the Market and the different agencies operating in the landscape. These agencies were grouped under one category, referred to as the Agency. The farmers own and take decisions about:

i) What to cultivate on their land plots - tea, vegetables and exotic trees (Silver Oak) or native trees referred to as jungle wood and fruit trees, and

ii) The quantity of inputs (fertilizers, pesticides) and labour they can afford to use.

The markets have an internal mechanism to establish the price of different crops. The agency has two roles, they: own forest so they regulate and protect the state forests and tress on private farms and offer advice and financial support to farmers to enhance production.

6.3.1.3 Phase 4. Selection of land use policies to be tested in the RPG

To initiate discussions around potential land use interventions the researcher proposed a typology of policy options that was shared with all the stakeholders. Individual members of the WG submitted a total of forty-five: i) comments and proposed changes to the initial policy mechanisms, and ii) specific schemes for the selected policy mechanisms that they wanted to discuss with the rest of the stakeholders.

To avoid power imbalances this stage involved individual discussions with the different stakeholders. The information obtained from stakeholders was centralised in a document and shared during a one-day workshop with all stakeholders. During the workshop I introduced the proposals along with their strength and weaknesses as highlighted by the different parties. Each proposed policy mechanism introduced was followed by a deliberation session that lasted a maximum of 45 minutes and each party was given the chance to express its views. Two assistants took notes and presented the main outcomes on flipcharts. In almost all instances there was unanimity in terms of accepting or rejecting a policy. A vote was conducted in one instance to understand whether the policies should be advanced or rejected.

Of the final list of policy mechanisms that was proposed for deliberation between all members, the stakeholders found plausible only one (Table 6.3).

Table 6.3 Selection of proposed policy tools by the WG and their reasons for and against the policies

Proposed policy mechanisms	Selected	WG's reasons for rejecting or accepting the policy tool
Market-based approaches		
A. Payments for ecosystem services linked to international markets such as REDD+	No	**Main reasons for rejecting:** -"No clear property rights in the area" (Farmers' Group) -Negotiations between the participants of the ecosystem service market can be affected by "unequal bargaining power; there can be cases where buyers are exploiting their position to the detriment of the providers' interest" (UPASI) - PES might lead to "further concentration of wealth and to excluding poorer land users from the land they have been using in order to capture PES" (Tea Board) -" Are there experts in the area that can assess and monitor ES?" (Concerns shared by all stakeholder groups) -"Volatility of payments" referring to the value of PES may vary significantly over time (Horticulture Department)
B. Economic incentives (not linked to international markets) Farmers get support to enhance agriculture as a condition to conserve nature on their farms	Yes	**Main reasons for supporting the policy:** -Reward farmers that conserve biodiversity on their farms by providing technical support to enhance yields or/and by giving monetary incentives (Tea Board and Horticulture Department) -The institutional infrastructure is available to support such schemes -"A better distribution of wealth is expected " (Farmers) -"Brining know-how to farmers" (UPASI) -Several schemes can be proposed and farmers can choose the one that suits them best (Forest Department, Farmers' Group and UPASI) -One main concern raised was that "problems can occur with sustainability of funds" (Tea Board)

Land use zoning		
A. Creating protected areas to conserve forests or conserve primary forest on individual farms.	No	**Main reasons for rejecting:** -"The existing forest is already under the protection of the Forest Department" (Forest Department) -"It targets a small number of farmers; less than 1% of the farmers own forest" (Horticulture Department) -"This measure can be of interest in a later stage once there are farms that have forests" (Tea Board)
Certification		
Certify tea farms that use more wildlife friendly farming practices	No	**Main reasons for rejecting:** -"The income from certified products is higher but farming practices are more labour intensive" (Farmers' Group) -"It is not easy to comply to certification regulations and it can take a long time before a farm is certified" (Tea Board offered the example of the neighbouring district, Gudalur) -"Connecting to the market is not easy" (Horticulture Department and UPASI discussing about the cases of the few farmers that have certified lands) -"There is no fixed price which means that in some years farmers may end up with loss " (UPASI)
Reverse auctioning		
Farmers bid for contracts for environmental management projects	No	**Main advantages and disadvantages:** -This tool was intensely debated and there was disagreement between WG members, those in favour argued that farmers get to choose activities that they have specific interests in, instead of choosing from a prescriptive list of one-size fits all options, whereas the opponents reasoned that such schemes are currently too advanced for the local communities and concerns were raised over the potentially high transaction costs and the level of expertise needed to support a diversity of schemes; Because one of the conditions for the policy tool to be approved was to have the support of all the relevant institutions the policy tool was rejected. Nevertheless the stakeholders decided to consider it in the future, in a second stage of policy implementation, provided the economic incentives interventions selected proved successful.

In the next step, the stakeholders' group participated in a one-day workshop that resulted in the proposal of specific economic incentives interventions to be tested in the RPG (Table 6.4). In the first phase of the workshop the stakeholders were divided into three teams and were asked to propose interventions that were further expanded upon and deliberated by all stakeholders in a second stage of the workshop. There were several variations of the same scheme. Given the limited time and resources for testing the interventions the stakeholders prioritised only one form of the intervention. All stakeholders were then given about 15 minutes each to think and add any comments or questions. The final selection of the interventions was done based on stakeholders' agreements and in a small number of cases using a vote system. Finally, individual discussions were held separately with each stakeholder to ensure their view was accurately represented. Stakeholders were satisfied with the outcomes and they did not want to make any changes before trialling the interventions in the role-playing game.

Table 6.4 Selected economic incentives schemes

Schemes Description	WG's arguments for selection	WG's comments
Scheme A. Wildflower meadows		
Farmers get support to enhance agriculture (increase yields) as a condition to set aside land for native grasslands in form of wildflower meadows	-This scheme has the potential to enhance soil fertility by leaving land on the farm uncultivated (UPASI raised concern about the "drastic decline" in soil fertility in the last 20 years) -The scheme has the potential to increase grasslands which are becoming increasingly scarce (Forest Department) – see *Section 2.4.4* for historical decline -Pollination was highlighted as a conservation problem and the scheme has the potential to mitigate the negative effects of agriculture on pollinators (Horticulture Department, UPASI) -Attracting birds means better pest control (Farmers' Group) -Higher yields allow farmers to leave some land uncultivated (Horticulture Department) - The use of inputs is limited by the household income from previous years, supporting the farmers will be beneficial for agriculture (Farmers' Group)	-Financial incentives should be given to farmers who spare land (Farmers' Group) -The value of incentives should be fixed for all farmers and it should be at a level that compensates for not using the land for agriculture (Horticulture Department, UPASI) -This scheme should allow farmers to enrol or come out at any time (Forest Department) -The scheme can be applied for how many years the farmer decides to (Farmers' Group)
Scheme B. Forest plantation		
Farmers get support to enhance agriculture as a condition to spare land for trees	-It has the potential to increase water reservoirs on the farm (Forest Department, Farmers' Group) -It decreases the pressure on the protected forests (Forest Department) -The use of inputs is limited by the household income from previous years, supporting the farmers will be beneficial for agriculture (Farmers' Group) -Those who are not in favour of jungle wood/fruit trees can decide to grow exotic tree species (but they need a special permit from the Forest Department); while the department acknowledged that jungle wood is more valuable for conservation, excluding those who are only in favour of exotic tree species will be ultimately at the detriment of biodiversity by increasing the pressure on protected forests -Farmers can generate extra income by selling timber or commercialization of fruits from the fruit trees planted (UPASI, Horticulture Department) -Mulch can be used as fertilizer (UPASI) -To ensure that farmers continue to maintain the forest on	- Financial incentives should be given to farmers who decide to spare land for trees (Farmers' Group, Forest Department) -The value of incentives should be fix for all farmers and it should be at a level that compensates for the agricultural loss/wildlife disturbance (discussed by all group members) - As a measure of forest protection once the farmers enrol in the scheme, they will have to participate for a minimum of 25 years; withdrawal at any time earlier than that attracts compensation fees (FD)

Continues from previous page	their land a financial bonus should be given every 3 years (Forest Department) - Having a tree logging quota on the farms instead of asking for tree felling permits from Forest Department can be a positive incentive to plant and maintain the forest (Farmers' Group)	
Scheme C. Tree intercropping		
Farmers get support to enhance agriculture on their farm as a condition to intercrop more trees	-There is water scarcity in the study area so the scheme has the potential to increase water reservoirs on the farm (Forest Department, Farmers' Group) -It decreases the pressure on the protected forests (Forest Department) -The use of inputs is limited by the household income from previous years, supporting the farmers will be beneficial for agriculture (Farmers' Group) -Those who are not in favour of jungle wood/fruit trees can decide to grow exotic tree species, but only with special permits (Forest Department) -Extra income can be generated from commercialization of fruits from the fruit trees planted (UPASI, Horticulture Department) -Mulch can be used as fertilizer (UPASI)	- Financial incentives should be given to farmers who decide to intercrop more trees on their farm (Farmers' Group) -The value of incentives should be fixed for all farmers and it should be at a level that compensates for the agricultural loss/wildlife disturbance (discussed by all group members) -Once the farmers enrol in the scheme, they will have to participate for a minimum of 25 years; withdrawal at any time earlier than that attracts fines -Bonuses should be given for landscape connectivity of the lands under one of the schemes (Forest Department)
Bonus: The stakeholders considered the value of biodiversity conservation can increase if farmers receive bonuses for connecting the areas of land enrolled in any of the two schemes that spare land for conservation on the farm (Schemes A and B).		
Note: Stakeholders' discourse revolved around how agricultural practices of the last century related to conversion of wetlands and forests, over-grazing, excessive use of pesticides and synthetic fertilizers, soil degradation and erosion and lack of organic material inputs led to unsustainable agricultural practices that are already reflected in yield penalties. As a result intensification under scheme A and B should only be promoted in a way that doesn't contribute to these downward spiral.		

Out of the three agri-environmental strategies proposed for testing in the RPG, two incentivise segregation of nature and food production: Wildflower Meadows (Scheme A) and Forest plantations (Scheme B). The third scheme incentivises integration of the two on the farm, Tree Intercropping (Scheme C). What is of particular interest is the way the stakeholders set up the first two interventions, Wildflower Meadows and Forest plantations. More specifically stakeholders considered that enrolment in any of the two interventions leads to an automatic increase in production coupled with the protection of biodiversity. One doesn't happen without the other, one assumes the other. The decision to test the interventions following this assumption prevents situations such as corruption and free-riding to manifest. For example, corruption could manifest when farmers are claiming financial benefits without taking measures to increase production or setting aside land for conservation. Free-riding could occur when farmers are not setting aside land for conservation but using ideas about how to improve productivity by learning from farmers that enrolled in interventions. In a land sparing context this assumption has major implications for both productivity and biodiversity conservation. In their current form these two interventions lead to an optimal land sparing outcome. In reality corruption and free-riding are important aspects that will need to be factored in to obtain a more accurate representation of the outcomes of the interventions and their potential dangers.

All of these schemes are a mix of incentives under the second and third category of land-use interventions (*Economic incentives and Strategic deployment of technology, infrastructure and knowledge*) as identified by Phalan et al. (2016). Whether the interventions represent forms of land sharing or land sparing is discussed in *Section 6.4.1*.

Scheme incentives

The minimum level of financial incentive per acre of land that would motivate farmers to take part in the schemes varied between the three schemes (Figure 6.4).

The majority of respondents felt that an incentive of a minimum 50,000 INR per acre of land would motivate them to enrol in Schemes A and C, whereas over 80% of respondents considered that Scheme B should start at a minimum of 60,000 INR per acre.

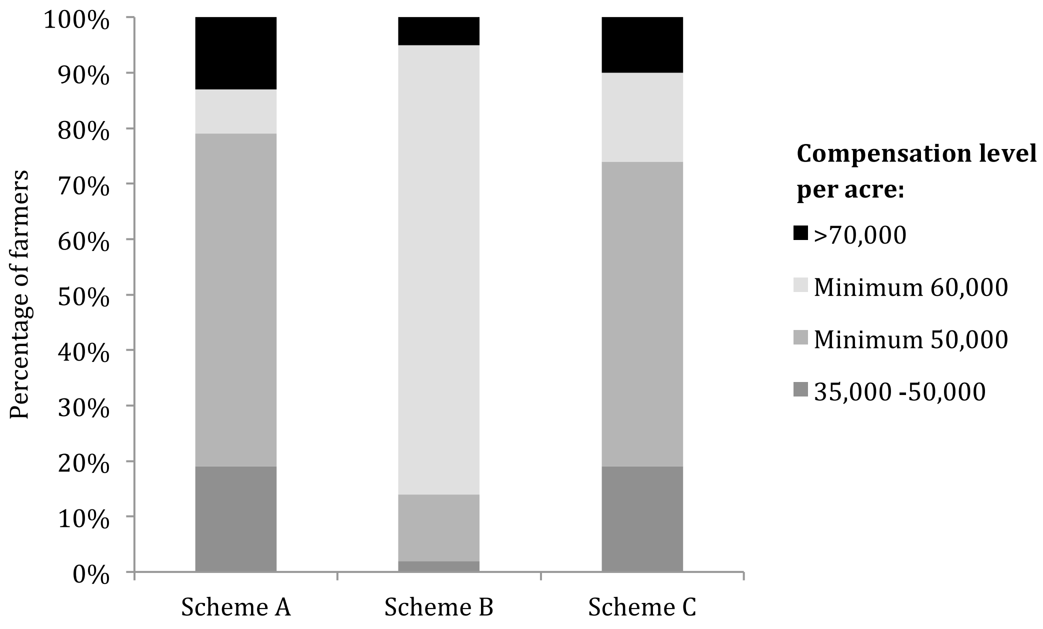


Figure 6.4 The proportion of farmers interested to join Scheme A, B, C by minimum compensation levels (*n*=48)

With the results from the survey the WG decided to establish the compensation levels at the minimum levels that would satisfy the majority of farmers. The financial incentives were therefore set at the following levels:

- Scheme A: 50,000 INR per acre per year
- Scheme B: 60,000 INR per acre per year
- Scheme C: 50,000 INR per acre per year

Final RPG Schemes

The final schemes to be tested in the RPG are summarised in Table 6.5. The stakeholders were the ones that set all the terms and conditions of the schemes.

The proportional increase in production in the RPG under Schemes A and B is universal for all farmers. This means that regardless of the physical characteristics of the farms or the management practices all farmers that have enrolled in the two schemes will receive a 10% increase in their production. Similarly they will have a 10% decrease in production under Scheme C. This of course represents a simplified assumption. In reality production increases will vary widely between farms. However, the scope of the study was not to focus on closing yield gaps, which other studies have already done (e.g. Phalan et al., 2011, Phalan et al., 2013). Instead, the aim was to understand the *acceptability* of such interventions in a landscape where closing yield gaps is believed to be possible.

The increase in production was set at 10% for all farms, though there is potential for yields to increase beyond this level. Stakeholders decided that the success of the interventions has to be first demonstrated and then in a later stage efforts could be focused on increasing production further and tailoring the interventions to better meet the needs of farmers while continuing to improve biodiversity conservation.

Table 6.5 Terms and conditions of scheme enrolment used in the RPG

Schemes	Benefits of enrolment	Incentive
Scheme A Creating land on the farm for grasslands (wildflower meadows)	Farmers that set aside land for wildflower meadows get a 10% increase in yields on the rest of the farm.	50,000 INR/acre of wildflower meadows/year
Scheme B Creating land on the farm for forest (forest plantations)	Farmers get a 10% increase in yields as a condition to set aside land for native tree plantations (200 trees/acre).	65,000 INR/acre of tree plantations/year (Initially the incentive was established at 60,000 INR/acre, but after the RPG test and calibration sessions the value was adjusted)
Scheme C Intercropping trees on the farm	Farmers get support to enhance agricultural practices on their farm as a condition to intercrop more native trees (100 trees/acre). In the ABM to increase enrolment in the intervention the stakeholders decided to allow farmers that oppose having native trees on their farms to plant exotic trees. There is going to be a 10% decrease in production on the farm as a result of reduction in area under harvest following intercropping.	50,000 INR/acre of intercropped land/year
Production	To achieve a 10% increase in production the Tea Board, UPASI and Horticulture Department proposed a series of measures through which they will provide framers with: • Technical advice on soil and nutrient management; • Technical advice on integrated pest and disease control; • Support with tea saplings for revitalizing the plantations; • Technical advice on fine tea leaf plucking; • Access to high yielding vegetable seeds; • Technical support with the set up of self-help farmers' groups to eliminate middlemen, increase profit and enable farmers to reinvest some of the earnings in farm and labour inputs.	
Bonuses	In order to increase the connectivity between native vegetation farmers receive a one-off payment if they enroll together at least 1 acre of adjacent land in Scheme B or C. The bonus is 10,000 Rupees/acre of land enrolled.	
Dropping out fees	Farmers that enroll in Scheme B and C and decide to drop out pay a fee equivalent with 10% of the cumulated income received from the schemes over the duration of enrollment.	

6.3.1.4 Phase 5. Designing the RPG: general description

This section describes the RPG co-constructed with the stakeholders.

Venue

The game sessions were organised in community halls within the 5 Badaga villages where the workshops were conducted. Three other assistants that fulfilled different roles throughout the workshop helped with the organisation of the RPG.

Representing the landscape

The playing environment of the agents is a 2-dimensional board representing an abstract version of the local environment with its three main land uses: tea, agriculture and forestland. Tokens were used to display the different land uses.

The game board was formed of 6 plots of land, one for each player (Figure 6.5). The players placed their tokens on their plot to represent the different land uses owned. The size of the tokens (land) was expressed in cents, which is the local land size metric used by the farmers (1 acre = 100 cents). Different colours and sizes of tokens were used to represent the size of land, the land use and to represent the three schemes (A, B, C) that farmers enrolled in. The forest is represented at the edge of the board. In the game the farmers could not alter the edge of the forest because it is under protection and because it represented what happened in real life at the time of the study. Also, the farmers do not start with trees on their farm, they are cultivated only as part of the interventions.

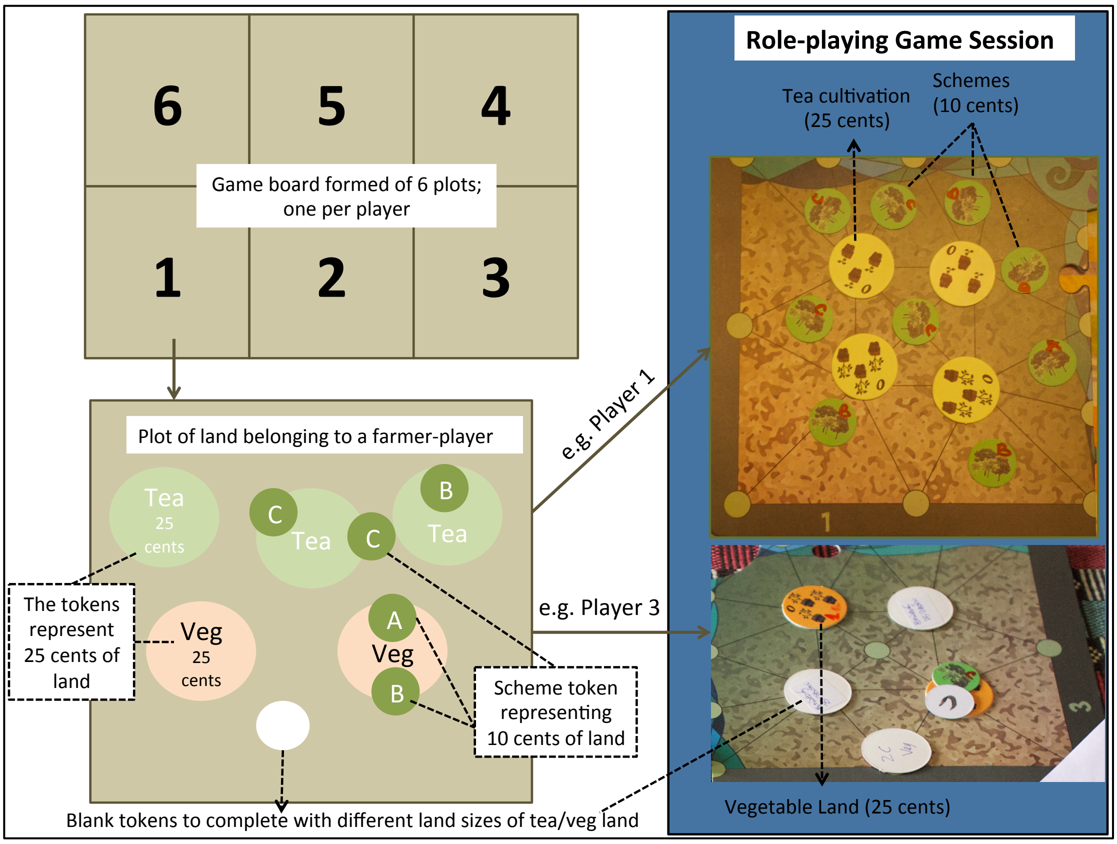


Figure 6.5 Representation of the RPG board and the tokens used to describe the land uses. The size of land is expressed in cents as per the local metric (1 acre=100 cents). The game board and tokens were based on Sierra Springs game García-Barrios et al (2015)

Players

A RPG workshop was designed for 6 players. The players were selected Badaga farmers from the study villages that play the role of a farming household in the game. In a RPG the 6 farmers distinguished themselves based on assets; land size, land use, crops cultivated, on-farm and off-farm income. Farmers also distinguished themselves based on economic factors, specifically the different costs associated with their household-agriculture, education, food costs and house maintenance. Finally farmers had varying demographic characteristics: family size and dependency ratio. The profile of the farming households was intended to capture the diversity of low to high-income households as well as the different types of farms by land use. The characteristics of the farms at initialization are presented in detail in Appendix 6.1 and the details of selecting the characteristics for the farms are presented in Table 6.6.

Table 6.6 Data used in constructing the household profile of the six RPG players using information from the in-depth household survey and recommendations of the stakeholders in the Working Group

Profile components	Description	Data source and comments
1. Landholding size	The area of land allocated to each player varied from 0.5 to 2 acres. Farmers received tea plantation and/or agricultural land. On the agricultural land they had a choice to grow up to four vegetables: cabbage, potatoes, carrot and beans. Tea owners did not have to take any decisions regarding tea plants cultivation. It was assumed they already own yielding tea plants so there was no start up investment required.	Tea and vegetable plot sizes for each farmer were established based on the distribution curves from the in-depth household survey and the recommendations of the WG. The food crops represented in the game were selected based on the top most cultivated crops in the landscape as per Horticulture Department recommendations (which also coincide with the results of the in-depth survey-see *Section 4.3.6.2*).
2. Family size	Each player represented a household of 2 to 7 members.	Family size was established based on the in-depth household survey (*n*=265) results, which show that family size varies between 1 and 11 members, with most of the families having below 7 members and a family average of 3.73 (*Section 4.3.3.1*)
3. Annual off-farm income	The annual income varied from 0 to 180,000 INR per household and that remained constant throughout the game for most of the households.	The off-farm household income was selected by the WG based on the information in the in-depth household survey (*Section 4.3.4.1-4.3.4.2*) and their knowledge of the area as to what makes a representative earning for a household.
4. Annual on-farm income	On-farm income is dependent on: • The farmers' decisions on what to grow on the farm • The investment made on the farm (costs with labour and fertilizers) • The amount of production retained for consumption and • The price negotiated on the market when selling the crop.	The farmer is the one that takes decisions about what to grow on the farm, how much to invest on the farm and how much to retain for consumption. At landscape level, each crop has an annual average yield (historical data from Horticulture Department) and an average cost per unit of production that remains constant throughout the game (reported by Horticulture Department). Based on these data, each farmer receives a yield for each crop cultivated, calculated proportionally to the investment the farmer has made with that crop. The average price at which the crops can be sold on the market changes every year following the historical data reported by farmers' group. Examples about the crop yields, costs per unit of production and market prices used for players are found in Appendix 6.2.

Profile components	Description	Data source and comments
5. List of costs	A set of minimum costs that they need to cover: education, food, household maintenance and farming costs	The 4 expenses are the top main factors (identified in the in-depth household survey) that impact directly or indirectly on the farmers' livelihood strategies.
Education costs	Education costs varied for each household and changed over the 10 rounds. Educations costs were set at 50,000 INR/year per child for secondary education (high school) and 100,000 INR/year for tertiary education (university level)	Data was provided by the WG based on the average local fees reported in Tamil Nadu. Those that could not pay for education fee had the option to put the children in public schools where minimal fees are paid.
Food costs		The WG decided to establish the food budget for each household above the food security borderline (see *Section 5.4.2.2*) to allow observation of who will find it difficult to meet the costs and would proceed to diminishing their costs.
Other costs	Household maintenance varied from 10,000 to 25,000 INR per household	The maintenance costs represent a general category and they included expenses associated with festival days contributions, unforeseen events, budget with transportation, items and clothing required for the household members. The survey did not provide information about all these costs. As a result, in the game, the maintenance costs of each household were randomly selected from a range proposed by the farmer members of the WG after consulting with village members from their own community.
Farming costs	The households were provided with the average cost of production per crop and they could decide whether to maintain, increase or decrease the cost (as per the description in this table, row ***4. Annual on-farm income***)	
6. Land use transactions and conversion prices	A list of prices at which they can convert their land (tea to agriculture and agriculture to tea) or at which they can buy/sell tea and agricultural land was provided for each player.	In establishing the buying or selling prices for each player the WG used the data from 81 land transactions (29 bought land and 52 sold land) recorded in the in-depth HH survey. The majority (over 50%) of transactions involved scrubland plots which were not of interest to the RPG. The price of agricultural land transacted varied between 3,500,000 to 7,000,000 INR/acre, whereas for tea transactions as high as 18,000,000 INR per acre, were recorded. The conversions costs were established by the WG farmers, based on their experience and knowledge of the area and varied between 4,000,000-15,000,000 INR/acre.

The 6 profiles of the farms, which can be referred to as the initial conditions, were common between all 5 RPG workshops. The role of the players was to take decisions, similar to their real life, on how to manage their land and what livelihood strategies to adopt. Players had to ensure they are able to satisfy the needs of the households by covering the costs with food, education, household maintenance and agricultural costs. Every round they had to explain the land use decisions made during the past year to meet those objectives. When land use policies were introduced in the landscape the RPG followed farmers' response to the policies and the change in land use and livelihoods strategies.

Other players in the game

As per the conceptual model diagram presented in *Section 6.3.1.2* (see Figure 6.3), there are two main stakeholders that interact with the farmers: the Market and the Agency. The Agency represents the joint interest of the institutions that are responsible for implementing, funding and monitoring the three agro-environmental schemes selected by the WG in Phase 4. The Market's role was to negotiate the selling prices of crops with farmers. Two trained RPG assistants played the role of the stakeholders. In the RPG workshop I was the game master- the person that holds all the information about the game, coordinates the session and ensures that the game proceeds according to the rules.

Number of rounds and scenarios

Given time management constraints the game was played for an optimum of 10 rounds, the equivalent of 10 agricultural years. As requested by the stakeholders, in the first five years the RPG followed the land use processes and livelihoods strategies that occurred under business-as-usual scenario, whereas in the second half of the game the same processes were monitored following the introduction of all the land use schemes, at the same time, operated by the Agency.

For the ABM the stakeholders wanted to see all the interventions tested one at a time as well as all interventions together, which would have been difficult to test in the RPG.

Game sequence and organisation of the workshop venue

Farmers follow several steps in one agricultural year (Figure 6.6).

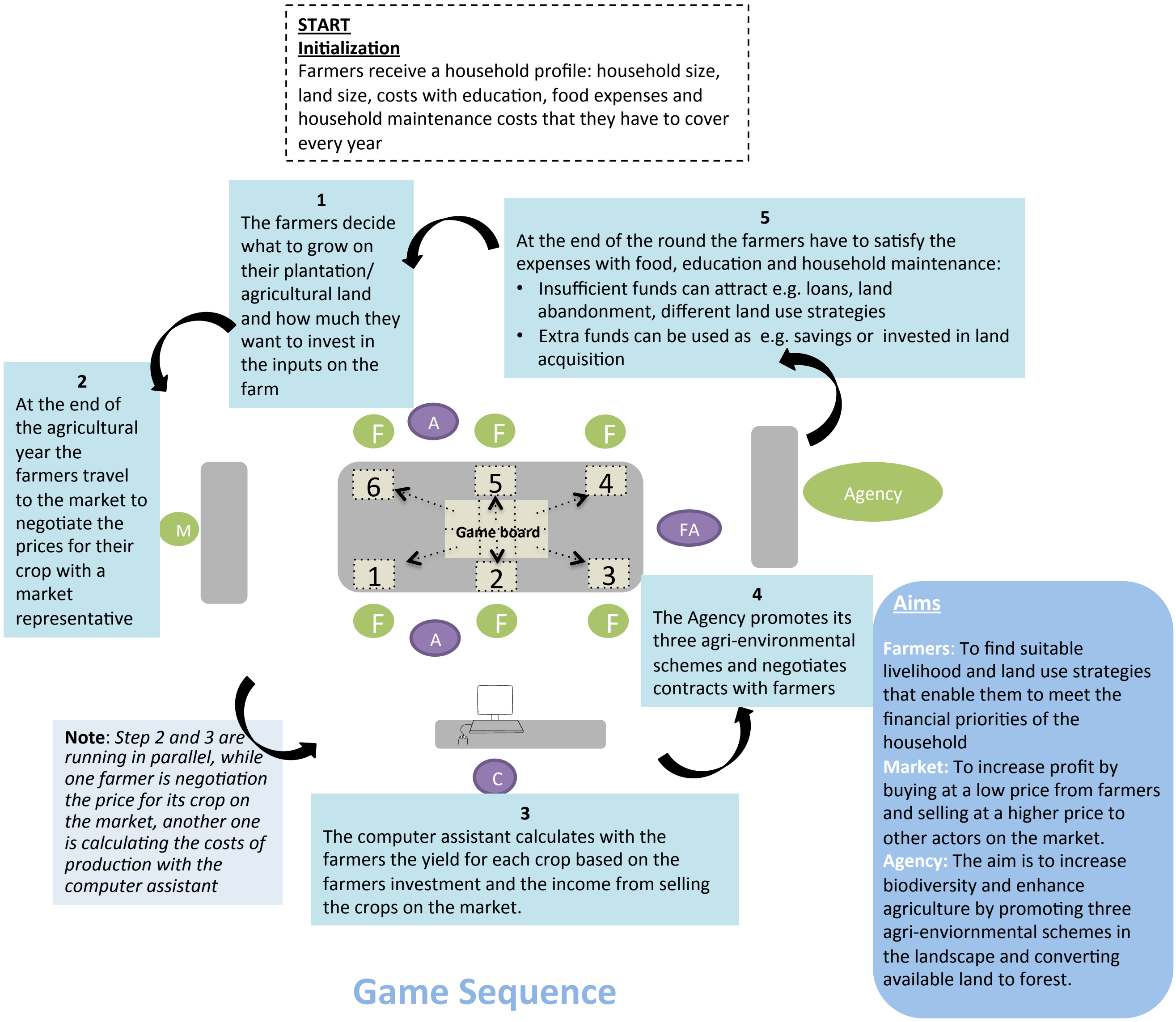


Figure 6.6 RPG game sequence, the aim of each player and the spatial organisation of the workshop venue.

Game players are represented by green ovals: 1. Farmers (F), 2. the market (M) and 3.the Agency. The support team is represented in purple: 1 Game Master/Facilitator (FA) that knows all the rules of, and coordinates, the game; 2 Assistants that facilitate the game and translations (A); 1 Computer Assistant that calculates the yield, profit and income for each farmer based on their decisions (C).

First they decide what food crops to grow on their vegetable land and for how many seasons to grow them for (between 1-3 seasons). Season three is not always successful due to variability in weather conditions (see *Section 4.3.6.2*), so farmers can decide to risk growing food crops in season 3 or not. The household then decides how much they can invest on the farm inputs (labour and fertilizers) on tea and food crops and based on their investment they receive an estimated yield. At the end of the agricultural year the farmers negotiate the prices of their crops on the local market and with the money obtained from selling their crops and the off-farm income they decide how to allocate their budget to meet their livelihood strategies.

The Agency introduces agro-environmental schemes in year 5 of the RPG. Farmers can decide at this stage whether they want to enrol land in any of the three schemes. They negotiate directly with the Agency the size of land to enrol and the level of incentive they receive. The interventions follow the conditions presented in *Section 6.3.1.3* (Table 6.5).

If at the end of the year the household did not manage to cover the living costs they can take several actions including: borrowing money from the bank, decreasing costs or abandoning the land. If they have extra money they can decide to save it, increase their costs in order to have better livelihoods or to buy more land. Not all these actions are specifically stated to the players because the game aims to understand what processes emerge under different financial conditions experienced by the households.

6.3.1.5 Phase 6. Testing and calibration of the RPG

There was a general consensus among players that the game was entertaining and it reflected real-life land use management and livelihood decisions. While some of the players found the game complicated others thought it was easy to follow. Additional observations regarding the game play arose from the trial sessions. Firstly, stakeholders raised concerns about the lengthiness of the game. The trial sessions lasted around 10-12 hours, some of the farmers were eager to play in one day while others wanted to have the game divided into a two-day session. Secondly, delays occurred as people were seeking support from the game assistants. This was because farmers had to calculate and divide their budget for different activities in each round and some of the computations were more demanding. Thirdly, the players considered that the negotiation mechanism around the prices of the crops and the agro-environmental schemes was very well set in place. However, they reported that some players were cheating and trying to take advantage by deciding the crops to grow only after their neighbours reported on the most profitable crop on the market that year. Finally the agro-environmental schemes were popular and considered to be well thought out and feasible, but farmers felt that compensations to spare land for forest plantations (Scheme B), needed to be increased.

In order to improve the experience of the farmers and to address the issues raised in the debriefing session, several changes were proposed:

1. Allow the players to decide as a group on the schedule of the RPG session – a one day or two day workshop;
2. Introduce calculators to speed up the computation processes;
3. Introduce template forms that allow farmers to keep a clear breakdown of the incomes and costs;
4. Start the negotiation processes only after all the farmers have decided what crops to grow on their land;
5. Increase the compensation for scheme B from 60,000 to 65,000 INR per acre.

The next section (*Section 6.3.2*) presents the outcomes of the RPG workshops.

6.3.2 Role-playing game results

The RPG results provide insight into the decision-making processes that occurred during the game in the baseline scenario (business-as-usual) and following the introduction of land use polices in year 5. To better observe the land use dynamics and changes in livelihood strategies under the two scenarios the results are compared against each other where relevant.

6.3.2.1 Social acceptability of policy interventions (scheme uptake)

Scheme enrolment occurred in all 5 RPG villages.

Of the 30 players only two did not enrol in any schemes, whereas one enrolled in all three schemes, 19 players enrolled in one scheme only and 5 players enrolled in two schemes (Figure 6.7).

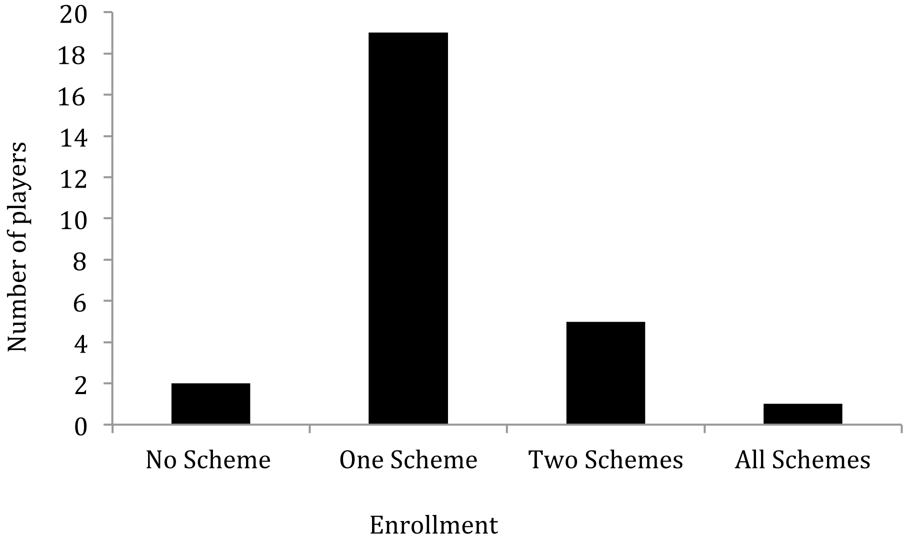


Figure 6.7 Chart showing the frequency of enrolment by number of schemes (*n*=30)

The most popular scheme, by number of players enrolled, was Tree Intercropping with 14 players (47%), followed closely by setting land aside for Wildflower Meadows with 13 players (43%). Forest plantations scheme was adopted by 6 players or 20% (Figure 6.8).

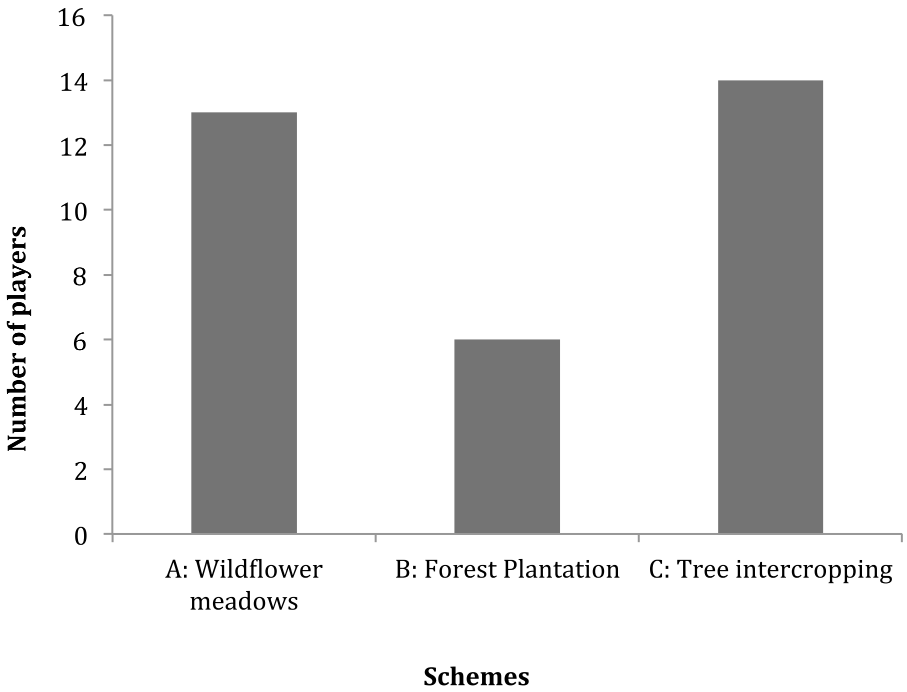


Figure 6.8 Chart showing frequency of enrollment by scheme type (*n*=28)

However, by land area enrolled, Tree Intercropping was the dominant land use policy, covering an area almost 4 times larger than Forest Plantations and 2/3 larger than Wildflower Meadows (Figure 6.9). This suggests that even if almost the same number of players enrolled in both Wildflower Meadows and Tree Intercropping, larger farms preferred tree intercropping.

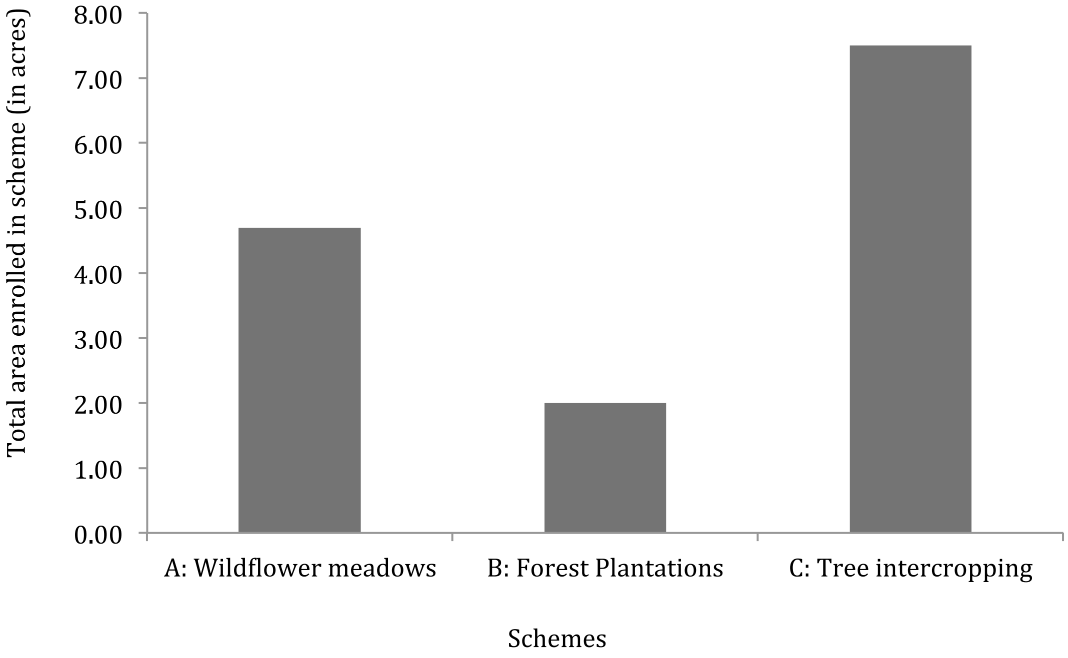


Figure 6.9 Chart showing total area enrolled (in acres) under each scheme

The average size of land per player enrolled in the schemes was: 0.36 acres for Wildflower Meadows, 0.33 acres for Forest Plantations and 0.53 for Tree Intercropping.

The size of land enrolled varied across the 5 years the policies were in place (Figure 6.10). Most of the land allocated to schemes was enrolled in the first year. There was a marginal increase in the land enrolled in Wildflower Meadows (Scheme A) and Forest Plantations (Scheme B) by the end of year 10, while enrollment in Tree Intercropping (Scheme C), almost doubled in the same period of time.

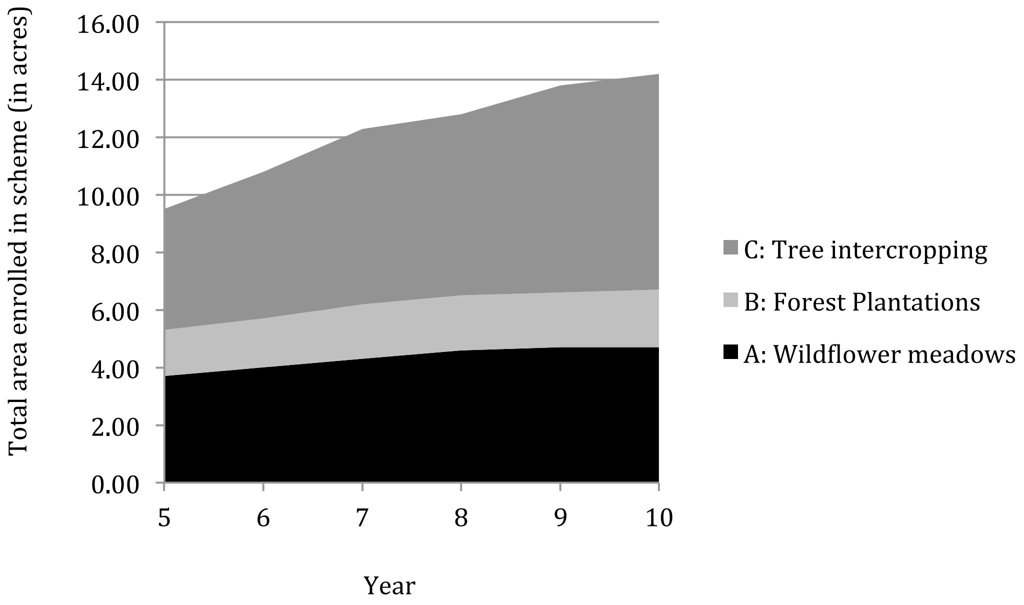


Figure 6.10 Stacked area chart showing changes in total area enrolled in each scheme over 5 years

In terms of land use type enrolled in schemes there was a preference towards tea land being enrolled in the agro-forestry intervention (Scheme C) and vegetable land being spared for wildflower meadows (Scheme A) or forest plantations (Scheme B).

6.3.2.2 Land use changes

Land use change is reported as aggregated results from all 30 landholdings in the 5 workshops.

During the RPG the total land under different land uses varied over time (Figure 6.11) as a result of land use conversion, scheme adoption or land transactions.

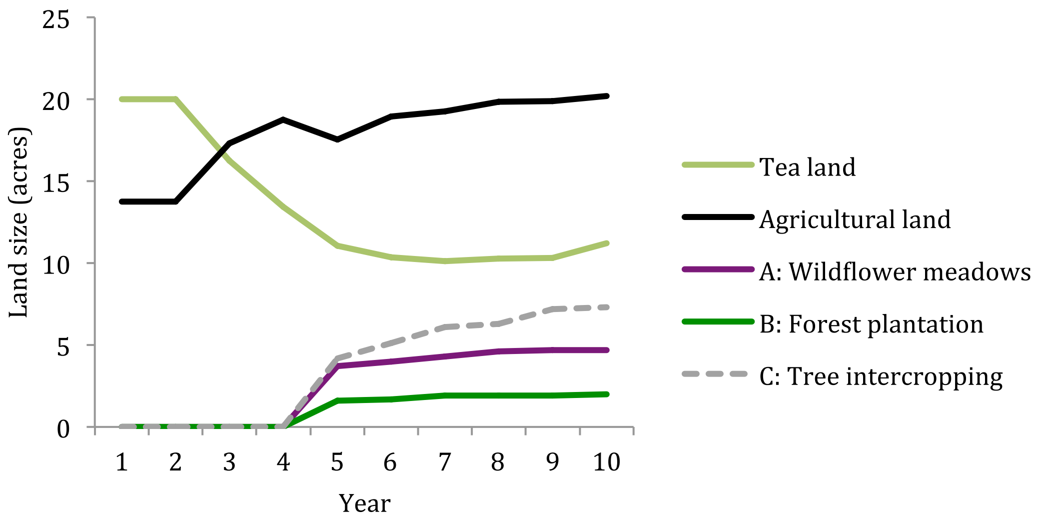


Figure 6.11 Line chart showing the evolution over time of land area under different land uses. Scheme C (represented with a dashed line) is not treated as a separate land use type but it is represented here to show the area of land on which trees were intercropped, either on tea or vegetable land.

The most noticeable change is the decline in tea land, which reduced to almost half the size from the initial value of 20 acres, mainly as a result of conversion to other land uses.

The main reasons for tea conversion that were stated in the decision-making forms are:

i) Insufficient income from tea to cover basic household needs;
ii) The crop is unprofitable;
iii) Low selling prices;
iv) Agriculture is more profitable and additionally more food crops could be produced on land for household consumption.

There were a total of 11 households (36%) that converted from tea to agricultural land. This led to an expansion in agricultural land by about 47% over the 10-year period. Most of the land conversion occurred prior to the introduction of the schemes.

Land use transactions show that 24 players (80%) acquired more vegetable land. The size of land transacted in a year by a player ranged from 0.03 to 0.25 acres. Land was transacted in all 5 villages. There were no players that converted to or bought tea plantation land.

Overall, the total farmland (agriculture, tea and tree intercropping) decreased by about 10%, from 33.75 to 31.43 acres (Table 6.7). Farmland accounted for about 82% of the land use and land cover (LULC) at the end of year 10 while land spared for nature covered the remaining 18%.

Table 6.7 LULC at the beginning and at the end of the game

Land use	Land size (Year 1)		Land size (Year 10)	
	Absolute (acres)	% of LULC	Absolute (acres)	% of LULC
Agriculture	13.75	40.74	20.20	52.98
Tea	20.00	59.26	3.93	10.31
Tree Intercropping (tea)	0.00	0.00	7.30	19.15
Wildflower Meadows	0.00	0.00	4.70	12.33
Forest Plantation	0.00	0.00	2.00	5.25
Total land	33.75	100.00	38.13	100.00

6.3.2.3 Environmental changes

Number of trees in the landscape

There was an increase in the total number of trees in the landscape as a result of the conditions of enrolling under Forest Plantations (Scheme B) and Tree Intercropping (Scheme

C). The latter intervention generated almost twice as many trees in the landscape as Scheme B, even though enrollment in Scheme B required the plantation of 200 trees per acre compared to 100 trees per acre under Tree Intercropping (Figure 6.12).

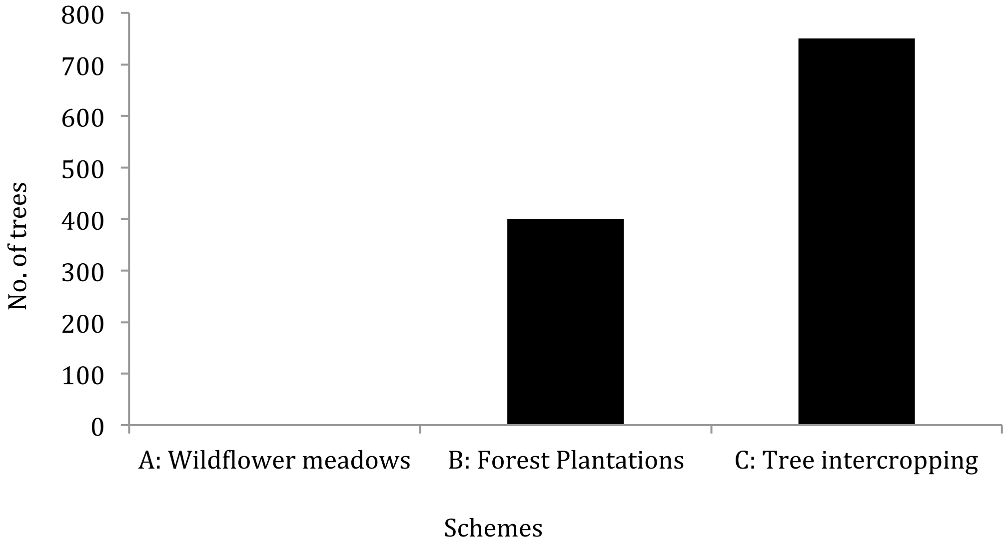


Figure 6.12 Chart showing the total number of trees planted under each intervention as a result of enrollment

Connectivity of native habitat patches

Connecting native patches of vegetation set aside for conservation (Wildflower Meadows and Forest Plantations) was motivated by a one-off bonus given to the farmers that joined the lands to create conservation land on a minimum of 1 acre. Nine farmers from all villages obtained the bonus and the areas of native vegetation connected varied from 0.5 acres (no bonus was given) in Kercombai village to 2.5 acres in Nedugula (the equivalent of about 35% of the total land cover of the village).

6.3.2.4 Production and size of compensation

The increase and decrease in production was the direct result of scheme enrollment and represented a setting of the RPG. The stakeholders decided to test the model with a 10% increase in production on those farms that spared land for Wildflower Meadows or Forest Plantations and a 10% decrease for those that enroll in Tree Intercropping. Under these production conditions 43% of the landholdings benefited from an increase in production by sparing land for wildflower meadows (Figure 6.13) and received a total compensation of 1,3 million INR ($20,000). Under Forest Plantations 20% of the landholdings benefited from a 10% increase in production and received a total compensation of 715,000 INR ($11,000), whereas 47% of the landholdings experienced a decline in production and received a compensation of 1,8 mil INR ($28,000) when they enrolled in Tree Intercropping scheme.

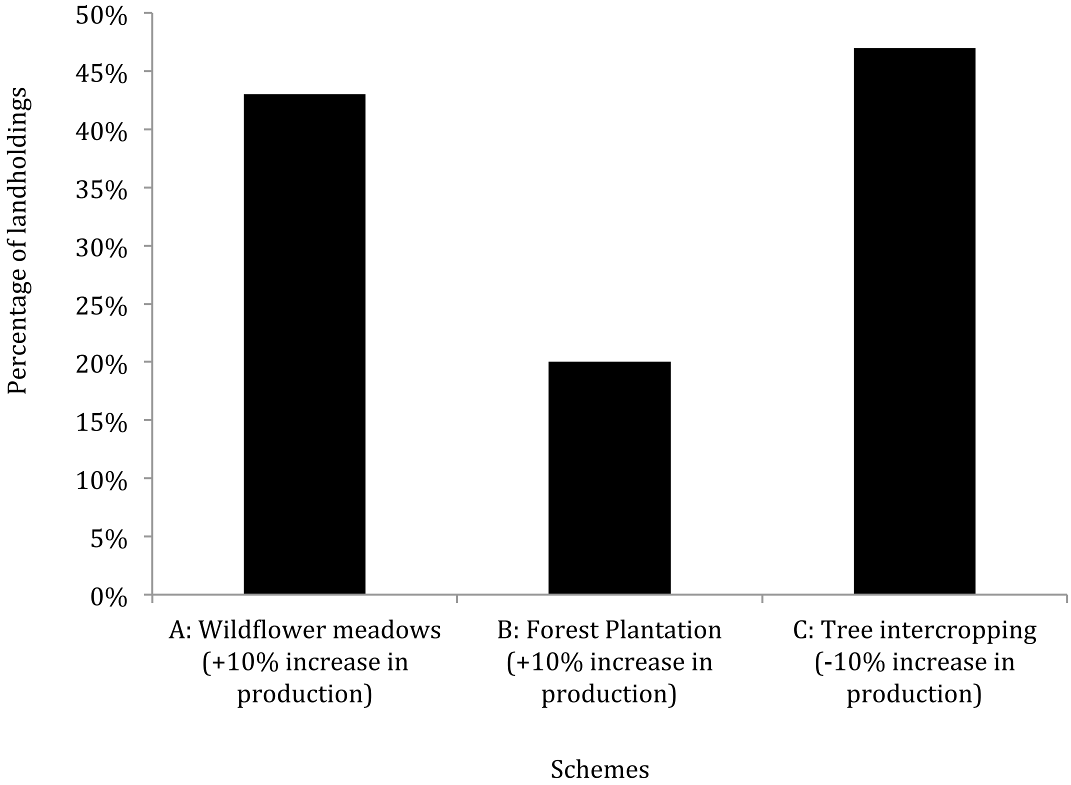


Figure 6.13 Chart showing the percentage of landholdings (n=30) that benefited from an increase or decrease in production as a result of scheme enrollment

Even if consideration was given to the methods and costs of increasing the yield on the farms by the Agency, the exact details were beyond the purpose of the RPG.

6.3.2.5 Economical processes and their outcomes

The different livelihood strategies that farmers adopted during the RPG sessions are best revealed by the situations in which farmers were confronted with financial balance changes. More specifically, how did farmers adapt to situations when there were insufficient funds to cover household costs and what did they do when they had money to spare?

Land use and livelihood strategies for years with positive balance

After covering the costs associated with agriculture, food, education and household maintenance farmers used the funds for the following:

1. Save the money for next year
2. Convert to a more profitable land use
3. Buy land

The order in which these strategies were performed varied slightly from player to player. It was observed that prior to buying land farmers preferred to convert their existing land to a more profitable land use if viable.

Even if the farmers had the option to improve their lifestyle by increasing their spending on farming, food, household maintenance or education, there was no player that performed that change.

The debriefing sessions and decision-making forms showed that the main reasons stated by farmers are:

- “In reality I would have increased my spending, but the game did not provide any advantage for increasing costs of food, education or household maintenance” (Farmer Nedugula No. 5)
- 17 farmers (over 57%) considered that the current costs were realistic to what an average-income family pays so there is no reason to increase or decrease them
- It was more important to convert or buy land first; 3 farmers added that by doing so their status in the community improved as they demonstrated more financial security and this in returned allowed them to get more loans from their neighbours when in need.

Financial shortages and adaptive livelihoods strategies

In all cases financial shortages occurred (13 players or 43% out of all players) either as a result of a reduction in the on-farm income (12 players or 40%) and/or an investment to cover the conversion to a more profitable land use (6 players or 20%).

The farmers followed a similar decision-making process and adopted a suite of coping strategies (Figure 6.14) to deal with years in which household costs exceeded their incomes.

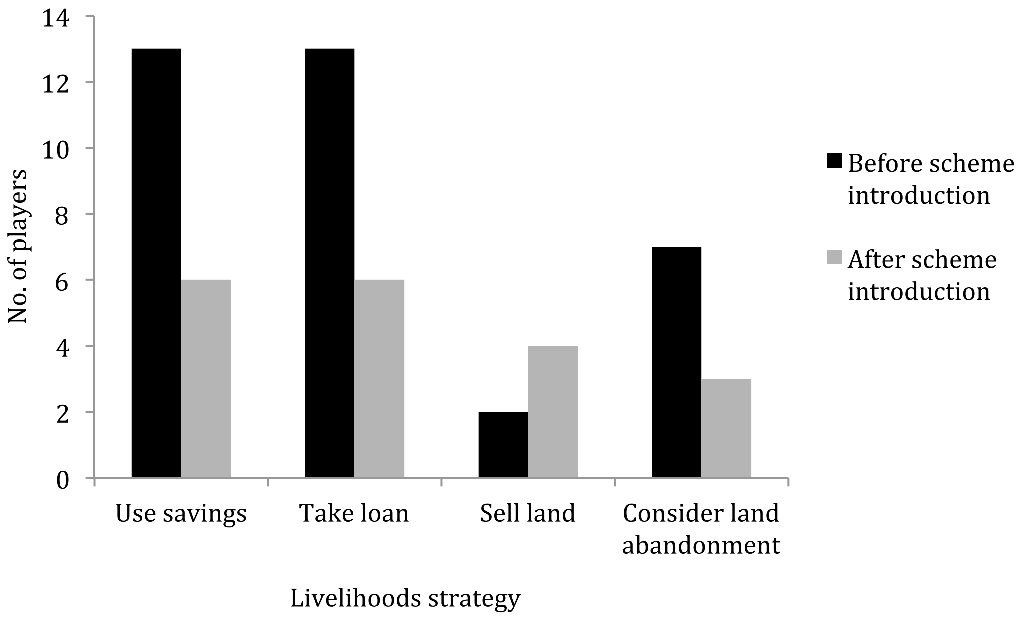


Figure 6.14 Charts showing the livelihoods strategies adopted to overcome financial shortages before and after the schemes were introduced

After using their savings from previous years the same players (13 players, 43%) opted for loans as a strategy to cover the negative balance. One player took a loan for a total of 5 years. Loans could be taken from the bank but for no more than three consecutive years, after which the households had to have at least one year of positive financial balance before asking for another loan. Alternatively loans could be taken from neighbours. While all players in debt used the bank to borrow money, 6 of the 13 players took loans from the neighbours as well.

The sale of land only occurred after the household has taken a loan from the bank at least once. In total 6 players (20%) sold land due to financial problems.

Throughout the RPG sessions there were no farmers that abandoned their land, however in the decision-making forms 10 farmers (33%) stated that under financial pressure they considered abandoning the land. In the debriefing session one of farmers from Sundatty village said *"this game that we played today allowed me to see the true extent of the financial pressure resulting from our dependence on a once profitable crop [reference to tea]; it is sad to see how good farmers and neighbours abandoned their field and their community because of this. The young generation they want to leave, but us [refereeing to his generation of middle age farmers] our land and our community is our pride"*. This is a representative statement and a common discourse shared by farmers in the debriefing sessions.

Unexpectedly there were no households that wanted to reduce their costs to accommodate for the years with financial shortages even if this option was available to them. The same line of reasoning applied as in the section above *(Land use and livelihood strategies for years with positive balance)*, when farmers were asked why they didn't make any changes to their spending budgets.

6.3.2.6 Food security

All the households started with a budget that ensured they were food secure. Throughout the RPG the farmers did not change their initial food budget. The rationale behind is that farmers did not want to decrease their food budget under financial pressure and preferred to cover the budget gaps by taking other actions. When spare money was available they did not want to increase the budget because they either thought it is an optimal food budget or because the increase did not offer any advantage in the game. Households did not retain any food crops for household consumption because they preferred to trade the crops for money.

6.3.2.7 Feedback forms

Most of the farmers (24 players or 80%) found the game complex, whereas the others though it was about the right level of complexity (4 or 13%) or too simple (2 or 7%). The game was found entertaining by 23 farmers (77%) whereas the others though it was reasonable (4 players or 13%) or too long (3 players or 10%).

In terms of how the land use decision-making processes compare to reality, farmers reported that: "I felt I was managing my own land" (15 players or 50%), "Quite close to the way I manage my land" (8 players or 27%), "Some aspects are relevant to my land use decisions" (6 players or 20%), "Nothing like managing my own land" (1 player or 3%). The resemblance of decision-making processes in the game compared to real life demonstrates that the RPG was fit for purpose and that it produced valid and useful results.

6.3.2.8 Extrapolating the RPG results to the ABM

Several decades ago Levins (1966) considered that the trade-offs involved when developing a modelling strategy lie between three main axes: reality, generality, and precision (Odenbaugh, 2003). The typology was not intended to be complete, but rather to capture some critical aspects. In general, improvements in any one area are accompanied by losses elsewhere. For example, global scale climate models that aim to quantify impacts as precisely as possible using general relationships that are applicable to all world regions would necessitate a loss of realism; what is happening nationally or below this level is lost. Thus, in order to develop a model that is general and precise realism would have to be sacrificed. Following a similar principle, models more grounded in realism and precision would have to sacrifice generality, whereas models that need generality and realism lose precision. In the current research, in order to allow the modelling of detailed socioeconomic dynamics, central to understanding the applicability of LS/LS strategies in a real world context, generality had to be sacrificed over reality and precision. The model is useful for specific circumstances being considered rather than its capacity to represent more general dynamics, such as global scale production and biodiversity. As such, it is important for the data obtained from the RPG to be as closely evocative of the real processes as possible. Understanding how far the results from the games can be extrapolated to real life (known as the external validity of those results) becomes an important matter when translating the RPG results into ABM processes. Triangulation of knowledge obtained through a variety of methods was key in aiding this translation and assessing the external validity of the RPG. The feedback forms and debriefings discussions held at the end of each game session helped validate the outcomes of the games. The dynamics that occurred during the RPG sessions, and were endorsed by the players, were translated into ABM processes in a straightforward manner (see details in Chapter 7, Table 7.4). There were, however, instances that revealed the RPG was not equipped or able to capture processes representative of the local reality. This section focuses on these processes and details how these limitations were overcome in order to translate them in ABM procedures.

The first processes that the RPG felt short of capturing were the increase and decrease in the households' costs over time associated with food, household maintenance and education (see *Section 6.3.2.5* for why this was the case). In the ABM this limitation was however resolved using data from the household survey. Households were asked about how they make these decisions and how do they prioritise their budget cuts/increases.

The second process that farmers debated was outmigration from the landscape. Farmers did not migrate out of the landscape (which translates into exiting the game) during the RPG. The feedback forms and the debriefing sessions revealed however that financial hardship would push some of the farmers to do so. In the ABM it was proposed for households that were left with no financial alternatives to covering basic costs of life, to exit the system. This represents a 'crude' assumption and future research would benefit from a more in depth understanding of the typology of households that are representative for outmigration. Identifying the respondents is however difficult and is likely to represent the main limitation of obtaining an illustrative image of the exodus dynamics.

The last process that the RPG felt short on providing information is the conditions under which the farmers leave the schemes they have enrolled in. To be able to observe this process the game would have had to be played over a longer period of time and its complexity increased. A trade-off was however needed given the already lengthy duration of the game. Thus, in the ABM it was proposed for a percentage of random enrollers to leave the scheme automatically without requiring any pre-conditions.

6.4 Discussion

6.4.1 Plausible LS/LS mechanisms identified by the stakeholders

Policy makers along other relevant stakeholders from the Nilgiris have proposed for deliberation four mechanisms through which the land use policies could be instituted in the landscape: market-based approaches, land use zoning, certification and reverse auctioning. Recognizing the current social, economic, environmental and political realities, stakeholders identified only one mechanism, market-based approaches, that could benefit food production and biodiversity conservation while dismissing the other three. This result highlights the importance of engaging with local stakeholders to determine the local suitability of potential interventions. The value of stakeholder engagement has been highlighted by studies from across the discipline of conservation (Reed, 2008, Brooks et al., 2013, Sterling et al., 2017). In Bezà Mahafaly reserve, Madagascar, local stakeholders have played a central role in conservation decision-making since 1975 and their engagement has been shown to increase the diversity in decision-making bodies, leading to higher quality decisions that are better adapted to the local social-cultural and environmental contexts (Richard and Ratsirarson, 2013). Stakeholders' ownership of this decision making process has then increased support for, and the successful implementation of, proposed conservation interventions (Richard and Ratsirarson, 2013). In other examples, stakeholder engagement has also been shown to: reduce implementation costs, help set more realistic targets, understand the barriers to success as well as shift direction if interventions where believed to diverge from intended targets (Martin and Sherington, 1997, Richards et al., 2004, National Audubon Society, 2011). In cases where stakeholders were not included in the decision-making process the risk of proposing inadequate solutions has been shown to increase (Reed, 2008). In Kalahari, Botswana, it was found that the adoption of land use strategies by local pastoralists without prior discussion of their suitability risked advancing policies that were likely to fail due to a lack of engagement (Reed et al., 2007). Similarly, without local insights into the Nilgiris context from the stakeholders the selection of the real interventions would be made top down without understanding the local context and could therefore risk local rejection or sub-optimal solutions.

The policy selected by the stakeholder group, economic incentives, is a hybrid between two of the mechanisms proposed by Phalan et al. (2016). It incorporates *Economic instruments, such as payments, land taxes, and subsidies* by offering farmers incentives to increase biodiversity in the landscape, and *Spatially strategic deployment of technology, infrastructure, or agronomic knowledge* through the measures proposed to increase yields on the farm. Phalan et al. (2016) anticipated that local solutions would probably involve a combination of mechanisms, since each mechanism is most likely to be effective if implemented in synergy with others.

This study adds a new dimension to the mechanisms proposed in the literature in that the selected mechanism is not only a combination of different mechanisms but also has the ability to mutate and incorporate additional strategies over time. In the selected mechanism, optimal solutions in terms of closing yield gaps are not always sought from the beginning. Stakeholders considered that in order for the interventions to be more effective in the long term there should be different stages in the life cycle of the policies. It was deemed that in a pilot stage the interventions should be universal, inclusive and attract as many enrollers as possible, with the aim to demonstrate their benefits and success. This will popularize the policy in the landscape, so that in the maturity phase they can attract more land users by better tailoring the interventions to the land users' needs. Switching to entirely new mechanisms, reverse auctioning, in the maturity stage was also proposed. In this later stage the yield and biodiversity conservation benefits are expected to increase. A study in the Colombian Andes on silvopastoral farmers showed the importance of such staged interventions, with 58% of participants that entered a programme in a second phase being influenced by observing the success of the participants in the first phase (Hayes, 2012).

This creation of a hybridized mechanism that evolves over time to best achieve its goals demonstrates that by combining the findings of participatory research with insights from scientific literature it is possible to produce new and more relevant interventions than either approach could have achieved alone. Stakeholder engagement is shown once again to have important benefits, this time in the form of creating novel approaches that add new dimensions to scientific models. The complementarity of local knowledge and scientific recommendations was also observed in the Kalahari, Botswana, where innovative conservation solutions to land degradation problems were generated through a participatory process (Reed et al., 2007, Reed, 2008)

The interventions (schemes) selected refer to the restoration of native vegetation, grasslands (Scheme A) and shola forests (Scheme B) - which have considerably reduced in size with the expansion of vegetable cultivation and tea growing (see *Section 2.4.4*). A third intervention (Scheme C) aims to increase the number and the diversity of trees intercropped on the farms, given a considerable loss of species diversity with the popularisation of Silver Oak intercropping within the landscape. As such, the three interventions proposed in the landscape align with the historical transformations observed in the landscape and the critical biodiversity conservation needs that resulted from these changes (see *Section 2.4*). As they aim to conserve different types of habitats, the interventions are likely to fulfil different biodiversity needs, making the strategies complimentary to one another (see review by Bunyan et al., 2012 for the fauna and flora characteristics of the different habitats).

Selecting locally appropriate interventions led to the formulation of some land use policies that do not align with classical forms of land sharing and land sparing, as classified by the original proponents of the framework. According to the classification by Green et al. (2005), tree intercropping is a form of land sharing, however the two interventions that aim to spare land for conservation of wildflower meadows or forest plantations while increasing the yield on the rest of the farm, have a less straightforward classification. The two interventions could meet both the sharing and sparing criteria depending on the scale at which the strategies are assessed and the configuration of the spared land over time. Setting aside areas for wildflower meadows and forest plantations could be forms of land sparing on the farm. However due to the pattern of land ownership within the landscape such set-aside areas would form small, dispersed fragments at the landscape scale, which would typically be identified as land sharing landscapes (Green et al., 2005). If bonuses are offered to connect these patches and create contiguous areas of land that have been set aside for biodiversity conservation then once again they would form a land sparing landscape, this time at the landscape level.

As other authors have stressed before, the loose definition of scale and landscape configuration in the debate has created confusion (Fischer et al., 2014, Kremen, 2015). Sparing of nature as a result of yield increases can occur at any scale or configuration. In England land sparing was shown to occur in the form of dispersed field margins (Hodgson et al., 2010), whereas in Costa Rica land was spared as small forest fragments interspersed in coffee plantations (Chandler et al., 2013). By contrast in Laos, eradication of shifting cultivation segregated the landscape in areas of high intensity agriculture and areas where large and contiguous forest blocks were spared (Castella et al., 2013). To avoid confusion this study proposes to refer to wildflower meadows and forest plantations as land sparing interventions, given that the land spared for conservation is directly linked to the increase in production.

The method by which the interventions were derived has also highlighted another particularity: that an intended focus on optimization, of either production efficiency or biodiversity gains, can be impeded by local realities. From a land sparing perspective the optimal solution in the Nilgiris landscape was to maximize production on existing farms while preventing further expansion into the protected areas. However, discussions with local stakeholders revealed that such an approach would be futile. Low market prices, a decrease in soil fertility on the farms and wide spread reliance on a single unprofitable crop are among factors that lead to land abandonment and make intensification unattractive to local farmers. Furthermore, the Forest Department considers that there is no imminent threat to protected areas from small-scale agriculture directly. On the contrary, an expansion of regrowth forest is observed (see *Section 2.4.4*). The real threat comes from farmers having limited livelihood alternatives as the reliance on an unprofitable crop continues, among other factors. The conclusion is that engaging stakeholders from an early stage can aid the formulation of policies that are better adapted to the local social-cultural, environmental and economic context that transcends a simple production efficiencies evaluation and that stand a better chance of materializing.

If a program's objectives are the optimization of biodiversity or yield then a focus is typically placed only on creating mechanisms to achieve these objectives. Such theory-based designs fail to account for important regional variation resulting from socioeconomic factors that could make the interventions unfeasible locally, as was observed in this case. If interventions are more likely to be successfully implemented by advancing sub optimal gains in biodiversity or yield then real world gains may be greater than a hypothetically superior but locally inferior mechanism design.

The next section (*Section 6.4.2*) looks at the socioeconomic and environmental results of the RPG and discusses their meaning primarily in the local context to ensure they are relevant for the development of the ABM. In the ABM (Chapter 8-9), where similar metrics are analysed, but at the landscape level, discussions are scaled up to the broader literature.

6.4.2 Characteristics of land use policy adoption and decision-making processes on the farm

6.4.2.1 Social acceptability (scheme uptake)

There is strong evidence that farmers see value in all the proposed agro-biodiversity interventions, with most farms favouring Tree Intercropping (Scheme C), followed by Wildflower Meadows (Scheme A) and Forest Plantation (Scheme B). The high rate of enrollment and the diversity of preferences, which manifests heterogeneously across the different farms, demonstrate that stakeholders selected interventions that are feasible in the landscape.

The reason why Tree Intercropping (Scheme C) is the preferred intervention seems to be dictated by the preference of tea land users for this practice. Given the local intercropping practices this is not a surprise. Land use as a factor of decision-making also seems to be important in determining the level of enrolment in Wildflower Meadows (Scheme A), with vegetable growers being the main participants in the scheme. Tree Intercropping (Scheme C) is not practiced in the vegetable fields due to operational reasons (intercropping will make cultivation and harvesting difficult). Wildflower Meadows (Scheme A) therefore represent a more flexible intervention that can be implemented on any area of the farm. Its contribution to enhancing soil fertility also addresses a problem frequently highlighted by locals.

Tree Intercropping (Scheme C) was more successful than setting aside land for Forest Plantation (Scheme B) despite the latter scheme generating both an increase in yields and a higher financial incentive. This unexpected outcome is considered to be the result of historical controversy around native tree ownership on private lands, which may drive farmers to be wary of having native trees on their lands (see *Section 4.3.7.4*). However, the configuration of native trees on the farms appears to change land users' perspectives on tree ownership. Farmers appear to have fewer concerns about tree rights when the trees are intercropped, compared to having contiguous areas of forest plantations. Probably this is the result of farmers associating intercropping with a common practice that carries fewer tree tenure risks as opposed to forest blocks, which is not commonplace on private land in the Nilgiris. The findings differ somewhat to observations in the neighbouring coffee plantations of Kodagu where intercropping of native trees was not favoured by farmers even after tree tenure rights were restituted to them in a similar RPG exercise (Garcia et al., 2013). The difference in preference could occur from the presence of a financial incentive in the current research that was not present in the Kodagu exercise. Farmers may consider this additional financial benefit as a form of insurance against the controversial legislation. A financial incentive to tree planting means that even if timber rights are subsequently withdrawn some financial benefit has been obtained. Alternatively the differences observed in the Nilgiris might be the result of strategic responses, or social desirability bias, whereby responses may be influenced by the desire to conform to social norms and be viewed favourably by others (Fisher, 1993, Carson and Groves, 2007).

The amount of land under enrolment was another important difference that was observed between the interventions. Although the number of enrollers under Wildflower Meadows (Scheme A) is similar to that of Tree Intercropping (Scheme C) farmers, more land is being enrolled in the latter intervention. There are two reasons for this emergent process. First, farmers own a larger area of tea land compared to vegetable land; as a result more tea land is enrolled in Tree Intercropping (Scheme C). Secondly, it was observed that tea growers enrol up to 100% of their land in the interventions, while no more than 30% is enrolled under Wildflower Meadows (Scheme A). Given that agriculture is more profitable than tea and that the incentive of the two interventions is the same it may be that vegetable growers have more economic advantages in retaining land in agriculture. For them the intervention is more a form of income diversification, while for tea growers it is a much-needed protection from an unprofitable crop.

Finally, it was observed that most of the farmers enrolled in one intervention, whereas a small proportion enrolled in two or more interventions. In reality it is expected that an even smaller proportion of farmers would adopt more than one intervention, as shown by the in-depth household survey, because farmers have strong farm management practices preferences (see *Section 4.3.7.4*).

6.4.2.2 Land use change

The RPG provided insightful information about how farmers manage their farms, which was not picked up in the household survey. For example, all the land conversions recorded in the household survey were from forestland or agricultural land to tea. During the RPG conversions manifested only in the opposite direction, showing that tea cultivation might have reached a tipping point triggered by the tea crisis. In real life conversion is expected to happen at a slower rate than it occurred in the RPG because of the terrain limitations, the limited availability of start up funds and the ease of management on plantations compared to vegetable land, which makes it less desirable for farmers to convert. The rate of conversion in reality is also likely to decelerate with the introduction of the interventions, as the RPG has shown (see Figure 6.11). This means that the interventions play an important role in land use decision-making locally.

6.4.2.3 Environmental changes

As a result of enrollment a combination of biodiversity-friendly farming and land set aside for conservation is observed in the landscape. From a biodiversity perspective both strategies are important locally. A number of wild species that otherwise reside within continuous forested areas frequently occur in plantation landscapes while foraging for resources, e.g. wild bees (*Apis* and *Trigona)* (Ghazoul, 2007), or to disperse between patches of suitable habitat e.g. wild elephants (*Elephas maximus)* (Kumar et al., 2010) and lion-tailed macaque (*Macaca silenus*) (Singh et al., 2002). The plantations landscapes also support viable populations of many generalist species (Bali et al., 2007, Karanth et al., 2016). Although important, this biodiversity-friendly landscape cannot sustain, by itself, many components of biodiversity in the long term. Protecting or restoring grassland and forest fragments will not only secure the ability to conserve biodiversity, but also enhance the effectiveness of biodiversity-friendly farming practices (Anand et al., 2010, Bunyan et al., 2012). It has been argued that in more complex and heterogeneous landscapes, where the characteristics of the broader landscape (particularly the size and configuration of remnant forests) strongly influence biodiversity, prioritizing the restoration and conservation of these habitats by setting them aside from human use is likely to be the most effective conservation strategy (Bennett et al., 2006). Due to large research biases in the taxonomic and land-use literature in the Western Ghats landscape, few multi-taxa or multi-land use comparisons are available meaning there is still much to be understood with regard to landscape structure and composition that favour biodiversity within these landscapes (Anand et al., 2010).

Observations regarding the connectivity of the landscape were another important outcome of the RPG. Overall the areas designated for biodiversity purposes only, accounted for 18% of the total land use, with most being land spared for wildflower meadows. One village managed to connect these assemblages on 35% of its land use and land cover, showing that there is potential for achieving the desired outcomes of the proposed interventions.

6.4.2.4 Production and size of compensation

A 10% increase in production on the farms that enrolled in the two sparing interventions (Schemes A and B) can be observed on more than half of the farms. The cumulative cost of compensations for the land spared for conservation under the interventions over 5 years rose to almost 4 mil INR (approximately $60,000). Given the price of land, if the policy maker had decided to buy the land for conservation purposes instead, it would be the equivalent of paying for 274 years of compensations.

The stakeholders proposed to have the Agency as a land buyer in the ABM to observe the extent to which the Agency could bring land into conservation and at what cost. This will enable more precise comparisons regarding whether the adoption of interventions or the Agency buying land into conservation would be more cost-effective for biodiversity conservation.

In the case of Tree Intercropping (Scheme C) farmers were paid to compensate the reduction in production on the farm. In the ABM where the results are scaled up it will be important to observe how the total production in the landscape, resulting from the three interventions, is affected, and how in return it affects the food security of the households.

6.4.2.5 Economic changes

The economic processes that manifested in the RPG or were discussed during the debriefings fitted the expectations of real life. For example it was observed that loans are a central feature in the Nilgiris landscape and households rely on credits to cover not only costs with education or investments but also years when there was a loss from agriculture. A practice that has long been acknowledged among Indian farmers (Narayanamoorthy, 2006). Unfortunately the magnitude of this phenomenon was not investigated in the in-depth survey and is seen as a limitation of this study. Furthermore, financial shortages or aspirations for higher standards of living in larger cities pushed about a third of the farmers to consider land abandonment in the game.

6.4.2.6 Food security

The introduction of schemes did not produce a change in the food strategy employed by the household. This was unexpected given that in the landscape households have different levels of food security (see *Section 5.4*). It is believed that under the current RPG design the game could not capture this heterogeneity because it did not provide sufficient incentives or constraints that would motivate farmers to change their food security strategy. A future design of the RPG could consider providing 'status' rewards, by which a household could be identified as belonging to a low, medium or high level of food security or economic wealth group. This could make farmers more competitive and willing to change between groups. A similar approach was implemented successfully with the farmers from the nearby coffee estates of Kodagu (Garcia et al., 2013).

6.4.2.7 Decision-making processes on the farm

The decision-making processes around farm practices demonstrate that farmers are not always acting as utility-driven users (*homo economicus)*. For example, most of the farmers chose a diversity of crops over profitability. Some farmers decided to cultivate for two agricultural seasons while others cultivated food crops for three seasons, giving the potential to increase their income under favourable climate conditions. Furthermore, in selecting what interventions to adopt on their lands farmers considered their compatibility with their current farming practices more than the monetary returns from adoption.

Thus, in considering the representation of decision-making process that occur in the Nilgiris landscape there is value to move beyond the rational choice theory and integrate in the agent-based simulations other models of human behaviours that are better adapted to local context. Details about the theories and choices that were found relevant for Nilgiris model are discussed in the next Chapter (*Section 7.2*).

6.5 Limitations

Through the design and implementation of the RPG process, several limitations are apparent. Firstly, understanding farmers' decision-making processes could be improved if more workshops are conducted in the study area and if the transition between the spending on different cost groups (food, education, household maintenance and farming) could be observed under a better design of the RPG that will stimulate farmers to produce these changes.

Secondly, a better understanding of the financial balance a household is initialised with would also add a valuable dimension to the RPG, given the extensive reliance of the Nilgiris farmers on financial support, primarily in the form of loans.

6.6 Conclusions

The results presented in this chapter show the importance of engaging local stakeholders to determine plausible land use mechanisms that aim to reconcile food production with biodiversity conservation. While stakeholders agreed on interventions that resemble forms of LS/LS strategies proposed in the literature, the stakeholders aided the formulation of policies that are better adapted to the local social-cultural, environmental and economic context. This was reflected in the high level of enrolment and the heterogeneity of preferences for the interventions. The value of stakeholders' engagement stems also from proposing innovative hybridized mechanisms, which evolve over time and could increase conservation and production efficiency in the long term. Combining findings of participatory research with insights from scientific literature to produce new and more locally relevant interventions demonstrates the utility of translating such an approach in other landscapes where policies are promoted.

The land use policies proposed transcend the simple yield-biodiversity evaluation by incorporating stakeholders' objectives and socioeconomic evaluations. By doing so this allowed for an important observation to be made, with implications for any landscapes that advance sharing-sparing policies. For interventions to be more lucrative accepting sub optimal gains in biodiversity or yield may lead to better outcomes than promoting a theoretically superior but locally inferior mechanism design.

PART IV

Agent-based simulation model development and outcomes

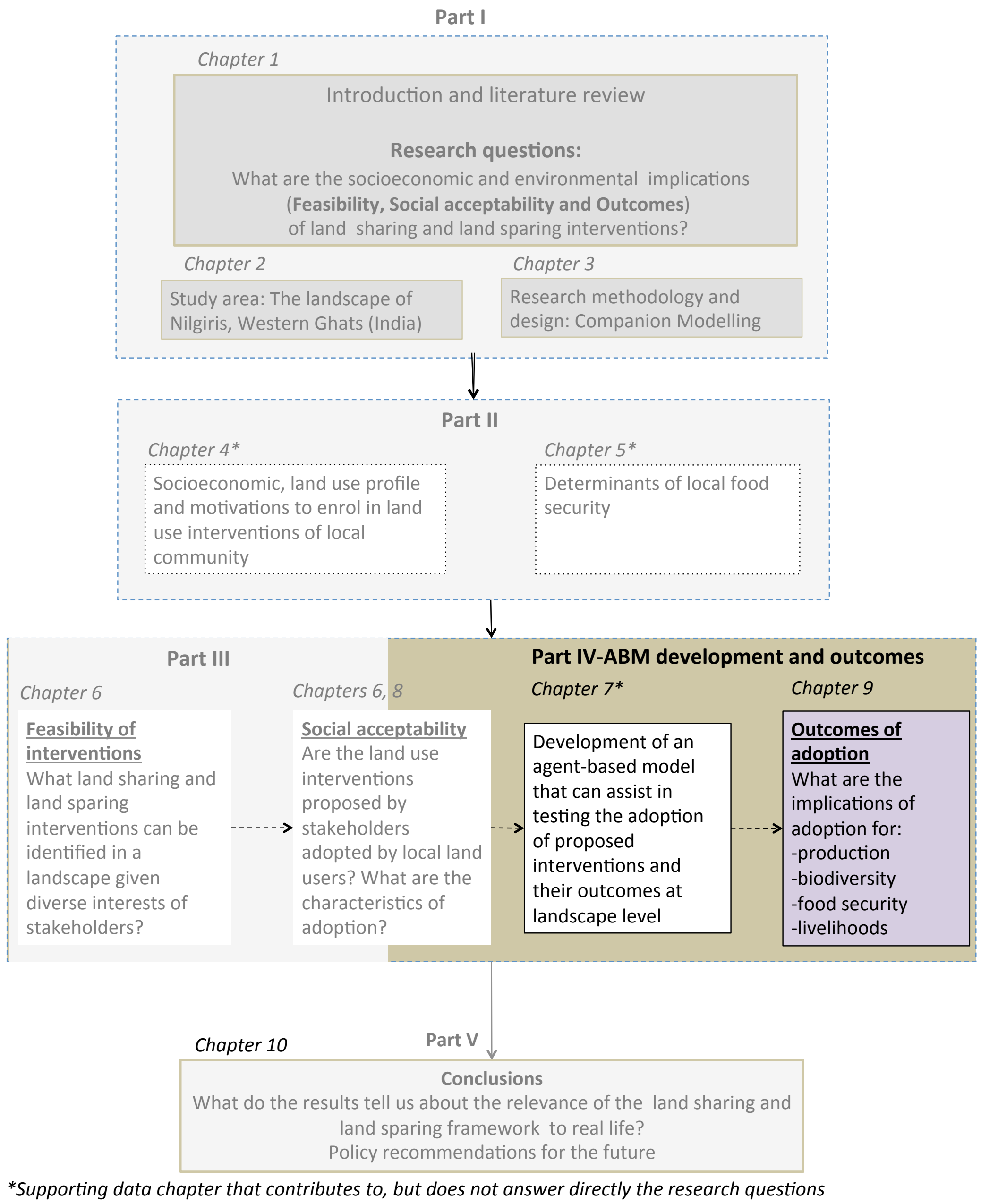


Diagram 1 Summary of research highlighting the questions addressed in Part IV-ABM development and outcomes.

Part II (Chapter 4 and 5) offered insight into the socioeconomic characteristics, land use profile and land use enrolment motivations of the communities under study through in-depth household survey and focus group data. Using a RPG, Part III (Chapter 6) further investigated farmers' land use decision-making processes, livelihood strategies and the characteristics of their enrolment in hypothetical agricultural and conservation land use interventions.

Part IV uses the findings of the previous chapters to simulate household decision-making in the Nilgiris agricultural system using a spatially explicit ABM, called the Policy Land Use Socio-Economic Simulation System (PLUSES).

This part of the thesis is divided in three chapters (Diagram 1). Chapter 7 introduces PLUSES using the Overview, Design concepts, and Details + Decision protocol (ODD + D), a standard protocol for describing agent-based simulations in a transparent manner that allows for reproducibility and facilitates the communication of the model and its results (Polhill et al., 2008b, Grimm et al., 2010, Müller et al., 2013). Chapter 7 concludes with a comparison of the model with eleven other land use decision-making simulators. Chapter 8 uses PLUSES to test the social acceptability (uptake) of different agro-ecological policy interventions by direct land users and Chapter 9 looks at the socioeconomic and environmental implications of adoption.

Part IV completes the last loop of the ComMod process.

Chapter 7

The development of an ABM for evaluating the socioeconomic and environmental implications of land use interventions

7.1 Introduction

The relevance of the LS/LS framework to real life is dependent on the social acceptability (uptake) of these interventions to direct land users and the environmental and socioeconomic implications (e.g. food security or livelihoods) of the two contrasting strategies (Fischer et al., 2014). Without understanding direct land users choices and the potential implications of their choices, proponents of the framework risk an incomplete picture that is not grounded in local realities and can paradoxically force into opposition the very conservation and development interests they seek to reconcile (Kremen, 2015, Bennett, 2017).

Simulating land users preferences can aid our understanding of the feasibility of such land use policies on the ground prior to their implementation. In the context of LS/LS, where research recommendations are yet to be translated into policy (Mertz and Mertens, 2017) and where there is little evidence of the social feasibility of these interventions (e.g. Jóhannesdóttir et al., 2017), engaging a land use decision-making simulation model could provide much needed insight. For example, testing proposed policies *ex ante* can elucidate how direct land users respond to such LS/LS policies, providing evidence to better inform the design of appropriate policies or interventions. Additionally ABM can provide insights into how a proposed policy design might translate to a novel context and how the socioeconomic and environmental implications of such policies manifest in the long term (e.g. Lee et al., 2014).

Agent-based land use simulation models have become important and powerful tools for assessing the uptake and impact of new policies on agricultural systems and the environment. This is because they allow for human decision-making to be represented in a flexible and context-dependent way (An, 2012). Land use systems behave as complex adaptive systems (Rindfuss et al., 2008) and few tools are better equipped than ABMs to simultaneously address aspects such as the heterogeneity among individuals and their interactions. ABMs can also represent the uncertainty of, and within, human behaviour whilst including structurally rich, dynamic, and diverse representations of social or ecological environments (Nolan et al., 2009, Milner-Gulland, 2012). When testing new policies, land use simulation models can help uncover potentially unanticipated adaptive system responses that a policy or intervention might trigger. It can help scientists and policy makers understand the implications heterogeneity (across individuals, contexts, or time) may have on a policy in the longer term or in contexts differing from those for which empirical evidence is available (Hammond, 2015).

Modelling farmers' decision-making

The application of agent-based simulation to modelling farmers' land use decision making in the context of agricultural policy is a relatively new but increasingly implemented methodology (e.g. AgriPoliS model developed by Happe et al., 2006, SimKat by Asseng et al., 2010, Abstract by van Oel et al., 2010, FEARLUS by Polhill et al., 2008 and Gotts and Polhill, 2010). While these models respond to different research needs, there is a lot of overlap in the decision-making processes they utilise. The models in the literature that are most closely related to the context of the current research, and could allow for the testing of policies similar to LS/LS are AgriPoliS (Happe et al., 2006) and LUDAS (Le et al., 2010). These are both sophisticated agent-based approaches to rural economics problems that allow farmer agents to make changes to their farms in response to shifts in agricultural and environmental policies. AgriPoliS was developed for the European farming context and the decision-making mechanism of farmers is dictated by economic factors. LUDAS was developed to find policy solutions for satisfying multi-stakeholders interests around natural resource use, namely a water catchment in Vietnam. The land users' decision-making process within LUDAS is informed by economic factors, social influence and the accessibility of resources.

Both models lack the capacity to simulate several of the human-decision making and contextual features that characterize the Nilgiris agricultural landscape and that are important for testing the LS/LS policies proposed by local stakeholders. Production in the Nilgiris is influenced by climatic variability and farmers base their land use decisions on financial profit and loss history. Selling land compensates for financial losses. Chapter 4 also indicates that policy enrolment can occur as a result of pro-environmental motivations and is conditioned by the type of farming practices adopted on the farms. A model of the Nilgiris that can simulate LS/LS policy must therefore incorporate the sale of land to cover financial needs, as well as the link between climate and productivity and account for the role of environmental motivations in determining land users' policy choices.

This chapter therefore describes the development of a land use decision-making simulator (PLUSES) that fills this research gap. PLUSES represents one of the first agent-based decision-making simulators based on empirical research in the Indian subcontinent (see review on land use simulators by Groeneveld et al., 2017).

Additionally, in this chapter I aim to position PLUSES in the recent literature on simulation models of land use change in agriculture by comparing it with eleven other land use simulators developed for testing policies in agricultural systems (e.g. AgriPoliS, LUDAS or FEARLUS).

7.2 Conceptual framework: integrating theories of decision-making into ABM

Within the last decade, a large number of agent-based land use models, which represent human decision-making, have been published. The majority of these models are not explicitly based on human decision-making theory and they often come along with a plethora of independent ad hoc assumptions of the decision process (Crooks et al., 2008, Groeneveld et al., 2017). Adequately representing human decision-making is not only an academic issue but also imperative for models in order to ensure reliable policy recommendations and avoid unintended consequences (Milner-Gulland, 2012, World Bank, 2014). Calls have been made for modellers to follow frameworks that better guide the choice of decision-making models (Groeneveld et al., 2017). These frameworks however are only just emerging (e.g. Balke and Gilbert, 2014, Schlüter et al., 2017).

To translate human behaviour observed in the Nilgiris into a formal model this research makes use of the most recent and overarching framework currently available, Modelling Human Behaviour or the MoHub framework (Schlüter et al., 2017). MoHub facilitates a broader inclusion of theories on human decision-making in human-environmental models drawing from the field of economics, biology, psychology and other social sciences. It is acknowledged that any chosen theory is unlikely to completely specify all aspects of human decision-making, hence models are likely to require additional assumptions (Schlüter et al., 2017).

The decision-making processes documented in the Nilgiris best align with bounded rationality theory that draws from two disciplines, psychology and economics (Simon, 1956). Bounded rationality assumes that agents have incomplete or uncertain information about the world. Their behaviour choice can be realized through maximizing utility, reaching an aspiration level or following a heuristic (Gigerenzer and Selten, 2001). This theory emerged in response to rational choice theory, the most prominent and commonly modelled economic theory of human decision-making (Bernoulli, 1954, Machina, 2008). Rational decision-making in neoclassical economic theory assumes that actors have perfect and complete knowledge and unlimited computational processing powers and they choose the option that promises the highest expected utility. But these assumptions have been widely challenged leading to the concept of bounded rationality (Simon, 1956). This decision-making theory has been successfully implemented in ABMs (e.g. Bell, 2011, Polhill et al., 2013).

As bounded rational agents, the Nilgiris farmers have limited information and knowledge of their environment and use heuristics to guide their decision-making choices. The heuristics have been drawn from the in-depth household survey and RPG data.

7.3 Data and Methodology

The overarching methodology of this chapter follows the ComMod approach detailed in *Section 3.3*. The ABM is developed using data from both of the previous ComMod loops in the form of input parameters, statistical distributions, probability rules as well as data on decision-making processes and derived algorithms. The sources of these data were:

i) Primary data from the Badaga in-depth household survey (*n*=265) on the socioeconomic, land use characteristic of the farmsteads and landless households and the different typologies of enrollers derived from their motivation to join schemes (*see Sections 4.3.1 and 4.3.7*);

ii) Secondary data on land use and land cover of the study area from Lakshumanan et al. (2012) that used cloud free Landsat-MSS, Landsat-TM and IRS-P6- LISS III satellite imageries for year 2009. Towards the end of this study more recent maps from the year 2016 have become available (Mamtha et al. 2016), but due to time constraints they were not incorporated in the last version of the ABM;

iii) Primary data on farmers' land use decision-making processes, livelihood strategies and characteristics of enrolment in hypothetical agricultural and conservation land use interventions derived from the RPG results (*see Sections 6.3.1.3, 6.3.2.1, 6.3.2.5 and 6.3.2.6).*

The model was coded in specialised software by a professional computer modeller based on the processes and data I provided.

The methodology used in the development and description of the ABM follows a step wise approach (Table 7.1) based on standard protocols and recommendations in the field that draw from the work of Grimm et al. (2010), Müller et al. (2013) and Macal (2016).

Table 7.1 Data, methodology and methods used in developing PLUSES

Phase/Aim	Type of data/Methodology/Method of collection/Description
Phase 1. Overview, Design concepts and Details + Decision Making	
Describes how the ABM operates by providing information on: agent attributes, the environment in which agents evolve and the behaviour of agents in response to the environment or agent interaction.	The description of PLUSES is done using the Overview, Design concepts, and Details + Decision protocol (ODD +D, Müller et al., 2013). The protocol is an extension of the ODD protocol developed by Grimm et al. (2010), to include the description of decision-making processes. Both of the protocols facilitate the standardization of ABM descriptions and have been positively regarded and embraced by the scientific community.
Phase 2. Experimental design	
Identifies the most productive and accurate methods for a. simulation run length b. model replication	a. Simulation run length is established based on stakeholders' interest and recommendation. b. Model replication is established based on the minimum number of replication that produced statistically reliable results.
Phase 3. Validation and Verification	
Conceptual Model Validation	Determines if the conceptual model reflects the aspects of the problem defined.
Data Validity	Determines if the data used to build, evaluate and test the system are correct and adequate.
Operation Validity	Determines if the operations and the results of the final software are consistent with the real system and sufficient accuracy for the model's intended purpose.
Computerized Model Verification	Determines if the programmed model accurately reflects the conceptual model.

The next sections present the three phases of PLUSES development (*Sections 7.4-7.6*)

7.4 Phase 1. Overview, Design Concepts and Details

PLUSES description follows the ODD+D iteration (Table 7.2).

Table 7.2 ODD +D protocol adapted from Grimm et al. (2010) and Müller et al. (2013). In italics are marked the processes that are not detailed in this study. They are either not relevant for the description of PLUSES model or have been already addressed in a different process of the protocol. With * are marked the processes detailed in Appendix 7.1

Structural elements	
Overview	1. Purpose
	2. Entities, state variables, and scales
	3. Process overview and scheduling
Design concepts	4. Design concepts
	• Theoretical and empirical background
	• Individual decision-making
	• *Basic principles (addressed in Theoretical and empirical background)*
	• Emergence*
	• Adaptation *
	• Objectives *
	• *Learning (Not Applicable)*
	• Individual prediction *
	• *Sensing (addressed in Individual decision-making)*
	• Interaction
	• Stochasticity *
	• Heterogeneity *
	• Collectives *
	• *Observation (Not Applicable)*
Details	5. Implementation details *
	6. Initialization
	7. Input data *
	8. Sub-models *

The full description of the model is presented in Appendix 7.1. Here I present a brief overview of how PLUSES operates.

7.4.1 Purpose

PLUSES is a land use decision-making ABM.

The purpose of the ABM is to understand:

i) If LS/LS policy interventions, proposed by local stakeholder groups, are adopted by direct land users, the Nilgiris farmers.

ii) What the impacts are of adopting (by direct land users) the three interventions, on local biodiversity, food production, food security and the livelihoods of a heterogeneous population of farm households.

PLUSES employs a scenario-based analysis to explore the impact of these changes. Agents represent households and their behavioural decision-making process is based on simple heuristics. Agents are assigned rules that have been derived from empirical data or observations from the RPG and household surveys collected during fieldwork. The model was developed independently from the local stakeholders, however questions raised during the modelling process were clarified with stakeholders where possible. Agent decisions depend on their land and financial assets, their priorities in satisfying different household needs, their interest in policy interventions, as well as on the decisions of other agents.

7.4.2 Entities, state variables and scales

Within the agent-based component the ABM has three hierarchical levels:

- *Agents* represent households, with as many agents modelled, as there are farm households in the six Badaga villages surveyed (*n*=1057). State variables of the agents include the location of the agents' farmsteads, farm size by land use, household composition and certain agent characteristics that define the policy enrolment profile (Figure 7.1). The farmers have a livelihood profile and strategy that is dependent on the available on-farm and off-farm income, the size of spending on farming activities, food and other maintenance and education costs and the order of priorities in satisfying household needs. The households can be landless or own vegetable or tea land, intercropped with trees or not. When the land use policies are introduced farmers can also own forest patches and wildflower meadows.
- *Population clusters* are groups of agents that belong to the same village, used for the initialization of the agent model component. PLUSES simulates six population clusters the equivalent of the six Badaga villages surveyed in the study area.
- *Populations* reflect social communication boundaries. Agents interact with other agents in the same population or with agents that are in close proximity but belong to other population clusters.

Within the cellular component, the environment is formed of patches. These patches represent the smallest landscape unit. Multiple patches can represent larger fields. State variables depend on the spatial and biophysical data available. PLUSES patch size was set at 1/10 of an acre (0.040 hectares), the smallest tradable unit in the landscape. The environment is formed of 501 X 501 patches or approximately 10 X 10 km and includes spatially explicit data on land use and land cover, slope, roads and village boundaries (Figure 7.2). The patches represent agricultural/vegetable land, tea plantations, forestland or rocky land and when the schemes are introduced there is a new land use, wildflower meadows. The farmers can only change the land use of tea and vegetable land and of the patches that have been enrolled in different schemes.

In other applications, the ABM can be parameterized at various spatial scales, ranging from a village community to a large region within a country, depending on model purpose and data availability.

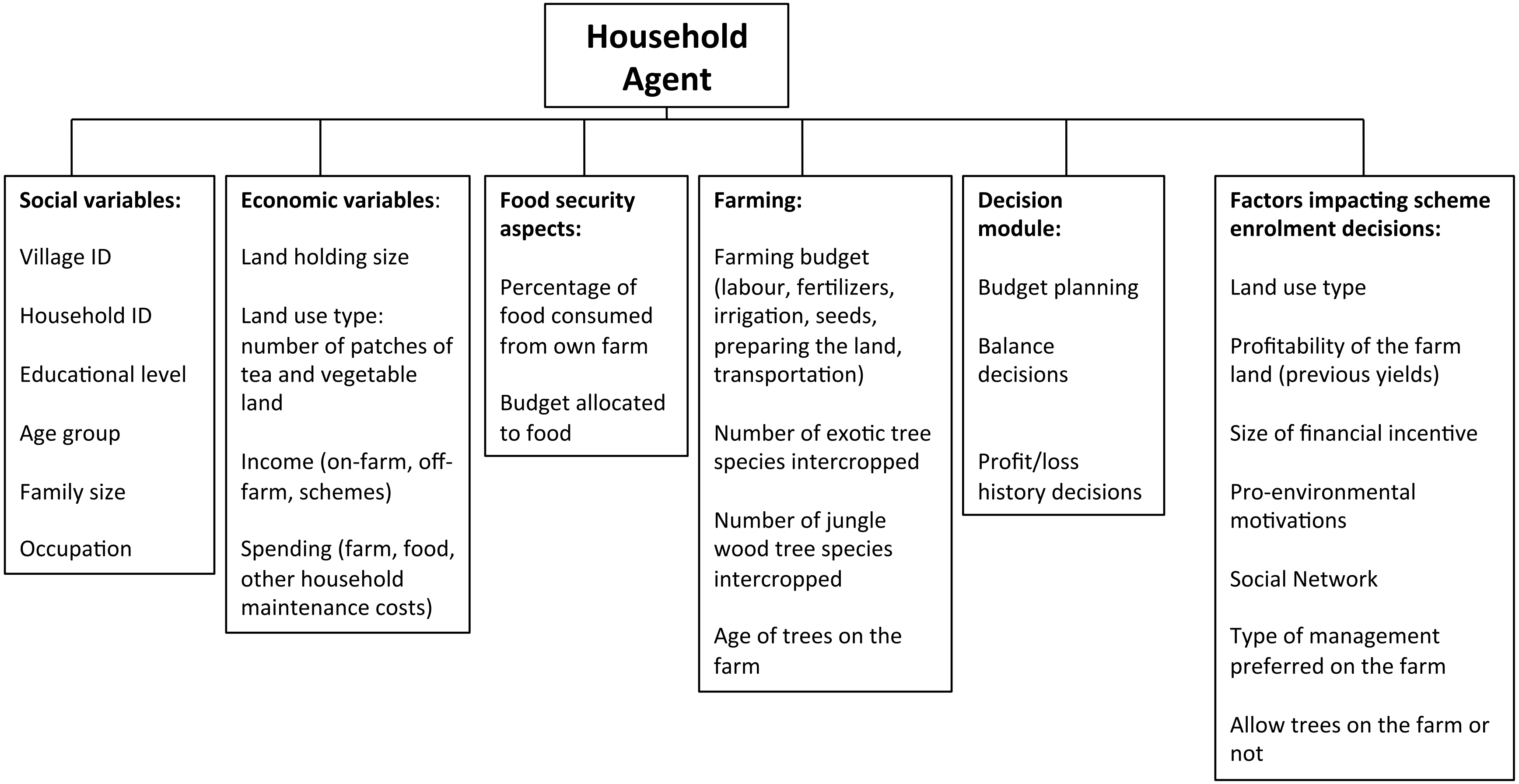


Figure 7.1 Agent-Based Model household agent profile

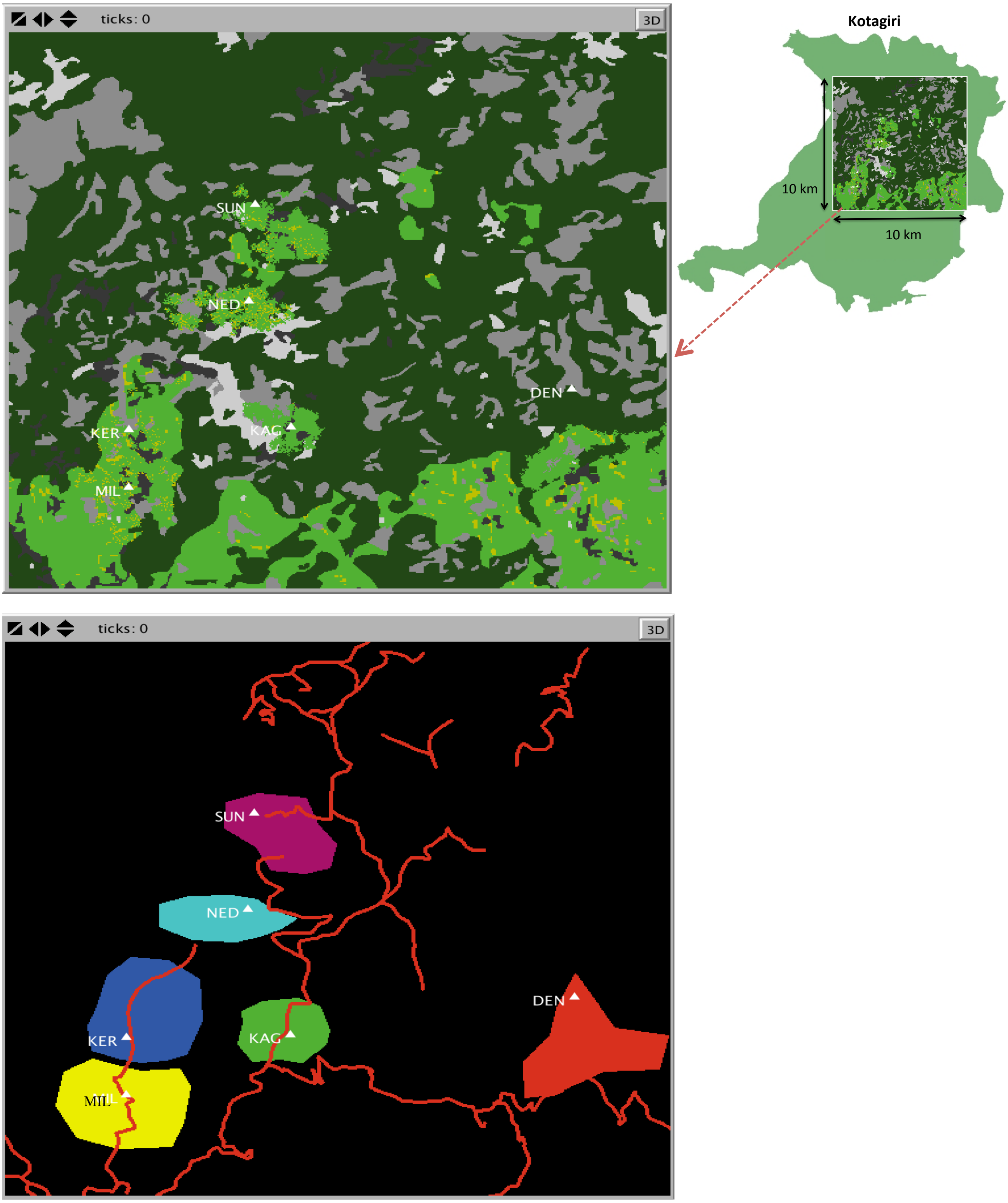


Figure 7.2 NetLogo representation of the land use and land cover map of the 10 X 10 km area selected (top maps) and the roads intersecting the six villages under study (bottom map).
Land use and land cover: forest (dark green), tea (light green), agriculture (yellow) rocky land and other land use cover (grey). The villages represented are: Sundatty (SUN), Nedugula (NED), Kercombai (KER), Milidhen (MIL), Kaggula (KAG) and Denadu (DEN).

7.4.3 Process overview and scheduling

The ABM proceeds in annual time steps. Within each time step, the agent decision module goes through 5 phases: policy enrolment procedure, spending decisions based on profit or loss history, budget planning, production and balance decisions (Figure 7.3). Four of the phases are agent decision modules and *Production* is classified as biophysical. While *Production* dose not represent a biophysical module in its true sense, as no direct modelling of ecological processes occurs, production is however influenced by environmental and climatic factors such as soil fertility and rainfall, which are reflected in variability across farms. The scheduling phases have associated sub-models (Figure 7.3) described in detail in Appendix 7.1.

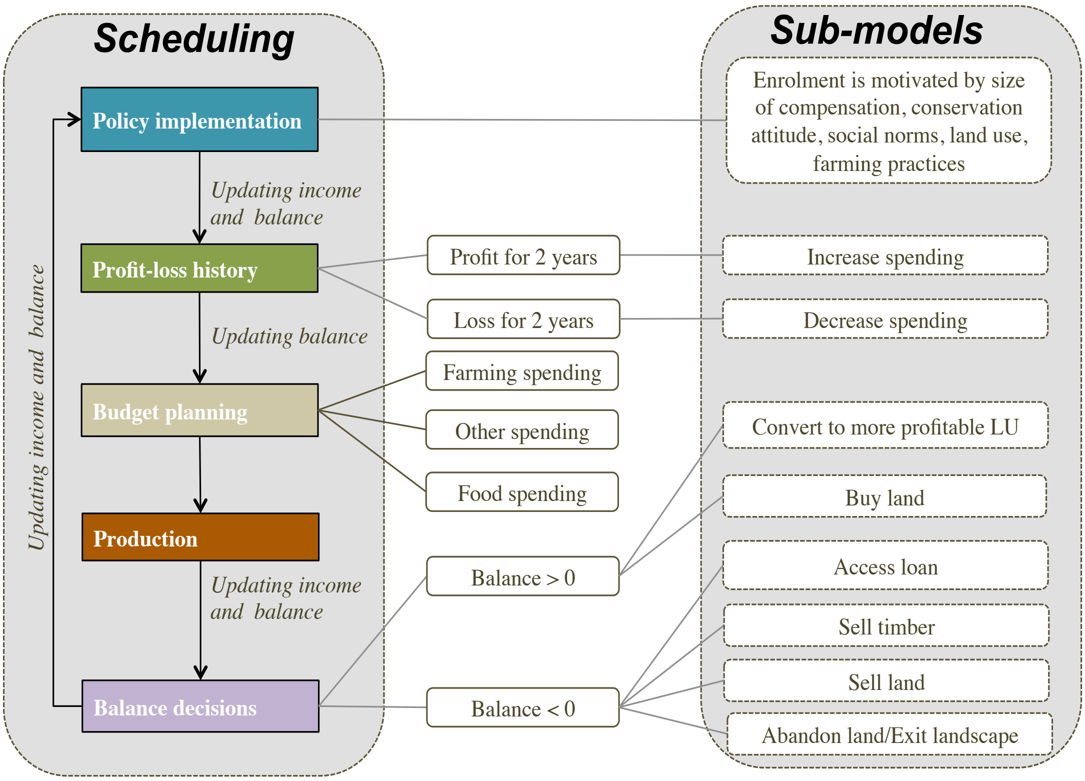


Figure 7.3 Agent-Based Model process overview and scheduling

Policy enrolment. In this module agro-environmental schemes that resemble LS/LS interventions on the farm are introduced in the system. Two of the schemes, Wildflower Meadows (Scheme A) and Forest Plantations (Scheme B), incentivise farmers to set aside land on the farm for wildflower meadows or tree plantations respectively while increasing production on the rest of the farm. The third scheme, Tree Intercropping (Scheme C), incentivises farmers to intercrop more trees on the farm (Table 7.3). As part of the enrolment process in Forest Plantations and Tree Intercropping farmers have to cultivate trees on the farm. Farmers are encouraged to grow native trees, however due to past tree rights controversies cultivation of exotic trees is also permitted. It is believed this way, more farmers will be attracted in the schemes and in a later stage of policy exotic tree cultivation can be phased out gradually. More information on scheme selection and specification are provided in *Section 6.3.1.3*.

Table 7.3 Terms and conditions of scheme enrolment used in the ABM based on the role-playing game

Schemes	Condition of enrolment	Effects of enrollment	Financial Incentive
Scheme A Wildflower Meadows	Own tea or vegetable land	-Land set aside for wildflower meadows on the farm -10% increase in yield on the rest of the farm	50,000 Rupees ($770) per acre of wildflower meadows set aside per year
Scheme B Forest Plantations	Own tea or vegetable land; Allow trees on farms	-Land set aside for forest plantations on the farm (200 trees/acre planted) -Choice between jungle wood or exotic species -10% increase in yield on the rest of the farm	65,000 Rupees ($1000) per acre of tree plantations set aside per year
Scheme C Tree Intercropping	Own tea land; Allow trees on farm	-Trees intercropped on the farm (100 trees/acre planted) -Choice between jungle wood or exotic species -10% decrease in production on the farm as a result of reduction in area under harvest	50,000 Rupees ($770) per acre of intercropped land per year

Before the next module, the model updates the household income and total balance based on the actual income from the farm and the off-farm revenue. The off-farm revenue is initialised at the beginning of the model for each individual household based on the household survey data and then held constant.

- *Profit or loss history* decisions. Consecutive years of profit means households will increase their spending with farming/food/other maintenance cost in the next year, whereas consecutive years of loss will attract the reverse action, decrease expenditure. The order in which the costs are increased/decreased is specific to each household and is determined by their priority in satisfying the household needs.

- *Budget planning* refers to household's decisions regarding how to allocate its available financial resources to meet farming costs (tea and agriculture), food and other household maintenance costs.
- *Production*. There are two production functions, one for tea and one for agriculture and they are both calculated in monetary terms using Cobb-Douglas function based on land size and the size of investment in farming (labour, fertilizers, pesticides, seeds, transportation, irrigation, preparing the land; Equation 7.1). The functions have been estimated based on data from the in-depth household survey. In the ABM at every time step the production is calculated for each individual farmstead.

Other alternative functions have been tested, such as cost-benefit evaluation or stepwise regression in R (R Core Team, 2016, Version 0.98.953) using explanatory variables ranging from land size, labour input, fertilizers inputs by type to number of tea plants and number of trees intercropped. However, none of the functions had a good statistical fit ($R^2 < 0.16$). Cobb-Douglas function was by far the most adequate model choice and recent studies have successfully implemented it as a production model in India (e.g. Singh et al., 2017).

$$Income\ Production = e^{Intercept} * Land^{alpha*Gradient} * Cost^{(1-alpha)*Gradient} * e^{Noise}\ ;\ Noise \sim Normal(Mean, Stdev)$$

Tea: Intercept = 5.96, Gradient = 0.93, alpha = 0.5, Noise mean= 0, Noise StDev= 0.3.

Vegetable: Intercept = 6.00, Gradient = 0.79, alpha = 0.3, Noise mean= 0, Noise StDev= 0.35.

Equation 7.1 Income from production for tea and vegetable expressed as a Cobb-Douglass function of land and cost.

<u>Estimating the Cobb-Douglas production function:</u>

- Calculate the natural logarithm (ln) of income, land and cost
- Construct a weighted sum of explanatory variables ln(Land) and ln(Cost) named *alpha* and *(1-alpha)*
- Use *alpha* and *(1-aplha)* as independent variables in an ordinary least squares (OLS) regression model with ln(Income) as the response variable
- Use Solver to find the value of the weight *alpha* that maximises the coefficient of determination (R^2) and plot the distribution of residuals

- Explore other values of *alpha* to observe how sensitive the Cobb-Douglass function and the residual distribution are to this
- To simulate production function, given parameters from fitted models, and values for agent's Land and Cost, the value for the residual noise was sampled from a normal distribution (Noise~Norm(0, 0.3) for tea and Norm(0, 0.35) for agriculture). The noise expresses the differences in production on each farm as a result of variation in productivity of land, slope, climatic conditions and market price variability.

For the tea production function (Figure 7.4) a value of *alpha* = 0.5 maximized R^2 and generated an approximately normal distribution of residuals (Figure 7.5). The gradient of 0.93 indicates decreasing return to scale (when inputs double, production output will be less than double).

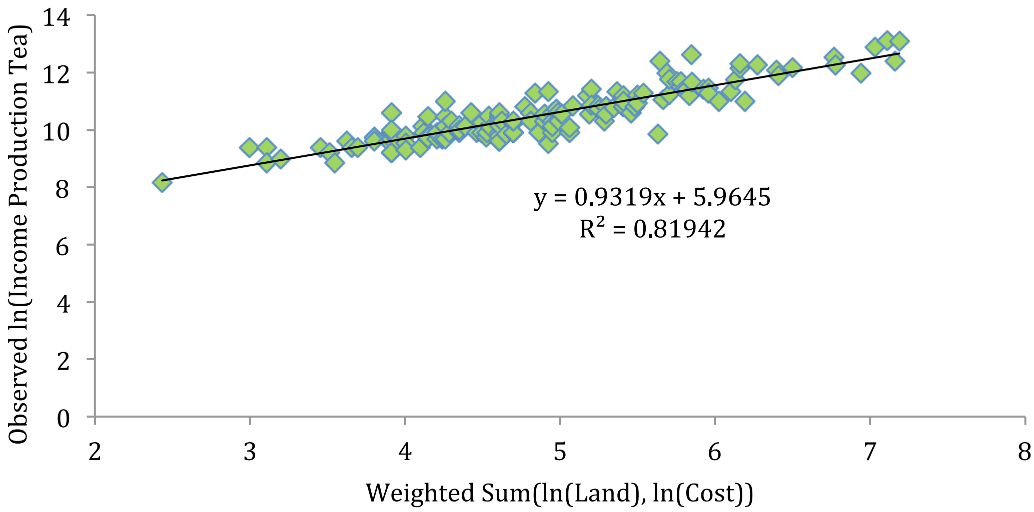


Figure 7.4 Estimated Cobb-Douglas function for tea yield (expressed in monetary terms) based on land size and size of investment in farming.

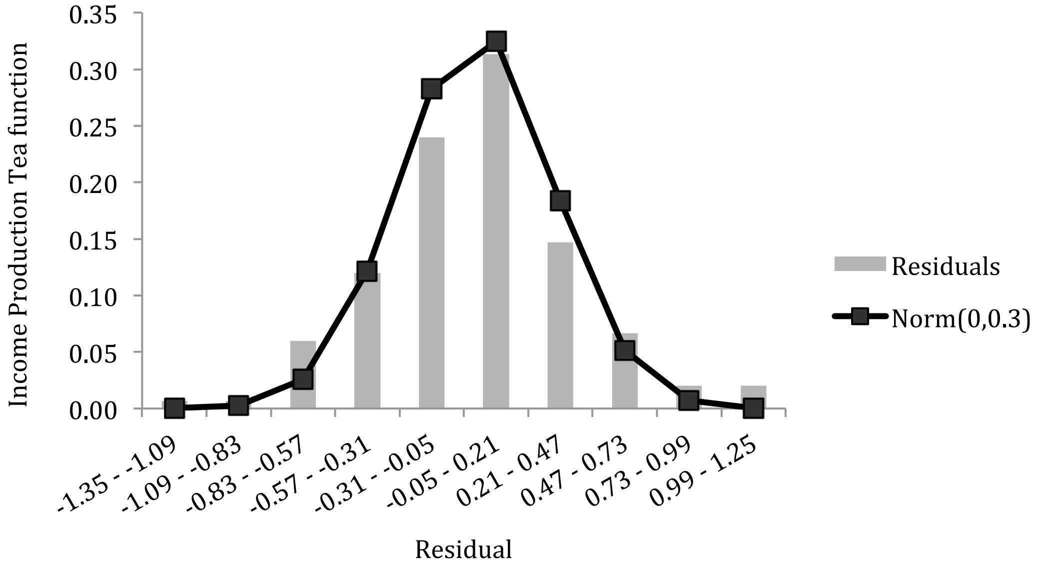


Figure 7.5 Histogram of tea production function residuals with normal probability density function fitted.

For the agricultural production function the value of *alpha* = 0 maximized R^2, which would imply ln(Land) was not a factor. Values of *alpha* = 0.3 produced values of R^2 nearly as good as *alpha* = 0 (0.68 versus 0.71), but the distribution of residuals was closer to normal (Figure 7.6). An agricultural function with *alpha* = 0.3 was therefore selected (Figure 7.7). Similarly to tea, the agricultural production function gradient of 0.79 indicates decreasing return to scale.

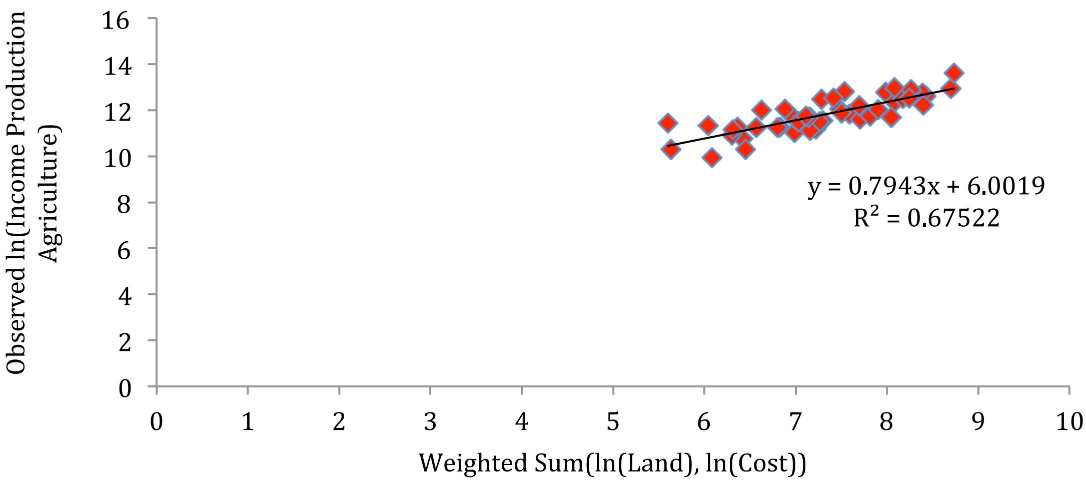


Figure 7.6 Estimated Cobb-Douglas function for vegetable yield (expressed in monetary terms) based on land size and size of investment in farming.

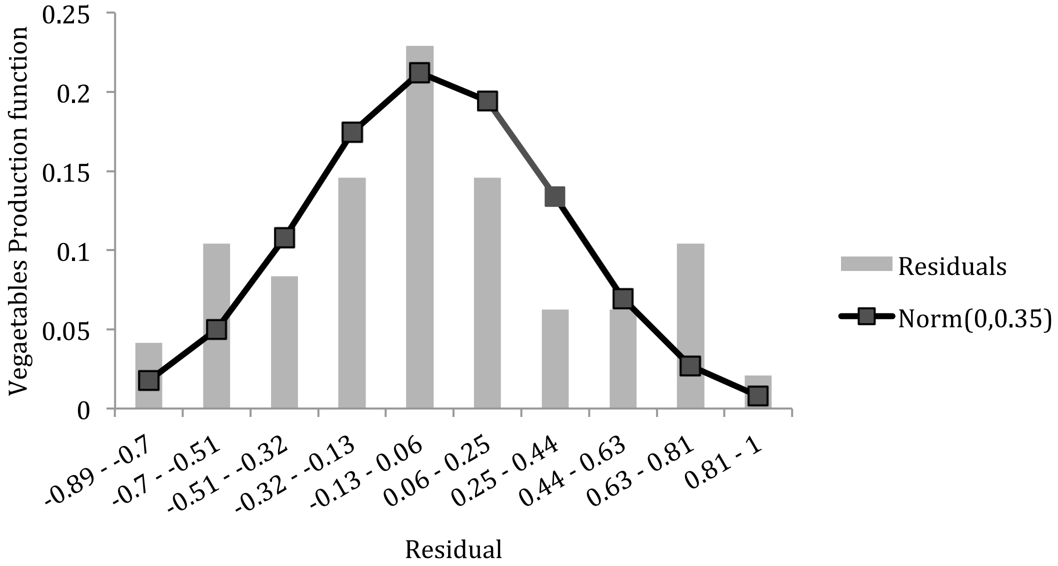


Figure 7.7 Histogram of agricultural production function residuals with normal probability density function fitted.

Unlike the RPG where farmers have a choice between growing different vegetable crops, the ABM uses an aggregated model to represent a mix of choices. Those growing vegetables will retain 10% of production for their own household consumption, based on average results of the household survey of Badaga communities.

- *Balance decisions* represent the last phase. The decisions influence agents' livelihood strategies. Agents with a positive balance can convert land to a more profitable land use or acquire more land. If the balance is negative the household will have to take some actions to cover its debt.

After completing the phases the ABM calculates the agents' household revenue. Part of the revenue is consumed or used to repay debts, and the remainder is added to savings that can be used for livelihoods and land use decision-making module in the next year.

At each time step two other processes occur in the model:

i) The age of trees on the farms is updated
ii) The land that became available for sale on the market and hasn't been bought by farmers could be acquired by the Agency and converted to forestland. The agency's decision to buy the land is based on a chance probability set by the user. Buying one acre of land and putting it into conservation is paying for the equivalent of 20 years of compensations (excludes management and protection costs). This represents a more cost-effective alternative on the long term and complements conservation on the farms.

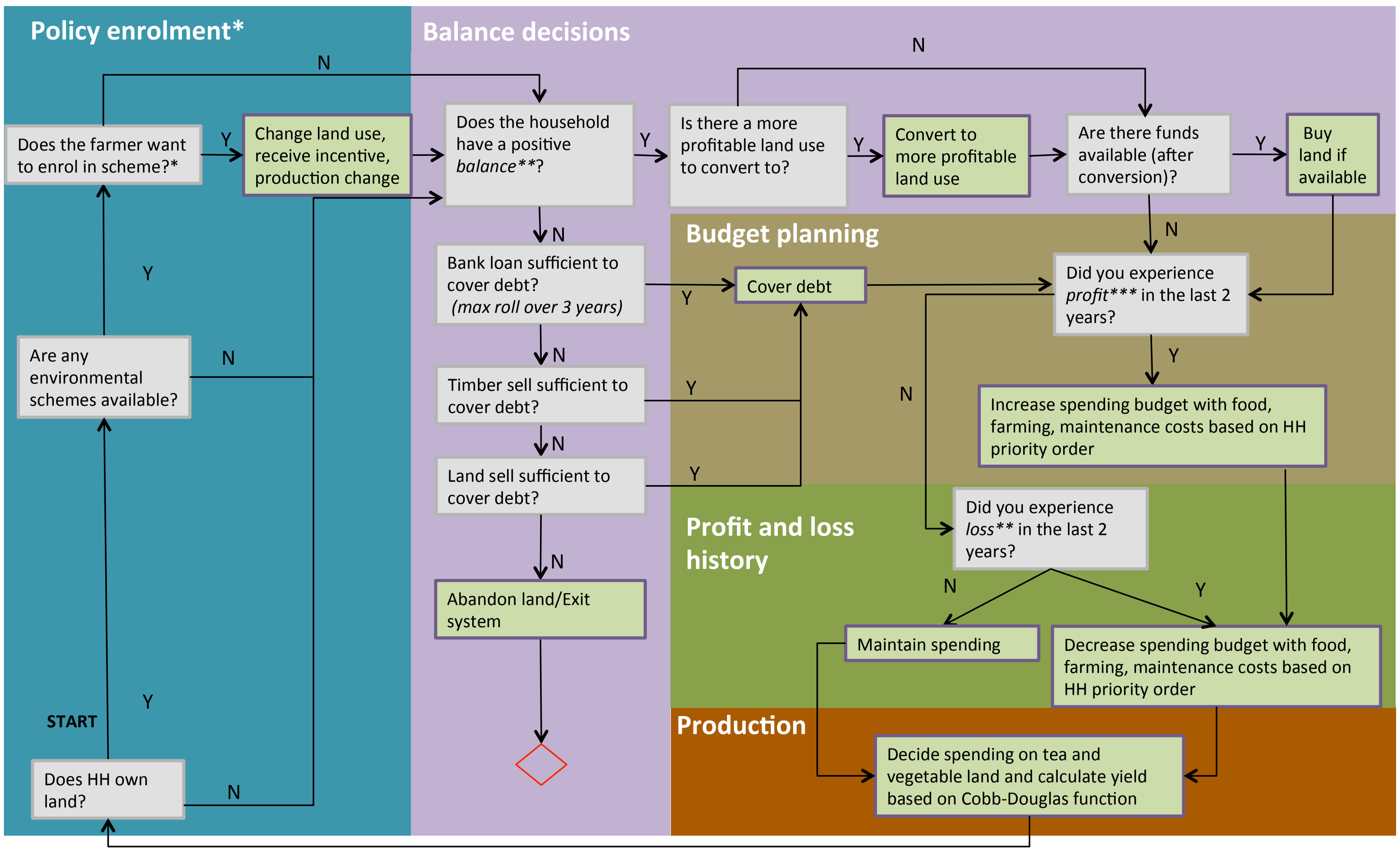
7.4.4 Design concepts

7.4.4.1 Theoretical and empirical background

The theoretical and empirical backgrounds have been detailed in this chapter in *Sections 7.1* and *7.2*.

7.4.4.2 Individual decision-making

At the core of the ABM are sub-models that simulate the decision-making of individual households. The sub-models are detailed in Appendix 7.1. Here I introduce a brief overview and a graphical representation of PLUSES decision-making (Figure 7.8) with the policy enrolment module detailed separately (Figure 7.9).



The Policy enrolment module is detailed in Figure 7.9

*** The aggregated difference between total income and total cost over time. It can result in savings or debt.*

****The difference between income and cost calculated at the end of one year of simulation*

Figure 7.8 PLUSES decision-making flow diagram. Colour coding based on process overview and scheduling diagram **Figure 7.3**

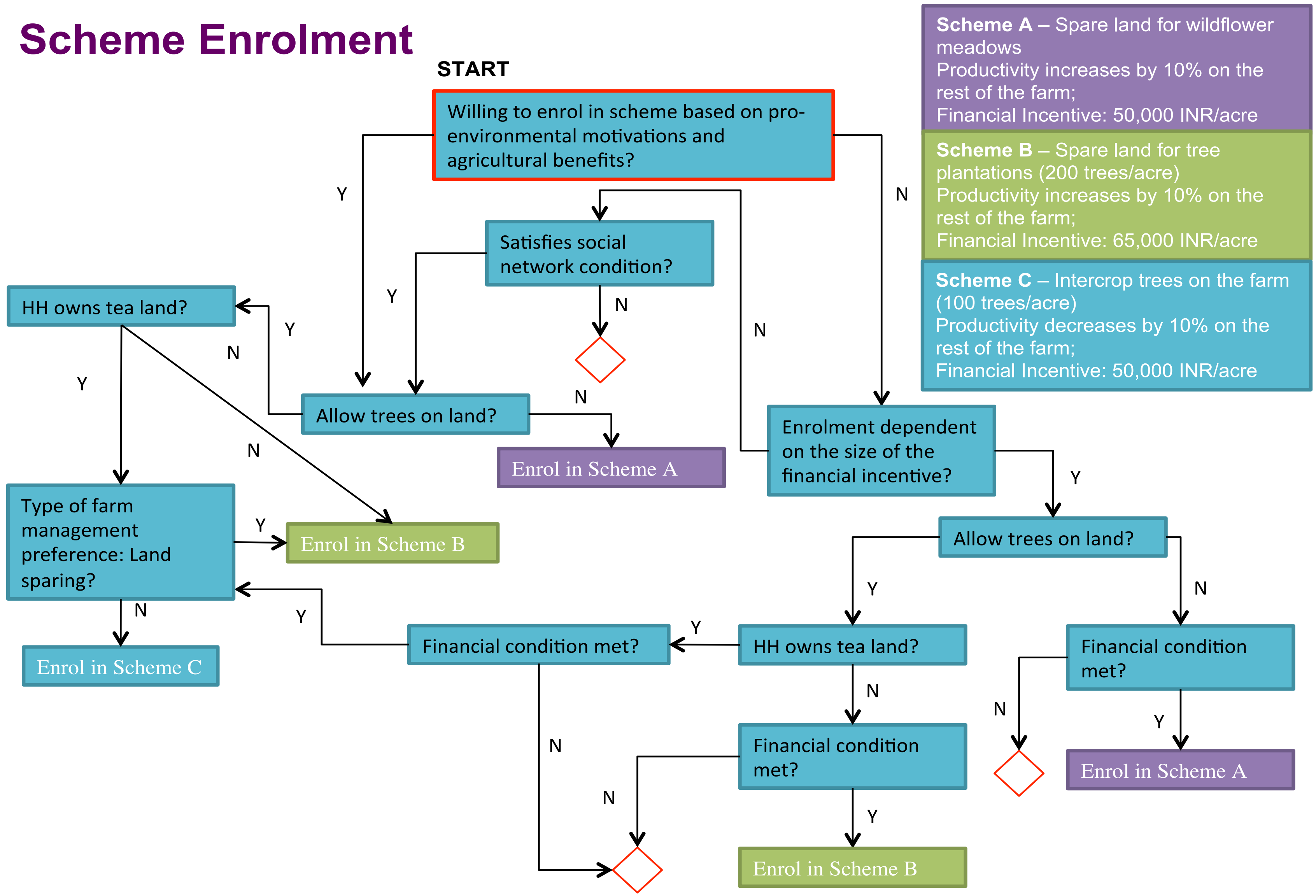


Figure 7.9 PLUSES scheme enrolment decision-making flow diagram

Agents' decision-making strategy is informed by financial, farming and scheme enrolment processes based on heuristics derived from the in-depth household survey or the RPG. All agents that own land follow the same decision sequence and go through the five scheduling phases (Figure 7.8). Landless households will omit the *policy enrolment* phase until they acquire land.

Farmers are aware of what is occurring on their property, how much land they have, crop profitability and how their land is distributed into land-use classes. Agents have incomplete information about their environment and they exchange information about farm profitability and scheme enrolment through their social network formed of neighbouring farms.

Scheme enrolment follows a stepwise process (Figure 7.9). First, agents' decision to enrol in the schemes reflects pro-environmental motivations, followed by financial motivation. Only when agents in this higher segment of enrolment have adopted, does the scheme become of interest to the agents in the lower segment. This stage includes a frequency-dependent contagion effect resulted from agents position and size of their social network and the size of the social influence threshold. The more agents join the schemes the more it is likely that other agents will learn about the effect of the schemes from their social network and reflect on enrolment. If the number of members from the social network is higher than a pre set social influence threshold (see details in Table 7.4), the agent will decide to enrol. Unlike the higher segment most of the agents in this lower segment are primarily motivated by social norms, whereby a farmer will enrol in scheme if their neighbours have already done so.

Regardless of the path of enrolment followed, all agents have to go through a condition check that will filter agents to the scheme that best meets their interest. The conditions look at the following factors: the type of land use, farmers' willingness to have trees on their land and the type of farming management accepted on the farm, which refers to the preference between integration or separation of production from nature on individuals farms. There is one more condition that applies only to those agents that are financially motivated and it refers to the size of the compensation. If the scheme incentive is more profitable than the return from agriculture, the agent is motivated to enrol.

All these preferences are mutually exclusive and as a result farmers will not leave to chance the decision of enrolling in one scheme or another. They will be guided by their choices to the scheme that best satisfies their preferences.

7.4.4.3 Objectives

Households may differ in certain attitudes relevant to the schemes, and in which spending budgets are prioritised. However, agents' objectives are not explicitly represented in the model. The decision processes imply that agents are motivated by profits (and negatively motivated by losses) and the return on investment on land. Additionally agents aim to improve their livelihoods by increasing their spending and not allowing a too greater gap between the socioeconomic identities implied by their respective levels of spending with farming, food and other household costs. Decisions about land conversions or transactions are motivated by long-term benefits or urgent financial obligations, whereas financial decisions influenced by livelihood strategies are optimized using short-term interests.

Agents are also obliged to clear debt when it has been rolled over three years in succession. These influences are common to all households. Agents that cannot repay the debt and cannot meet a minimum cost of living for multiple years are forced to abandon their livelihoods and migrate out of the landscape.

7.4.4.4 Interactions

Agent-agent interaction

Interactions between agents occur in three instances: during land transactions on local land markets, by sharing information on land use profitability and through scheme diffusion.

Land transactions occur between agents belonging to the same village. The ABM has an internal mechanism that connects the supply and demand in each village. Land that is not transacted remains temporarily on the market until buyers and sellers are paired. When the Agency is operating in the landscape it will buy the land that has not been transacted. The land will be used for conservation purposes.

Two further interactions occur within social networks and relate to agents' decisions regarding land use conversions and scheme adoption. Agents will gather information about their neighbours' return on investment from different land use practices in order to make more informed and profitable decisions about their land use strategy.

In a similar manner farmers that are reluctant to enrol in schemes benefit from the experiences of their neighbours before reaching a conclusion. Agent interactions in scheme enrolment diffusion were implemented as frequency-dependent contagion effect; thus the more neighbouring agents adopt a scheme, the more it becomes accessible to others.

Agent-environment interaction

The bidirectional interaction results from agents' direct impact on environmental dynamics through choice of crops, tree cultivation, logging strategy, investment in farming and scheme enrolment.

The total production influences farmers' crop choice, farming investment and for a category of agents the decision to enrol in the schemes available in the landscape.

Enrolling in schemes brings additional income to farmers, but places constraints on what agents can do with the land.

The sale of land also provides additional income for farmers. If bought by the Agency the land is converted to forest and taken out of production.

7.4.5 Initialization

There is a suite of parameters (Table 7.4) that were initialised using household survey data or the RPG outcomes. This section introduces the rationale behind the parameter initialization following their order in Table 7.4. Details about the functions used in the ABM to calculate the values of some of these parameters are presented in *Section 7.4.3* and in Appendix 7.1

Similar to the RPG, the farmers were initialised with no debt or savings due to a lack of financial data history. To understand how financial decisions might be affected sensitivity testing was performed on the initial household balance parameter. The outcomes and their implications are presented throughout Chapter 8 and 9. Ideally, the model would have included data about the financial history of each individual household.

Table 7.4 Baseline settings of the PLUSES parameters and the assumptions made in the simulation

Parameters	Baseline	Explanation and assumptions made
Miscellaneous		
Initial Household Balance (debt and saving from past years)	0	All households start with no debt or savings from precedent years because there is no financial history data available. Sensitivity testing was performed on this parameter to understand how financial decisions are affected by variation in initial budget.
Initial Land Allocation	Grow from centre	The allocation of households in the landscape happens from the centre of the village end expands towards the boarders, at random.
Yield calculation	Cobb-Douglas, variation each household, each year	The yield varies between each household each year to account for the production variability measured in the household survey.
Schemes, Incentives and Regulation		
Enroll in Scheme A, B and C	On	Farmers can join any of the schemes
Social Network Size	10	This value reflects the number of close contacts a farmer consults before taking a land use or scheme enrolment decision.
Social Influence Threshold (SIT)	5	Based on household survey data there are farmers that enrol in schemes only if members of their social network have already done so. This value represents the minimum number of members that have to enrol in any of the schemes before a farmer with a social network condition decides to join.
Financial Incentive Schemes	A, C: 5000; B: 6500 (INR Per year per patch)	See Table 7.3.
Production-Increase/Decrease	Scheme A, B: +10 %; Scheme C: -10%	See Table 7.3.
Bonus for neighbouring land	On	It applies when farmers enrol land together in Scheme A or B, on continuous areas
Bonus Incentive	1000 INR per patch	
Minimum number of continuous patches to obtain bonus	10	
Scheme Drop out chance	10%	There is a 10% chance that a household would drop out from a scheme at the end of a year. This is to account for households that, due to a variety of possible reasons, no longer want to be part in the schemes or are unable to remain within the scheme.
Scheme Exit Penalty	5% income from scheme	When farmers drop out of schemes they have to pay the equivalent of 5% of the total income made from schemes up to that point.
Delay in re-joining	5 years	It is expected that farmers that recently dropped out of a scheme will have a delay before enrolling again if they meet the conditions of enrolment.
Land use conversion		
Conversion of Agriculture to Tea and Tea to Agriculture	On	Farmers can convert land

Financial		
Profit-loss history length	5 years	Farmers remember the profit and loss history of the past 5 years
Number of years before increasing or decreasing spending budget	2 years	Increasing or decreasing the spending budget of a household comes only after 2 years of profit or loss respectively. The value of this parameter was chosen arbitrarily because there was no information available about the individual households.
A. Positive balance		
Buy land	On	Farmers can buy land that becomes available on the market.
Chance Agency buys left over unsold patches	100%	The environmental agency always buys land that remains available on the market at the end of the year.
B. Negative balance		
Max Loan roll over	3 years	Farmers that take loans have to repay them within a maximum 3 years.
Loan interest rate	5%	
Sell Timber	On	Farmers can sell timber on the market.
Sell Land	On	Farmers can sell land on the market.
Emigrate or Abandon land	On	The household is not part of the simulation anymore and the land becomes available on the market.

At the beginning of the simulation, farmsteads were allocated land of the size and type they have declared in the household survey. In the absence of cadastral maps the lands were not given the exact geographical location, but were allocated at random, starting with the centre of the village and growing towards the administrative village boarders. This parameterization means that households are sharing new neighbours compared to real life. Given that neighbours influence each other's choice of scheme enrollment and the size of land enrolled it was expected for the allocation to have an effect on the outcomes of these variables. Sensitivity testing showed that the effect is not statistically significant and that random allocation does not bias the results in favour of one scheme or the other; neither it changes the size of land enrolled in each intervention. Furthermore, PLUSES' landscape was initiated by importing GIS-raster files of landscape variables that are either secondary data (land cover, roads and digital elevation model) or produced by separate spatial analysis (village boarders).

The villages were initialised with agents from the household survey plus randomly sampled clones of the surveyed households to make the village population up to the known sizes following a similar methodology to LUDAS model (Le et al., 2010). The cloning was done at village level. By applying this method a heterogeneous population was created in the landscape with a close statistical fit to the surveyed population.

At initialization farmers received a social identity and household profile that includes the size and type of land declared in the household survey within the boundaries of their own village.

Based on land use type, distance from the road and slope each owned patch receives a land market value. Owned patches also receive a number of trees that was declared by the farmers in the household survey.

The yield functions for tea and vegetable crops were derived from the data obtained from the household survey. The functions are presented in *Section 7.4.3*. The yield is calculated yearly and it varies between each household each year.

The Social Network Size was introduced in the ABM based on the behaviour observed during the RPG and the information obtained in the household survey. Some households consult their social network before they decide whether to enrol in an intervention or not. The Social Network Size of a household is likely to vary between different households. As there were no data collected on the Social Network Size of the individual household, the value was standardized across the entire population in order to avoid making further assumptions. Similarly to Social Network Size, the Social Influence Threshold value is likely to vary between different households. Again, as there was no individual household measure, the value was standardized across the entire population. Sensitivity testing was then performed to understand how changes in its value affect scheme enrollment (see *Section 8.3.2.1*).
All the other parameters under "Scheme, Incentives and Regulation" described in Table 7.4 followed the same parameterization as the RPG. However, there are two additional parameters that are missing from the RPG and were introduced in the ABM: Scheme Drop out and the Delay in Re-joining interventions after a household left the intervention. There is no information about the conditions under which a farmer would leave an intervention (see *Section 7.7.1*) or re-enrol in one. Given the RPG debriefings with the local farmers it was considered important to have these parameters (see *Section 7.7.1*). Thus, they were added to the ABM and their baseline value was set based on the local stakeholders' group recommendations.

The financial decisions (see details in *Appendix 7.1 Decisions based on profit or loss history)* and initial parameterization of some of the variables related to budget decisions are based on the RPG rules and on observations and lessons learned from the game sessions (see *Section 6.3.2.5*). During the RPG feedback sessions, farmers debated that making important changes to their current budget only comes after several years of profit or loss. This is due to the unpredictability of farming outcomes. As a result in the ABM it was proposed to keep track of the profit and loss history of the farmers and to allow them to make budget adjustments based on this history.

Finally, there are two important processes that were added to the ABM that were deliberated during the RPG feedback sessions with the stakeholders and players. The first one refers to giving the Agency the ability to buy land that remains available on the market at the end of a simulation year and convert it into conservation land instead of being abandoned. This will have implications for the total land spared for conservation (see Chapter 8, Figure 8.8). The second difference is that farmers were given the option of selling timber from their lands, which was not possible in the RPG. This provides additional income for households that encounter financial difficulties and need to repay loans or cover costs with household maintenance, food, farming and education.

7.5 Phase 2. Experimental design

The output metrics of interest, the scenarios tested and the indicators varied during sensitivity testing are all detailed in Chapter 8 (Table 8.1, Table 8.2 and Table 8.3 respectively) and Chapter 9 (Table 9.1, Table 9.2 and Table 9.3 respectively). The output metrics include socioeconomic and environmental indicators such as population median income, Gini coefficient, food security, total number of trees cultivated in the landscape or connectivity of the protected patches enrolled in schemes. There are 9 scenarios tested that range from business-as usual to running the intervention one at a time or all together. Although stakeholders' participation prevented the development of unlikely or unfeasible policy scenarios, the ABM is equipped to test alternative, even more radical scenarios, and use the model as a testing space for such theories.

Indicators that were varied during sensitivity testing include initial household balance, Social Influence Threshold (SIT) or the level of the Financial Incentive (FI).

Simulation run length was established at 30 time steps, the equivalent of 30 agricultural years. The run length was established by stakeholders that considered anything beyond this timeframe would be difficult to predict in terms of institution stability, climate change, outmigration, land use decision-making processes, technology diffusion and policy implementation, monitoring and funding capacity.

The number of independent model replications was set at 20, the minimum number of replication that produced statistically reliable results for all indicators of interest.

An example for demonstrative purpose (Figure 7.10) shows that the model becomes stable after less than 20 years for two of the scenarios tested. Restricting the number of replications to 20 therefore minimised computational run time without impacting the reliability of results (Robinson, 2014).

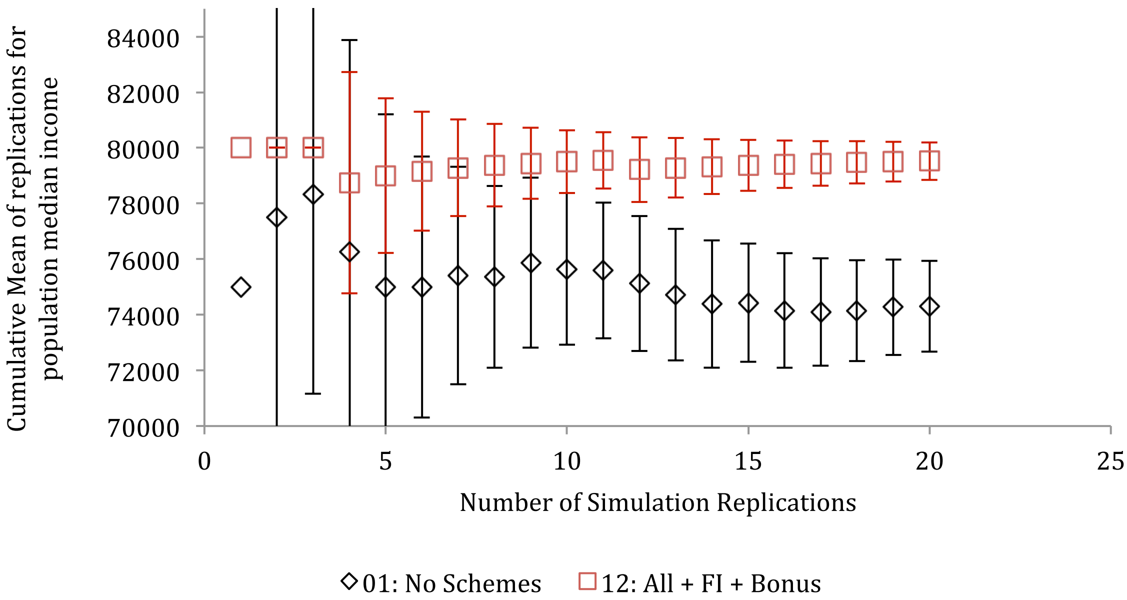


Figure 7.10 Example showing 95% confidence intervals for one of the output metrics of interest (population median income) based on the number of simulation replications, under two different scenarios. The "No Schemes" scenario means the simulation is running without any policy intervention. In the second scenario, "All + FI + Bonus", the model runs with all the schemes at the same time. The schemes carry a financial incentive and there is a bonus for farms that connect the land spared for conservation.

7.6 Phase 3. Validation and Verification

7.6.1 Conceptual model validation

The conceptual model validation process was carried with the stakeholders, in five stages: 1) before implementing the RPG, 2) during the RPG trial workshops, 3) post RPG workshop sessions, 4) before implementing the conceptual model into the computer simulation and 5) during the model implementation (but only sporadically for particular questions of interest, otherwise assumptions were made). See details in Appendix 7.2.

7.7 Discussion

7.7.1 So what? Linking model assumptions back to reality

PLUSES seeks to model land use and livelihoods decision-making in the Nilgiris landscape. A key process in making insights derived from PLUSES useful in the real world is understanding how model insights change as its assumptions are relaxed. In this model, a number of simplifying assumptions were made regarding food security, budget planning, land-use and land transaction decisions and policy enrolment. In this section I discuss how the more complex, real-world versions of these processes might impact the study results.

Firstly, all agents in the model follow a linear process in terms of their response to financial loss or gain (see *Section 7.4.3* and Figure 7.8). This is certainly a common strategy applied by the Nilgiris farmers, but is a simplification of the variety of human behaviours around financial decision-making. Farmers may respond to financial losses or gains following a different sequence or may choose to discard some of the steps in the sequence. For example, farmers that are better off may decide to invest their savings in other activities or assets, such as education or local businesses rather than land acquisition, which is the only investment option modelled in PLUSES. As a result, in the model, richer households accumulate more land than would be expected in the real world. Not accounting for this process is likely to produce more conservative biodiversity outcomes in the model. Wealthier households create more competition for the environmental agency on the land market and as a result less land is likely to be converted to forest.

Another assumption holds that agents convert tea to agricultural land based on crop profitability and on the slope of the terrain. Using profitability as a decision-making factor was observed for almost all players of the RPG. However tea is a long-term investment crop that requires a larger start up fund. Once established, it entails minimal maintenance and is also associated with a higher social status. Profitability and slope characteristics are therefore important decision-making factors, but not the only measures on which farmers base their decisions (Sharma and Barua, 2017). In order to avoid making further assumptions about different farming behaviours, profitability and slope were considered to be the most useful standard measures against which farmers take decisions about land conversion. In the real world the conversion rate of tea to agricultural land is expected to be lower than in the modelled scenario. The implications of this differentiation are more difficult to disentangle. It is expected that farmers will make more profit over time, as agricultural land is generally more profitable than tea, and as a result agents are less likely to face financial debt and exit the simulation. A higher proportion of agricultural land in the simulation landscape also means a reduced potential for the adoption of Tree Intercropping (Scheme C) given that it can only be adopted on tea land.

Within the model only land plots offered by farms in deficit enter the land market. This is certainly a major component of land that gets sold in the Nilgiris landscape. However farmers who do not have a debt may also attempt to sell their land in an effort to migrate to nearby cities. This mechanism is excluded from the model to avoid introducing further assumptions about which farms are likely to make the choice to voluntarily emigrate from the landscape. The impact of excluding this mechanism is likely to be a more conservative estimate of land aggregation, as only some of the means through which successful farms or the environmental agency can buy up neighbouring land are included in the model.

Another important simplification in the model is that there are no wholly unexpected costs borne by the farmers. In reality, injury or illnesses among family members are unpredictable shocks and can drive the need to reduce household spending, sell off timber and ultimately monetise land. It is reasonable to assume that the risk of injury or illness is uniform across the population, if not higher among poorer farmers, and that richer farmers will be better prepared to weather these shocks. This simplifying assumption likely leads to households having inflated financial assets over time and as a result poorer households are more likely to stay in the landscape for longer.

The representation of food security in the ABM was also simplified. Based on the analysis presented in Chapter 5 (see *Section 5.5*) food stability, access and utilization are important pillars of food security in the study area. Measuring food stability and utilization using the two metrics of interest, food shortage and Food Consumption Score, would have required a considerable level of additional complexity and computer power that were not feasible for this research. Excluding these two pillars from modelling means that conclusions about food security could be extrapolated at the population (landscape) level only in one component of food security, food access. This pillar was measured in the model as the total food budget allocated by a household and the amount of food retained for consumption from own production. In measuring the food budget the ABM included all the determinants of food security identified in Chapter 5 (see Table 5.8) except two: ‘education’ and ‘household type’.

These factors were not integrated in the model due to several reasons: i) limited information on the households' education processes over time, ii) time constraints, and most important iii) no demographic processes represented in the model. The absence of demographic processes (see justification later in this section) strongly influences the impact of the two factors on food security. If marriages and deaths would have been represented certain households could have changed, for worse or for better, their food security status. For example, by marrying into an educated male-headed household the most vulnerable households (female-headed with low level of education) could benefit from an increase in food security. The reverse could also occur. By losing the male head and becoming a female-headed household the level of food security could decrease. This simplifying assumption means that the model produces less variation in food security behaviour; but the long-term impact on population food security is difficult to forecast in the absence of demographic processes.

A final simplification of the model is that, in the first stage of enrolment, agents are influenced in their decision to adopt a scheme by only one of the three primary drivers: social influence, financial incentives or pro-environmental motivations. Data on secondary drivers of enrolment were collected using the in-depth household survey, however less than 2.5% of the Badaga households (see *Section 4.3.7.3)* declared they base their decisions on more than one driver. Hence secondary drivers were not simulated in PLUSES. In reality it is expected that more farmers will use a combination of motivations to determine whether to enrol in a scheme or not. A sufficiently detailed understanding of these motivations and their interactions will require a different data collection approach. For example, PLUSES could be used to unlock discussions on different motivations in communities such as the Nilgiris that have limited or no experience with land use policies on their farms. Utilising a single motivational driver per agent in the model means that more farmers are likely to enrol in each scheme than in reality.

Like most of the models, PLUSES comes with a series of limitations and the potential for improvement.

Firstly, in the current model version of PLUSES, neither the change in family composition nor the founding of new households is operational. As a consequence the number of households within the landscape cannot increase, but it can decline over the simulation period as a result of land abandonment. The abandoned plots become available on the land market. Model behaviour is then the result of financial, farming and scheme decision processes, not demographics. Omitting the latter reduces the variability in model output and allows seeing more clearly in the experiments what results from the structure formed by the former processes. At the same time, by not representing the formation of new households, primarily through marriages, there is an incomplete picture of how the land is being reallocated within the villages and how this might impact policy adoption.

In terms of financial limitation and future opportunities the model could be developed to incorporate an assessment of the financial 'health' of the agent before being granted a loan. Other improvements could be made using spatially explicit data of the farms' location, either from farm survey or cadastral maps of the area.

While in its first stage of development PLUSES successfully combines social, environmental and economic components, the dynamic interaction between them is still limited. Integrating these interactions is desirable to better capture management options for agricultural systems in which the economic processes and social interactions of farmers and other land users partly depend on ecological changes, and in which the environment changes in response to the decisions and interactions of all land users (e.g. Schreinemachers and Berger, 2011). Such development will enable PLUSES to achieve a more sophisticated form of modelling, that of socio-ecological systems (Janssen and Ostrom, 2006).

7.7.2 Comparison of decision-making processes with other recent simulators

This section presents a brief comparison of PLUSES to other agent-based simulations of human decision-making in agricultural systems. The purpose is to position PLUSES in the current literature by looking at the different purposes the models were developed for and by comparing the decision-making routines used across different software packages.

The models for comparison were selected from 134 agent-based land use models reviewed by Groeneveld et al. (2017). Three selection criteria were used to identify the most relevant ABMs to the current research:

i) The objective of the research should be decision-making in agricultural systems.
ii) The models were developed to test land use policies.
iii) Agent decision-making is influenced by at least any one social, economic or environmental factor.

By applying these selection criteria, ten relevant land use simulators were identified. The list was expanded to eleven models to include AgriPOLIS simulator (Table 7.5). AgriPOLIS did not meet all three selection criteria as it only focused on economic factors of decision-making. However, an exception was made and the model was included for comparison due to close similarities in the land use processes simulated in PLUSES.

Table 7.5 Description of decision-making agent-based simulators in agricultural systems selected for comparison with PLUSES

	Study Area	Agricultural System	Study purpose	Decision-making	Factors influencing decision-making	Yield function
AgriPOLIS (Happe et al., 2006)	Original model based on an abstract agricultural region	Abstract agricultural system; interface equipped to initialize the model with empirical data of existing regional agricultural structures	System understanding and management or decision support Analyse the impact of a regime switch in agricultural policy on structural change under various framework conditions	Bounded rationality A farm agent's decisional rule is to maximize household income with respect to a set of farm resource constraints	Economic	Crops' yields expressed as a function of land, labour, and capital (includes both money and assets for production)
Bell, 2011	Ji-Paraná River Basin, Rondônia, Brazil	Cattle ranching	System understanding, management or decision support and hypothesis testing Investigates the social, economic, and environmental outcomes that can be expected as a result of environmental licensing in the context of climate change	Bounded rationality based on heuristics	Economic, Social influence	Grass regeneration function
Bone and Dragićević, 2010	British Columbia, Canada (292 km^2)	Forest companies that have been granted a license for harvesting a specified volume of timber within a designated jurisdiction	System understanding and management or decision support Multi-stakeholder forest management agent-based model that aims to achieve optimal forest harvesting strategies through the integration of reinforcement learning.	Bounded rationality using reinforcement learning based on cognitive maps	Economic, Environmental - altruistic	Forest growth modelled by increasing the age and volume of each stand in the forest
Caillault et al., 2013	Abstract landscape. The landscape is composed of 25 X 25 spatial units, or 625 farms.	Farmers own three type of land uses numbered 1, 2,3	System understanding and theory development. Understand the effect of three different incentive networks on fragmentation and heterogeneity of the landscape	Bounded rationality Agents have limited cognitive capacities and have to respect agronomic constraints.	Economic, Social influence	-

	Study Area	Agricultural System	Study purpose	Decision-making	Factors influencing decision-making	Yield function
Chen et al., 2012	China, Sichuan province, Wolong Nature Reserve	Farming households part of Grain-To-Green-Program	System understanding Understand how social norms are affected by the design of PES programs in a landscape with rapid degradation of the local ecosystem due to deforestation for agricultural land, and timber and fuel wood harvesting	Bounded rationality	Economic, Social influence	- Grain-To-Green-Program PES programs designed to reduce soil erosion by compensating for conversion of cropland into forest or grassland
LUDAS (Le, 2005, Le et al., 2010)	Central Vietnam (100 km^2)	Subsistence agriculture at forest margins, including forest logging	System understanding, management or decision support and theory development To provide technical decision support for stakeholders in land use planning	Bounded rationality based on heuristics combined with random elements. Theory of Normative Conduct.	Economic, Social influence, Accessibility	Crop yield is a function of input and labour use, physical soil characteristics and land use history
BIOCAPARO (Moreno et al., 2007)	Caparo Forest Reserve, Venezuela. (70 Km^2)	Slash and burn subsistence agriculture	System understanding Explore the outcome of three governmental policies (hands-off, pro-forestry and agro-forestry) on the local environment	Bounded rationality The behaviour of the agents is influenced by past action and decisions of other agents, by competition over space and information flows. Agents have diverse goals, resources and behaviours.	Economic, Environmental - non-economic benefits	-
FEARLUS-SPOMM (Polhill et al., 2013)	Abstract. The environment consists of a toroidal grid of 25 X 25 land parcels	Abstract agricultural system. Can be used worldwide but was developed based on rural Scotland.	System understanding and management or decision support Coupled with an ecological metacommunity model explores the effect of increasing government incentive to improve biodiversity	Bounded Rationality Land managers use a satisficing algorithm to choose land uses compared to other application of FEARLUS where land managers seek profit maximizing (Polhill et al., 2008, Gotts and Polhill, 2010)	Economic, Environmental - non-economic benefits	Each land use has a different yield, and this together with an exogenous economy time series and input costs determines the economic return from the market

	Study Area	Agricultural System	Study purpose	Decision-making	Factors influencing decision-making	Yield function
Sengupta et al., 2005	Illinois, USA	From small to large commercial farms (56ha-730ha mean size)	System understanding and management or decision support Understand enrollment in a conservation program (Conservation Reserve Program) by using agents within spatial decision support system	Rationality and bounded rationality Three typologies of behavioural characteristics that determine farmers' enrollment, ranging from profit maximizers to non-optimizers	Economic, Social influence, Environmental - non-economic benefit	Estimates farm profit based on farm model of the optimum crop and tillage practice for each soil type in a farm (Sengupta et al., 2000)
Sun and Müller, 2013	Yunnan, China	Grain-To-Green-Program farms The modular architecture and the software implementation can be customized with modest efforts to other areas	System understanding Provide a better understanding of the potential impacts of payments for ecosystem services on land use and household livelihoods	Bounded rationality Land-use decisions based on beliefs, consisting of internal beliefs (e.g., income, number of plots, and land quality and exogenous factors such as food price and agriculture subsidies) and external influences.	Economic, Social influence	-
Valbuena et al., 2010	Achterhoek, Netherlands (600 km^2)	A mixture of small-scale agriculture, natural elements and open landscape with large-scale agriculture	System understanding, prediction and communication (participatory approaches) Explore how future responses of farmers' decision-making to endogenous and exogenous processes can affect the regional landscape structure.	Bounded rationality	Economic, Social influence, Environmental - altruistic	-
PLUSES	The Nilgiris, Tamil Nadu, India (100 km^2)	Frontier landscape with commercial agriculture on small-scale farms at forest margins	System understanding and management or decision support Analyse the impact of land use policy interventions on production, biodiversity, food security and livelihoods	Bounded rationality based on heuristics combined with random elements. Agents have limited cognitive capacities.	Economic, Social influence, Environmental - non-economic benefits/ altruistic	Yield function is based on land and capital (labour, fertilizers, seeds, transport, irrigation)

Similarly to most of the agent-based simulators selected, PLUSES is spatially explicit and based on empirical data from existing agricultural structures. Unlike, Caillault et al. (2013), AgriPoliS and FEARLUS-SPOMM models, PLUSES has not been designed to deal with abstract landscapes.
There is a broad range of agricultural systems represented by the models including small subsistence farms, large commercial farms, slash and burn agriculture and frontier landscapes. The BIOCAPARO, LUDAS and PLUSES models have been specifically adapted to deal with frontier landscapes and they all represent small-scale farming. PLUSES differentiates from the other two by focusing on commercial farming as opposed to subsistence farming. As such, the model is better equipped for research in landscapes that are defined by one, or a combination of, the planation of non-food crops (such as tea, coffee, sugarcane) and commercial farming of food crops, sold for income as a means of livelihood, rather than grown for household consumption. Modelling these systems has implications for better understanding food security in small scale farming systems that rely on cash crops and the dynamics of local, national and international markets for their income (e.g. Frelat et al., 2016). In this context, PLUSES is the only model out of the models selected that specifically measures household food security.

According to the characteristics of the empirical objective, the twelve models could be seen as covering the three classes of ABMs described by Boero and Squazzoni (2005). AgriPoliS and FEARLUS, without the SPOMM extension, can be classed as *typification*, a class of more theoretical models designed to explore a range of phenomena and questions within a particular area of study. Caillault et al. (2013) belongs to the class of *theoretical abstractions* models, which are more metaphorical in their representations, aimed at building on theory. The remaining 9 models (includes PLUSES) are better described as *case-based models*. They have been fitted to specific case studies at the micro and macro levels through application of survey data and validation of spatial patterns. These three classes should be however regarded as continuum rather than mutually exclusive sets (Boero and Squazzoni, 2005). Given that PLUSES is interested in exploring the uptake of interventions under LS/LS framework but at the same time tailored to a specific case study, the model would probably fit best somewhere between the first and third class. In future research PLUSES can be adapted to answer questions that relate to either the typification or case-based scenarios, or a combination of the two.

In all cases the eleven models and PLUSES were designed to better understand a system in which land use policies are implemented. Additionally, some of the models were developed to explore specific theories (Caillault et al., 2013 and LUDAS), test hypothesis (Bell, 2011) or were implemented to enable predictions (Valbuena et al., 2010). PLUSES could be used for such applications. However, PLUSES was primarily designed as a decision support tool to facilitate discussion between multiple stakeholders and to provide local policy makers with a representation of a complex system that can answer a particular research question of interest. Six of the other models were also developed for similar purposes (AgriPoliS, Bell, 2011, Bone and Dragićević, 2010, LUDAS, FAERLUS-SPOMM and Sengupta et al., 2005). From these six models only Bone and Dragićević (2010) represent the stakeholders as different agents and therefore allow for observing the interactions between them. This is an advantage compared to the other models, including PLUSES, because it allows the understanding of how complex interactions amongst multiple stakeholders influence the ability to achieve different objectives. PLUSES assumes that stakeholders' objectives are constant over the 30-year simulation (as per the stakeholder workshops) and as a result there are no additional barriers to land use policies adoption. This means that the number of adopters is expected to be higher than in reality.

In terms of decision-making and the factors that influence decision-making, PLUSES has communalities and both strengths and weaknesses when compared with the other eleven simulators. Like all other models, PLUSES uses bounded rationality as a decision-making theory. However, the way it was implemented differs with the other models. Bone and Dragićevićs (2010) model is superior in this regard to PLUSES in that it allows farmers to learn from the past and use that information in their advantage in future decisions. BIOCAPARO can also be considered more advanced in the way agents are represented. Within BIOCAPARO farmers have diverse goals and behaviours, unlike the agents in PLUSES that follow rules without having a defined goal and objective that they pursue. These limitations affect the capacity of the PLUSES' farmers to avoid debt traps by repeating the same behaviour. As a result they are more likely to be forced into leaving the system earlier than might be expected in the real world.

Nevertheless, PLUSES is more sophisticated than most of the other models in two important regards. Firstly, it has the ability to incorporate social, economic and environmental decision-making factors. Only two of the other models allow this breadth of decision making factors (Sengupta et al., 2005 and Valbuena et al., 2010). Secondly PLUSES provides a more overarching representation of policy outcomes including: land use change, the rate of adoption, livelihoods changes, food security and environmental impacts. This has important implications when informing the design of policies. Being able to compare and contrast between the outcomes of different policies considering socio, economic and environmental implications allows decision-makers to understand the potential synergies, trade-offs, opportunities and unanticipated risks at a finer scale and, as a result, plan better. The next chapters (8 and 9) use PLUSES simulator and demonstrate its relevance and capacity in doing so.

Chapter 8

Evaluating the uptake of land use interventions using PLUSES

8.1 Introduction

The challenges of improving food production and biodiversity conservation are intricately linked. To date, the LS/LS framework has viewed this nexus primarily through an ecological lens. This perspective has been criticized for being too narrow, and failing to consider other relevant factors such as the social acceptability of the proposed interventions by direct land users (Fischer et al., 2014).

In either approach, the involvement of local land users is likely to be an important factor in shaping the success of conservation projects (Emery and Franks, 2012). Knowledge of the willingness and capacity of landowners to engage with conservation has been shown to be of key value in planning successful LS/LS land use management strategies (Jóhannesdóttir et al., 2017). However, there is still little evidence on the desirability of these interventions to farmers in a real landscape context.

This chapter proposes to address this lack of evidence by answering the following questions:

Q1) How do direct land users respond to proposed interventions that promote land sharing or land sparing? Are they willing to adopt them on the farm?

Q2) Who are the adopters of the different strategies and why do they adopt them?

The chapter answers these questions using predictions from PLUSES regarding adoption of the three LS/LS interventions proposed by local stakeholders (see Table 7.3).

8.2 Data and Methodology

To assess the adoption of the interventions by the Nilgiris land users different output metrics were used (Table 8.1). The metrics are measured at the end of 30 years of simulation and the results are averaged over 20 simulation runs (see justification in *Section 7.5*).

Table 8.1 Data type and ABM output metrics. The research question addressed by the metric is marked in brackets.

Indicator group	Metric
General outcomes (Q1)	• Number of households left at the end of the simulation (quantitative) • Number of landholders left at the end of the simulation (quantitative)
Social acceptability (Q1, Q2)	• Total number of households enrolled in schemes (quantitative); • Total area enrolled in schemes (quantitative) -Percentage of households enrolled in schemes by landholding size (quantitative) -Percentage of households enrolled in schemes by income per capita (quantitative) -Number of patches enrolled in schemes over time (quantitative); • Motivations for enrolment • Incentive payments: Opportunity costs for financial incentive payments (quantitative and qualitative)

The metrics are analysed under nine main scenarios (Table 8.2) that aim to reflect differences between having no schemes in the landscape compared with running schemes one at a time, or all together.

Table 8.2 The nine scenarios tested using PLUSES simulator

Number	Scenario	Description
01	No Schemes	Simulation running with no policies interventions in the landscape.
	One Scheme + No FI:	
02 03 04	Scheme A + No FI Scheme B + No FI Scheme C + No FI	Schemes A (Wildflower Meadows), B (Forest Plantations) and C (Tree Intercropping) are simulated in the landscape one at a time. They carry no financial incentive (FI).
05	All + No FI	All schemes are running in the landscape, but they carry no financial incentive. Land users can select any one of the schemes, two schemes or all three.
	One Scheme +FI:	
06 07 08	Scheme A + FI Scheme B + FI Scheme C + FI	Schemes A, B and C are simulated in the landscape one at a time. They carry a financial incentive.
09	All + FI	All schemes are running in the landscape and they carry a financial incentive. Land users can select any one of the schemes, two schemes or all three.

The schemes are tested when they have no financial incentive for enrolment and when they include a financial incentive. The financial incentive represents the amount a farmer receives for joining an intervention (see the amount for each intervention in Table 7.3).

One-way analysis of variance (ANOVA) is used to test if there are any statistically significant differences between the means of the different scenarios. To meet the assumptions of ANOVA test, where necessary non-normally distributed data was transformed. Tukey's Honest Significant Difference (HSD) test was used in the post-hoc analysis to test for statistically significant differences between pairs of means.

To assess how sensitive the output metrics are to changes in model settings, sensitivity testing is performed. Indicators that are either part of the process that can influence the metrics or are thought to have an important effect on the output metrics are varied (Table 8.3). In the sensitivity testing analysis the new values given to the indicators are tested against the baseline value (Table 8.3). The statistical difference between the outcomes is established using a two-tailed t-test. The sensitivity testing results are always presented for *"All +FI"* scenario, which is the scenario stakeholders wanted implemented in the landscape. Results are averaged over 20 simulation runs after 30 years of simulation.

Table 8.3 Table showing which indicator variables, and their values, were assessed for key output metrics during sensitivity testing. The third row of the table shows the values at which each of the indicators was tested. The baseline value of an indicator used in the scenarios of the simulation is marked (B).

Output Metrics	Indicators							
	Initial household balance			Social Influence Threshold		Financial Incentive		
	0 (B)	Savings of 5x annual income	A debt of 5x annual income	5 links (B)	0 links	As a continuous variable (by scheme)	5000 INR per patch for A and C and 6500 INR per patch for (B)	As a continuous variable (by land use)
General outcomes								
Number of households left (end of simulation)	X	X	X					
Proportion of households that own land	X	X	X					
Social acceptability								
Households enrolled				X	X	X	X	X
Patches enrolled				X	X	X	X	X

The next section (*Section 8.3*) presents the outcomes of adoption, followed by the interpretation of the results (*Section 8.4*).

8.3 Results of scheme uptake and sensitivity testing

The following section presents the results of the different indicators measured under the nine scenarios. It includes results of sensitivity testing which aim to provide more insight into the way the ABM operates and its outcomes.

8.3.1 General outcomes

8.3.1.1 Number of households left at the end of the simulation

Households leave the system during the simulated 30 years as a result of a debt problem that could not be cleared. However the current model structure does not allow for the total number of households in the landscape to increase (see *Section 7.7.1*).

The simulation started with 1057 households. Under the *"No Schemes"* scenario the number of households reduced to a mean of 993 (SD=7.50). The introduction of Schemes A, B, C or all schemes combined, either with or without a financial incentive, produced no statistically significant difference in the total number of households that remained in the system compared to the *"No Schemes"* scenario [$F(8,171) = 0.017$, $p = 0.999$].

Sensitivity testing

In the baseline settings of the model, households start with no debts or savings. Sensitivity analysis shows that changing the initial financial balance of the households influences the number of households remaining at the end of the simulation. If households are initialised with a debt of five times their annual income then the total number of households left is significantly reduced to an average of 633, a reduction of 36% compared to the baseline scenario [F (23,456)=3628.82, p<0.001]. If households are initialised with savings of five times their annual income then the total number of households left is statistically different, from 993 under baseline settings to 1002 [F (23,456)=7.56, p< 0.001].

8.3.1.2 Number of landholders left at the end of the simulation

When investigating the proportion of land owning households (landholders) that remained in the landscape at the end of a simulation there is statistically insignificant variation between the *"No Schemes"* scenario and all the other eight scheme-scenarios [F (8,171)=0.015, p=0.999]. 64% of households own land at the end of the simulation (n=933) under any of the scenarios tested compared to 61% of households when the model was initialized (n=1057).

Sensitivity testing

As with the total number of households remaining in the system, sensitivity analysis shows that increases and decreases in initial budgets affected the proportion of landholders left in the landscape at the end of the simulation [increase: F(23, 456)=5.44, p< 0.001] and [decrease: F(23, 456)=5796.18, p< 0.001]. While a budget increase raises the total number of farmsteads slightly, to 661 (out of n=1002 households), the decrease in budget leads to a total of 620 farmsteads (out of n=633 households).

8.3.2 Social acceptability (scheme uptake)

When assessing the uptake of Schemes A, B and C by households, comparisons were made between each scheme being run independently "*One Scheme*" or simultaneously "*All Schemes*". Scenarios were investigated either with or without a financial incentive (FI) for enrolment.

8.3.2.1 Total number of households enrolled in schemes

When the schemes run one at a time without any financial incentive, *"One Scheme + No FI"*, enrolment occurs for all three agri-environmental schemes (Figure 8.1). The most frequently adopted scheme was Scheme A, Wildflower Meadows with a mean value of 97.75 households (SD=8.29). This level of adoption accounts for 15% of all the remaining farmsteads at the end of the simulation run (N=644). Scheme B, Forest Plantation, was adopted by 2.5% of landholdings (16.15, SD=5.20), whereas Scheme C, Tree Intercropping, saw an enrollment of 8.2 % of all farmsteads (53.1, SD=5.38).

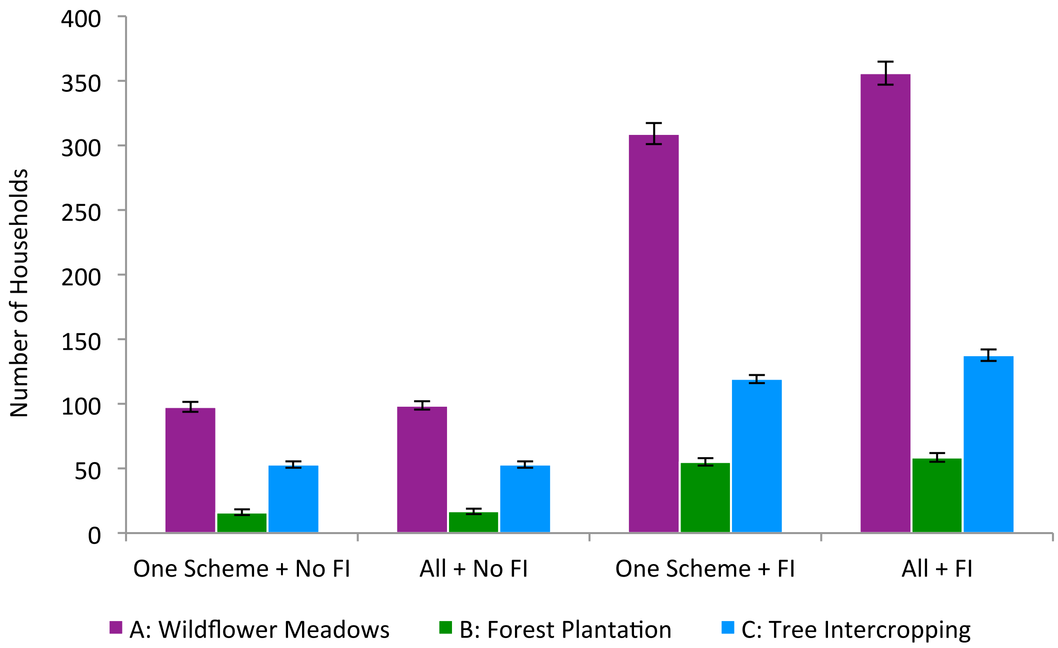


Figure 8.1 Total number of households enrolled in Schemes A, B and C predicted by the model under "One Scheme + No FI", "All + No FI", "One Scheme + FI" and "All + FI", scenarios after 30 years of simulation. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

Results of a one-way ANOVA and Tukey's HSD test between each pair of scenario groups under Scheme A, B and C respectively (Figure 8.1) show that running all the schemes simultaneously with no financial incentive, *"All + No FI",* produced no statistically significant difference compared to the first scenario, *"One Scheme + No FI"*. This is because there is no interdependence between adoption decisions when there is no financial incentive; farmers have a specific set of conditions on the farm that lead them to a particular schemes that is able to satisfy those conditions.

When a financial incentive is introduced there are statistically significant changes in the enrollment in Schemes A, B and C compared with no financial incentive scenarios. This trend is observed in comparisons between both *"One Scheme + No FI"* with *"One Scheme + FI"* and *"All +No FI"* with *"All + FI"* (Table 8.4). The introduction of a financial incentive triples enrollment for Scheme A and B and doubles enrollment in Scheme C (Figure 8.1).

Enrollment in Scheme B does not vary significantly between the *"One Scheme + FI"* and *"All +FI"* scenarios. However, for schemes A and C the *"All + FI"* scenario increases enrolment significantly (Figure 8.1).

Table 8.4 One-way ANOVA results of the total number of households enrolled in Scheme A, Scheme B and Scheme C under different simulation scenarios and Tukey's HSD post hoc results between each pair of scenario groups under each scheme. If the mean difference between the pairs of scenarios is statistically different (p < 0.05) it is shown in bold and marked with an asterisk.

	Results for scenarios with Scheme A: Wildflower Meadows			
ANOVA	$F(5,114) = 1228.6, p < 0.001$			
Tukey's HSD test		Scheme A + No FI	All Schemes + No FI	Scheme A + FI
	Scheme A + No FI	-		
	All Schemes + No FI	1.05	-	
	Scheme A + FI	**211.45***	**210.4***	-
	All Schemes + FI	**258.15***	**257.1***	**46.7***
	Results for scenarios with Scheme B: Forest Plantation			
ANOVA	$F(5,114)=240.3, p<0.001$			
Tukey's HSD test		Scheme B + No FI	All Schemes + No FI	Scheme B + FI
	Scheme B + No FI	-		
	All Schemes + No FI	0.6	-	
	Scheme B + FI	**38.9***	**38.3***	-
	All Schemes + FI	**42.4***	**41.8***	3.5
	Results for scenarios with Scheme C: Intercropping			
ANOVA	$F(4,95)=283.8.6, p<0.001$			
Tukey's HSD test		Scheme C + No FI	All Schemes + No FI	Scheme C + FI
	Scheme C + No FI	-		
	All Schemes + No FI	0.2	-	
	Scheme C + FI	**66.1***	**66.3***	-
	All Schemes + FI	**84.55***	**84.75***	**18.45***

Sensitivity testing

Sensitivity analysis was carried out on two indicators directly related to scheme adoption, Social Influence Threshold (SIT) and incentive level.

The first indicator, SIT, makes enrollment conditional on a number of fellow farmers from the same network also enrolling (see Table 7.4). In the baseline settings farmers need at least 5 members of their social network to join the schemes before they decide to join too (SIT=5). Enrollers that met the condition under Scheme A accounted for an average of 31.60 households (SD=5.78; Figure 8.2). When SIT was set to its lowest possible level (SIT=0), no social network condition, enrollment in Scheme A was twice as high (69.40 households; SD=6.73). This difference is statistically different [$t(38)=-28.132$ $p < 0.001$]. The SIT therefore plays an important role in the uptake of Scheme A. An SIT > 3 leads to a rapid drop in Scheme A enrolment (Figure 8.2).

Scheme C enrolment also shows a statistically significant change with SIT level. When SIT is reduced from the baseline level to zero the number of adopters increases from an average of

7.95 (SD=2.60) to 19.9 (SD=4.03) [$t(38)=7.652$ $p < 0.001$]. In contrasts with Schemes A and C, enrolment in Scheme B is not influenced by a reduction in SIT level from 5 to 0 [$t(38)=1.401$ $p=0.169$].

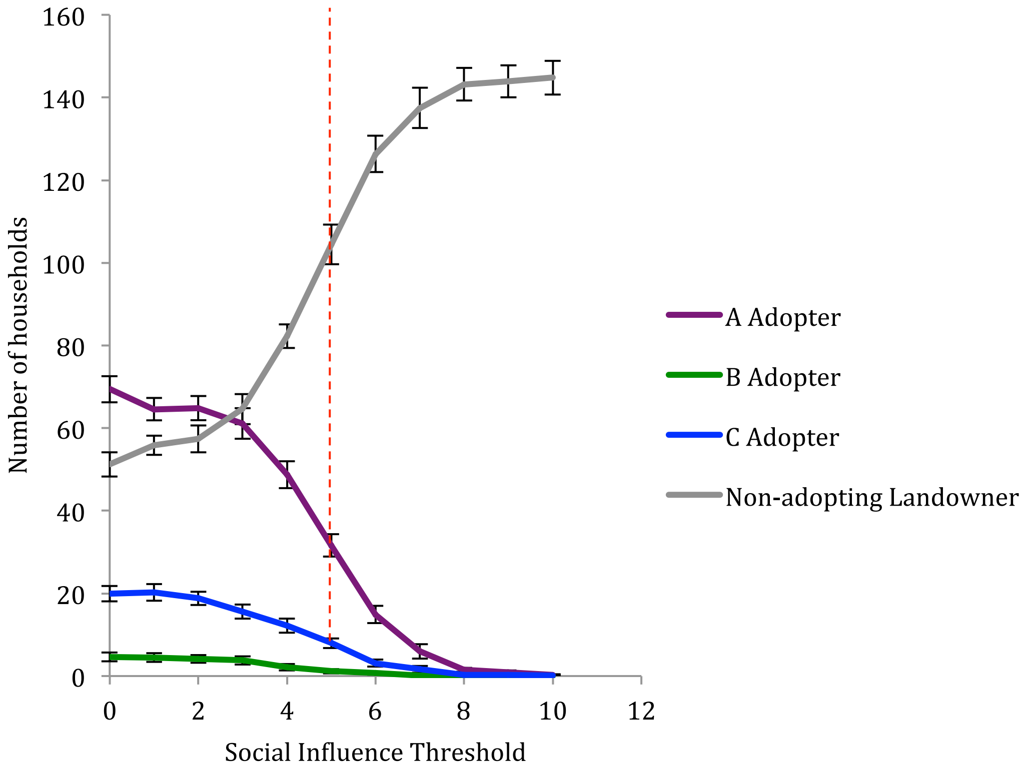


Figure 8.2 The number of households that enrol in the interventions (A Adopter, B Adopter or C Adopter) or refuse to adopt interventions (Non-adopting Landowner) at different levels of Social Influence Threshold. The red dotted line signifies the SIT baseline value of the model.

The second indicator that was tested for sensitivity was the variation in financial incentive (FI) level by scheme type. Overall significant enrolment occurs in all schemes at rates as low as 20% of the baseline value (Figure 8.2).

At the current baseline setting (FI=100%) there is an average of 138.25 households (SD=5.35) that enrol in Scheme A. These are the households for which the return on investment from their land that is smaller than the FI and as a result enrolment in the scheme is at least as profitable. Increasing the FI above the current value to FI=200% brings an average of only 10 additional enrollers, a 7% increase. Reducing the incentive by 50% reduces enrolment in Scheme A by an average of 19 enrollers (13%). It is estimated that the optimal level (number of enrollers per unit of money spent) for the FI for Scheme A enrolment is between 80 and 100% of the baseline (Figure 8.3).

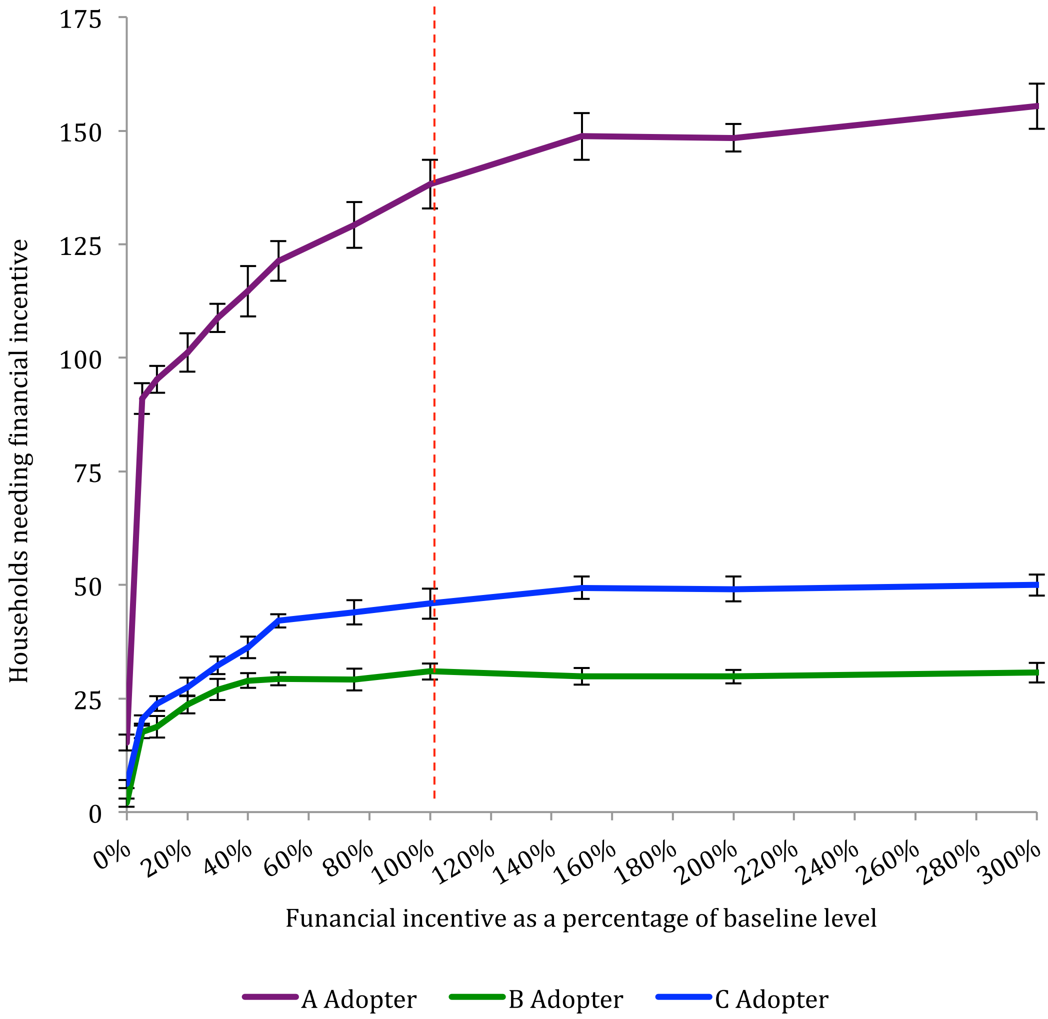


Figure 8.3 The number of households that enrol in schemes for different levels of financial incentive. The red dotted line signifies the FI baseline value.

Providing an optimal FI level is not straightforward because it is necessary to consider the effect of FI level on overall enrolment, which is in turn also linked to changes in social networks and influenced by the land use type (Figure 8.2, Figure 8.3, Figure 8.4). Extracting this information from the model requires adjustments to be made to the model that will considerably slow down the simulation experiments. Given time limitations and the fact that cost-effectiveness was not the main focus of this research it was decided not to include this calculation in the model. The 'optimum levels' calculated here are indicative and not precise.

For Schemes B and C the FI can be set at much lower values. At the current baseline setting the two schemes attract 30.95 (SD=1.81) and 49.5 (SD=3.35) enrollers respectively. If the level of FI was set to 30% of the baseline level then enrolment in Scheme B would only drop by about 6% or an average of 2 enrollers. A similar small decrease in enrolment (6% or 3 enrollers) is observed for Scheme C when the FI is reduced to 60% of the baseline level.

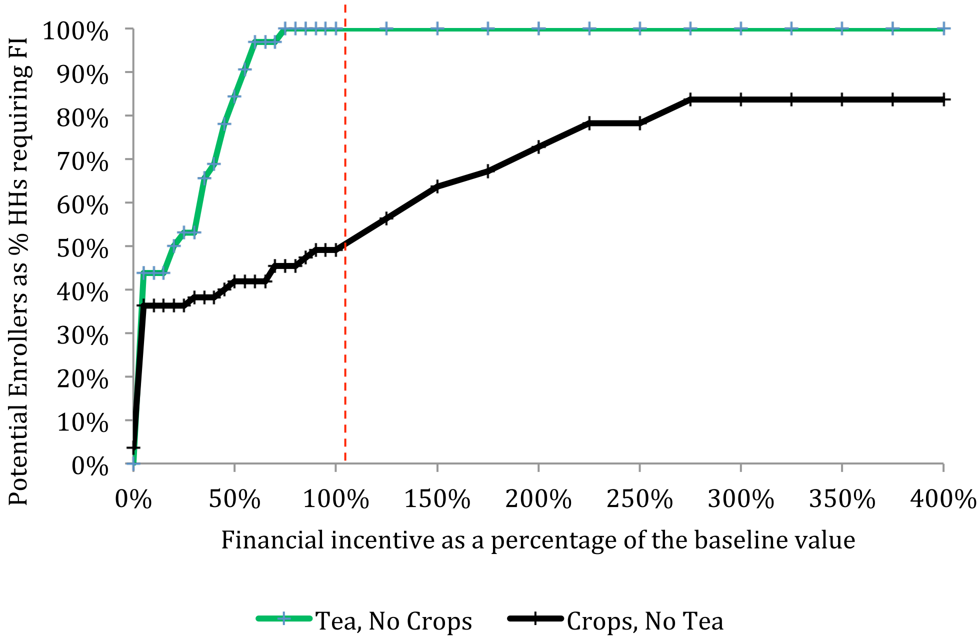


Figure 8.4 The percentage of households enrolling at different financial incentive level for two alternative land uses. The baseline value for FI is 100%. Scenario "All + FI"

Sensitivity testing was also performed on the relationship between the size of the financial incentive and land use types. Overall, crop owners require higher incentives to enrol in schemes than tea owners (Figure 8.4). At the baseline level of financial incentive (100%) all tea owners satisfy the financial condition of enrollment, whereas less than 50% crop owners do.

The optimal FI level for the tea owners would be at 60% of the baseline level where 96.9% of tea owners would enrol. Increasing the FI level above 60% shows only an incremental increase in enrolment. For crop growers the optimum FI level is more than 2.5 times the baseline level (FI=275%) where 83.6% farmers enrol.

8.3.2.2 Total number of patches enrolled in schemes

This section assesses the area of land covered by each scheme under the same nine scenarios, but uses overall group names for an easier graphical representation: 1) *"One scheme + No FI"*, 2) *"All schemes + No FI"*, 3) *"One scheme + FI"* 4) *"All schemes + FI"*. Land area in the modelled landscape is measured in patches. A patch represents 1/10th of an acre, the smallest area of land that can be bought or sold within the landscape (see *Section 7.4.2*).

In the *"One Scheme + No FI"* scenario, out of the total of 908 patches enrolled across the three schemes, the majority (61%) were enrolled in Scheme C (555.15, SD=89.25). Scheme A accounted for 33% of enrolled patches (298.25, SD=47.91), and Scheme B accounted for the remaining 6% (55.65, SD=28.11; Figure 8.5).

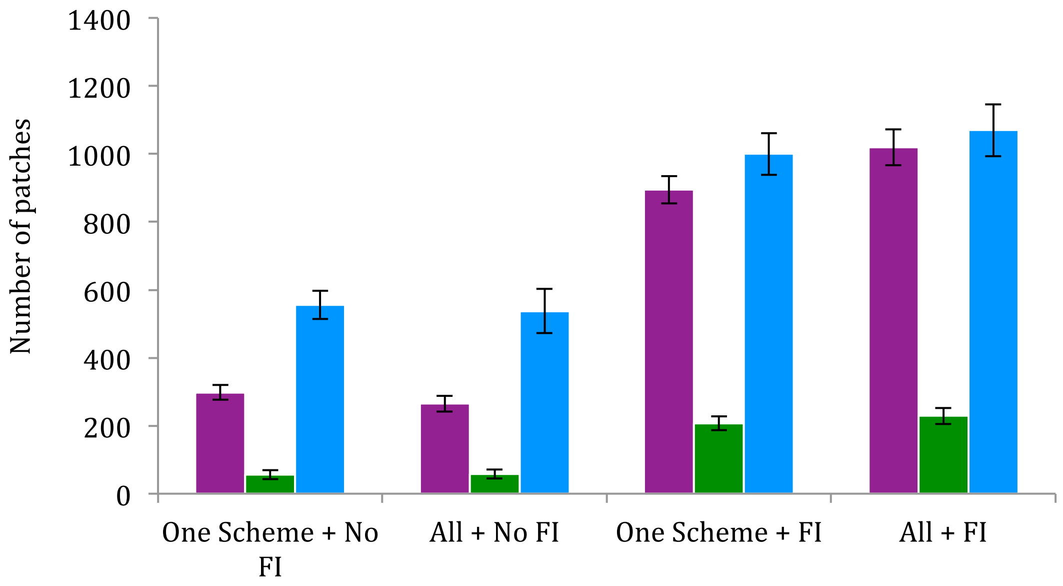


Figure 8.5 The total number of patches enrolled in Scheme A, B and C as predicted by the model under the 4 scenarios, after 30 years of simulation. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

A positive association between the size of a farm and Scheme C adoption was observed which contrasts with a negative association between farm size and enrollment under Scheme A (Figure 8.6).

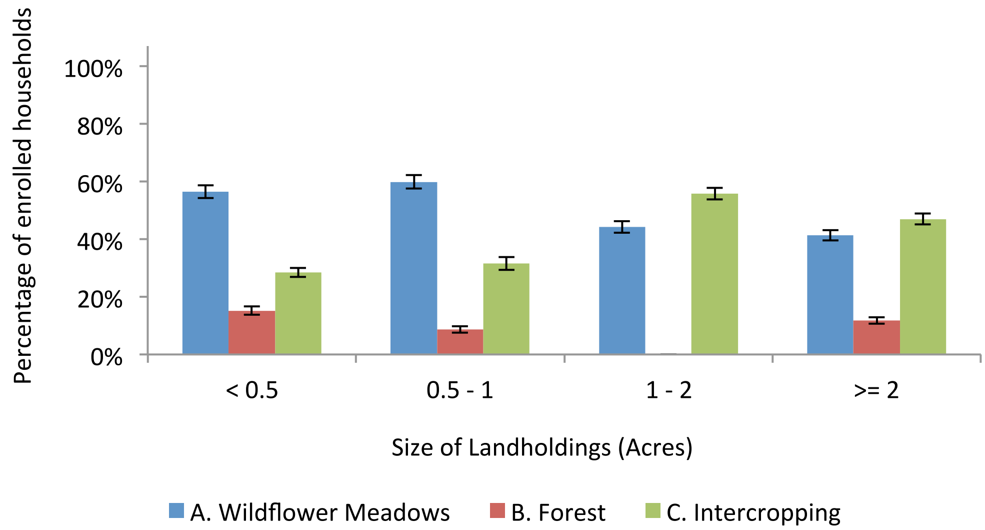


Figure 8.6 The percentage of households enrolled in Schemes A, B and C by landholding size under the "One Scheme + No FI" scenario, after 30 years of simulation. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

When all schemes are simultaneously available to agents without a financial incentive "*All + No FI*" there is no statistically significant difference in the total numbers of patches enrolled under Scheme A, B or C when compared with each scheme being run independently *"One Scheme + No FI"* (Table 8.5).

Table 8.5 One-way ANOVA results of the total number of patches enrolled in Scheme A, Scheme B and Scheme C under different simulation scenarios and Tukey post hoc results between each pair of scenario groups under each scheme.

	Results for scenarios with Scheme A: Wildflower Meadows			
ANOVA	$F(5,114) = 278.2, p < 0.001$			
Tukey's HSD test		Scheme A + No FI	All Schemes + No FI	Scheme A + FI
	Scheme A + No FI	-		
	All Schemes + No FI	21.35	-	
	Scheme A + FI	**568.7***	**547.4***	-
	All Schemes + FI	**701.6***	**680.3***	**132.9***
	Results for scenarios with Scheme B: Forest Plantation			
ANOVA	$F(5,114) = 38.13, p < 0.001$			
Tukey's HSD test		Scheme B + No FI	All Schemes + No FI	Scheme B + FI
	Scheme B + No FI	-		
	All Schemes + No FI	9	-	
	Scheme B + FI	**125.7***	**134.7***	-
	All Schemes + FI	**122.9***	**131.9***	2.8
	Results for scenarios with Scheme C: Intercropping			
ANOVA	$F(4,95) = 49.7, p < 0.001$			
Tukey's HSD test		Scheme C + No FI	All Schemes + No FI	Scheme C + FI
	Scheme C + No FI	-		
	All Schemes + No FI	14.25	-	
	Scheme B + FI	**427.2***	**412.9***	-
	All Schemes + FI	**407.4***	**393.2***	19.75

When a financial incentive is introduced the number of patches enrolled across the schemes increases compared to the no financial incentives scenarios (Figure 8.5). Under the scenarios, *"One Scheme + FI"* and *"All +FI"*, the total land enrolled under Schemes A tripled and B quadrupled compared to no financial incentive scenarios. The amount of land under Scheme C doubled (Figure 8.5).

When comparing running the schemes one at a time, *"One Scheme + FI"*, or all together, *"All + FI"*, a statistically significant difference is only observed for Scheme A (Figure 8.5).

As households' financial security increases the proportion of households that enrol under Scheme C decreases, whilst the opposite trend is observed for Scheme A (Figure 8.7). Scheme B follows a different pattern and attracts more enrollers at the extremes, both from poorer households and from financially secure ones.

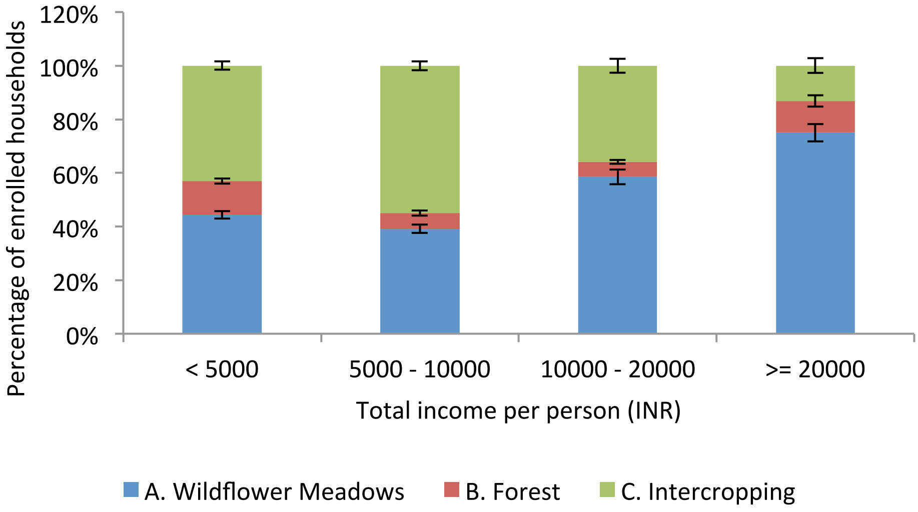


Figure 8.7 The percentage of households enrolled in Scheme A, B and C by income per person under the "All + FI" scenario, after 30 years of simulation. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

When this trend is considered alongside the influence of farm size on scheme adoption (Figure 8.6) there is a tendency for larger, but less financially secure farms to enrol in Scheme C. These are the characteristics of tea farms. In contrast Scheme A is preferentially selected by smaller but more financially secure farms; the characteristics of vegetable farms.

The idea that land use type could determine scheme choice is supported by results which show that over time there is a sustained preference for Scheme A among vegetable (agriculture) farms and for Scheme C among tea growers. Tea growers who enrolled in Scheme A initially are predicted to leave the scheme at a constant rate until very few remain (Figure 8.8).

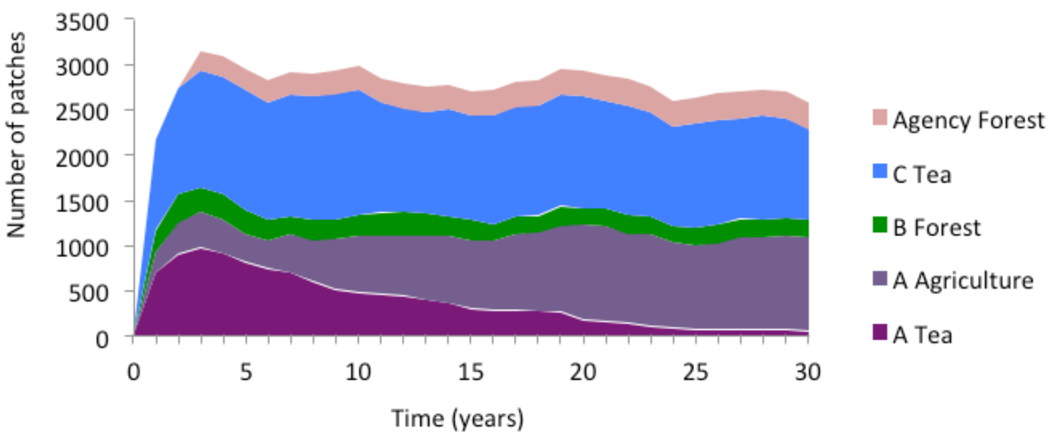


Figure 8.8 The number of patches enrolled under each Scheme or converted to forest by the agency under "All + FI" scenario.

8.3.2.3 Motivations for enrolment

Farmers' motivations for adopting land use policies on the farm have both parallels and differences between the three schemes (Figure 8.9).

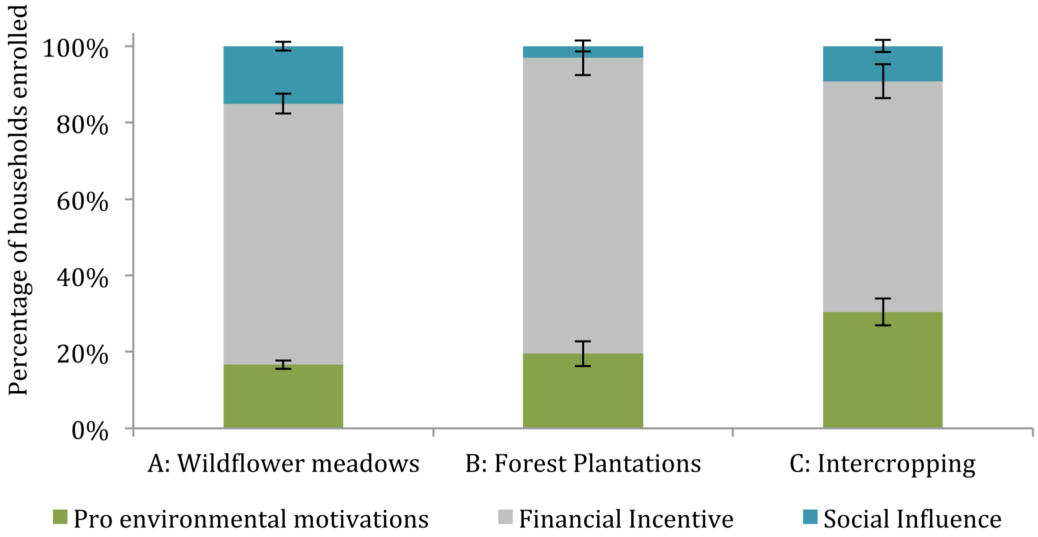


Figure 8.9 Land owners reason for enrolling in each of the three schemes under the "All +FI" scenario. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

Economic benefits are the most common reason for farmers to enrol in all three of the schemes, followed by pro-environmental motivations and social norms. Scheme B has the highest proportion of enrolment due to financial incentives (77%) when compared to Scheme A (68%) and Scheme C (60%). Far fewer households are motivated to enrol by their social networks, Scheme A (15%), Scheme B (3%) and C (9%). Scheme C has the highest proportion of enrollers motivated by environmental beliefs, 30%, compared to Scheme A and C, 16% and 19% respectively.

8.3.2.4 Incentive payments

The total budgetary requirement of the agency to pay for all households that have enrolled in interventions over a 30-year period was estimated at $ 7.13 mil (*"All + FI"* scenario) out of which: $ 3.05 mil would be for Scheme A, $ 0.88 mil for Scheme B and $3.2 mil for Scheme C. The total figure covers the costs of the incentives for 30 years ($ 0.23 mil per year) on 2,316 patches (9,372 ha) but does not consider the costs associated with extension services for providing support to farmers to increase production. This budget would, alternatively, enable the agency to purchase 4,571 patches (18,498 ha) of land for conservation, almost twice the number of patches covered through the schemes. However the management costs of the converted land over the 30-year period are not covered. In the ABM, in order to maximize the benefits for the environment, the agency has a mixed strategy; it encourages farmers into adopting conservation strategies on their land, while buying land available for sale and converting it to forest (see Figure 8.8).

8.4 Discussion

8.4.1 General outcomes

The outcomes of this chapter show both anticipated and surprising results. For example, it was expected for the 'survival' of the households in the landscape to be strongly linked to the profitability of the farms, access to land and their initial household budget (debt or savings). Unexpectedly, under Wildflower Meadows, Forest Plantations, Tree Intercropping or all schemes combined, the model shows that total number of households remaining in the system and the proportion of households that own land at the end of the simulation is not statistically different to the business-as-usual scenario. This suggests that: (i) the income generated from scheme enrolment could not satisfy the financial needs of the most vulnerable households or (ii) households that abandon the landscape are landless and the schemes have no effect on their financial decisions. Understanding how the interventions permeate through different social strata has important implications for the design of more effective policies. If the schemes do not provide sufficient financial protection for debt traps (as it happens in this case), farmers are forced to sell their land and eventually abandon the landscape. This contrasts with many European countries (e.g. UK, France, Italy, Romania) where agri-environmental schemes form an important contribution to the profitability of the farm (DEFRA, 2016), up to the point where they are used to encourage farmers to remain on the land even though no output is produced (Baylis et al., 2008). While supporting unprofitable land uses might seem an irrational approach to the economy and biodiversity conservation in the Nilgiris, the low profitability of tea raises questions about what will happen to the increasingly abandoned land. A review of 276 published studies describing various effects of farmland abandonment on biodiversity found that countries in Eurasia reported mainly negative effects on biodiversity, whereas the New World reported predominantly positive effects (Queiroz et al., 2014). The assessed taxa and conservation focus significantly affected how those impacts were reported. Contrary to the main findings in Eurasia, the studies conducted in nearby tea plantations show that abandoned tea land offers an opportunity for restoration of native forest (Chetan et al., 2012, Chetana, 2013). Nevertheless, there is limited information on what happens with the households that abandon the land and what new local economies might replace tea cultivation in these areas, some of which could ultimately be more harmful for biodiversity in the long term.

The other general outcomes observed provide useful insights that help with the external validation of the model; these outcomes are nothing unexpected and remain within anticipated margins. For example, the total number of households remaining in the landscape and the proportion of landholdings at the end of the simulation were influenced by changes to the initial household budget conditions. When households started with debt considerably fewer households were able to meet their livelihood goals and financial obligations and therefore abandoned the landscape. The households that survived the initial financial deficit were those able to cover their debt over time. Households that could not cover their debt were landless and had fixed sources of income from off-farm activities. These households were not able to rollover credits for longer than 3 years and had no other alternative income generation options such as the sale of timber or land to meet financial shortages. The outcomes of the model therefore stay true to India's agrarian economy in which landless households are among the most vulnerable groups of the society (Besley and Burgess, 2000). If on the other hand, the households started with an increased initial budget (as opposed to no debt, the baseline value) the model predicts a statistically different but not meaningful variation in the number of households that remain in the system at the end of the simulation. This is expected to be the effect of households with limited sources of income. Their initial budget allows them to stay longer in the landscape, but ultimately it is inevitable that certain people are going to fail to meet their financial requirements. The model assumes that they abandon the landscape. Some indeed might be able to find ways to create opportunities elsewhere (Rigg et al., 2016), in which case there will be land abandonment in the area (only marginal though). It is expected that the poorest will not be able however to afford to migrate and will remain in the landscape (Jaquet et al., 2016). This will potentially increase the labour force or could increase the pressure on local resources. Again this will only have a marginal effect on the economy and the environment given that the difference observed in the variation of the number of households that remain in the system is not meaningful.

8.4.2 Scheme adoption and farmers' motivations

The outcomes of scheme adoption provide new and valuable insight into the uptake of LS/LS interventions on the ground by demonstrating the flawed argument on which the LS/LS debate was founded. Contrary to the LS/LS argument of one scheme being superior over the other, the outcomes show there is potential for both LS/LS strategies to meet the expectations of land users in a complimentary way. Moreover the results demonstrate the utmost importance of understanding the multiple alternative motivations and farm characteristics that dictate the choice between LS/LS policies. For example, the results show that when the simulation is running without any financial incentives for joining an environmental scheme, enrollment in each of the schemes occurs among households that are motivated by pro-environmental behaviours. The importance of conservation-oriented motivations for driving agro-environmental schemes participation is well documented across a range of agricultural practices and countries e.g. Mediterranean farms in Europe, agricultural watersheds in the USA, organic farms in Switzerland (Wilson and Hart, 2000, Ryan et al., 2003, Manner and Gowdy, 2010, Karali et al., 2014, Darragh and Emery, 2017). The pro-environmental enrollers play an important role that moves beyond that of direct adopters of environmental behaviours. Parallels can be made with diffusion theory where they would be referred to as *pioneers* of innovation (Rogers, 2003). Their role is pivotal because they facilitate others (*followers*) to replicate their novel behavioural trends (Rogers, 2003). In communities with limited exposure to interventions, dissemination can be a key determinant in the success of new policies (Crona, 2006, Scholz and Wang, 2006, Isaac et al., 2007). In the context of this study it was indeed observed that the first wave of enrolment, motivated by pro-environmental beliefs, prompted the adoption of schemes among another fraction of land users who were driven by social norms. *Pioneer* and *follower* farmers have been observed in the context of adopting organic agricultural practices in Ireland (Läpple and Van Rensburg, 2011). In this context *pioneer* farmers were driven by environmental attitudes, social learning and innovation, and *followers* were constrained by risk consideration and were more motivated by financial rewards. The distinction between the motivations of early and late adopters is important, as each different set of stimuli will require a different type of institutional support.

Another important outcome that emerges from the model, and shows differences from what was observed in the RPG, is that the largest number of households have enrolled in the

Wildflower Meadows scheme. This observation is likely due to a large number of farmers having a disinclination to grow trees on their land, as required by the other two interventions. This unwillingness to plant trees has arisen as a result of past tree tenure controversies. Historic tree tenure reforms across regions of India in which the ownership of trees on private land has fluctuated between the land owner and the state have created confusion and uncertainty regarding the legality of tree harvesting and ownership rights (Hallsworth, 1982). As a result farmers are unwilling to gamble on planting a slow growing resource for which they perceive there is a risk, based on historic precedent, that they may not have ownership of when it is ready to be harvested. A similar effect of uncertainty over tree tenure has been observed in Indonesia, Tanzania, Nigeria and Uganda (Fortman, 1985). Farmers' past experience of changing tree rights must therefore be considered, along with other factors, in the design of tree planting policies if they are to be successful (Garcia et al., 2013, Kakuru et al., 2014, Ashraf et al., 2015). Surprisingly, in the context of the Nilgiris landscape it is not only landowners' past experiences of tree rights, but also tree-planting configuration, that influences farmers' policy preferences (discussion covered in *Section 6.4.2.1*). Such insights into the drivers of farmers' decision-making can lead to more effective interventions. Agencies seeking to implement environmental policies can either discard what is likely to be an unsuccessful policy or adapt to social 'anxieties' (Jóhannesdóttir et al., 2017).

The inclusion of social network processes in the ABM shows some surprising results as well that were otherwise difficult to observe using the RPG or the household survey. The social network of an agent farmer plays an important role in the uptake of Wildflower Meadows (Scheme A) and Tree Intercropping (Scheme C). In contrast, social networks play a trivial role for enrolment in Forest Plantations (Scheme B). The reason why social network plays an insignificant role for Forest Plantations is probably because the low rate of enrolment under Forest Plantations does not allow for the social network to manifest. This failure for a social network to occur can arise in two ways. Firstly the small number of enrollers may be geographically isolated from other potential enrollers within the landscape. Or secondly by having clusters of farms belonging to the same social network that have enrolled, in which case the social networks become the ones isolated.
The use of the ABM also helped understand the importance of the social influence threshold and revealed some insights about its use in modelling the dissemination of land use policies. What is common between the three schemes is that at even small social influence threshold

values farmers find it difficult to find neighbours already enrolled in the same scheme that will help them satisfy the enrolment condition. As such, the assumptions made in the model about the social network size and the influence threshold, provide a conservative image of adoption. That is because farmers have small social networks and large social thresholds. In reality, network size could vary between farmers and positive experiences of scheme enrollment could disseminate beyond a landowner's immediate social network and attract more enrollers in each of the three schemes. Therefore, individual information on farmers and their networks would be favourable for making more accurate predictions than a general rule. Similar limitations were observed in modelling the dynamics and dissemination of agri-environmental schemes on European farms (Weisbuch and Boudjema, 1999).

The largest number of enrollers in each of the three interventions was driven by the introduction of financial incentives. This importance of financial compensation for lost income from land no longer used for crop production has been previously reported (examples in Darnhofer and Walder, 2014). However this pattern is not uniform and the importance of a financial incentive for scheme adoption contradict the findings of Jóhannesdóttir et al. (2017), who report that farmers were less likely to participate in LS/LS interventions if they were to receive financial compensations. They attribute this behaviour to farmers in Iceland not being familiar with the concept of agri-environmental schemes. While farmers in the Nilgiris study area are similarly unacquainted with such interventions, they were observed, during the RPG, comparing the profitability of their land with the size of a financial incentive before deciding whether to enrol in schemes or not.

Financial incentives for joining a scheme were most important for Forest Plantations (Scheme B) followed by Wildflower Meadows (Scheme A) and to a lesser extent for Tree Intercropping (Scheme C). This pattern is largely anticipated given that Forest Plantations were the least popular intervention and financial motivations were expected to be the main leverage for attracting enrollers (see Table 7.3). In contrast the comparatively low importance of a financial incentive in driving enrolment in Tree Intercropping (Scheme C) was not expected. The ABM showed that Intercropping was preferred by less financial secure households in comparison with Wildflower Meadows, which attracted more financially secure households. It was therefore predicted that financial incentives would play a more important role in encouraging the adoption of Intercropping. There is a growing realisation that smaller and less profitable farms are not necessarily more prone to financially motivated behaviour and there are many regional differences in the extent to which finance is the prime driver of land use decision-making (Wilson and Hart, 2000).

The model predicts that many of the financially motivated enrollers adopted the schemes even when the financial incentive was as low as 0 INR. This is the result of households having negative returns on their tea farms. As discussed in the earlier chapters (see *Section 4.3.4*) farm unprofitability represents a reality not only for farmers in Nilgiris but across all states of India (Narayanamoorthy, 2006). Further, all tea growers enrolled in the interventions at incentive levels lower than the baseline value, whereas only about half of the agricultural landowners did at the same level, showing the difference between the profitability of the two crops (see *Section 4.3.6*). It is believed that the assumption made in the model, by which farmers decide to enrol based on a direct comparison between the profitability of the farm and the level of incentive, reflects local realities. However, this is not likely to be the only driver for real farmers in the Nilgiris landscape. Other considerations such as ease of farm management for example are likely to deter some of the enrollers at small compensation levels. This adds complexity to the already intricate decision of choosing an optimal level of incentive given the differences observed by the two land uses. Nevertheless the model strongly suggests that, from the three interventions, Tree Intercropping is probably the only scheme for which a lower level of incentive, set at around 60% of the current value, would likely lead to similar levels of enrolment.

Adjusting the incentive levels will also have to consider the effect it produces on the social network. Similarly, to the effect pro-environmental adopters have on the diffusion of the interventions in the landscape, the enrolment motivated by monetary rewards has a cascading effect on scheme uptake by expanding the social network of adopting members.

The observation of preferences according to the area of land a farm has and its comparative wealth has implications for policy makers. Such trends allow a potential match of interventions to landowners not only based on motivations but also tailored to the needs of the different groups that can maximize both enrolment but also the financially efficiency of interventions (Wilson and Hart, 2000, Greiner and Gregg, 2011, Greiner, 2015).

Finally, one of the most important emerging phenomena in the ABM is the minimal difference observed in scheme uptake (without FI) when running the interventions individually or with all schemes. This shows that the schemes were attractive to different kinds of households (as expected, given the different farming practices preferences-see *Section 4.3.7.4*). Therefore, it did not trigger any particular social trade-offs that needed to be resolved. The alternatives are rather complementary. For proponents of the LS/LS framework this has important implications for understanding the limitations of promoting one intervention over the other in landscapes where both strategies are favoured. By choosing to promote any one intervention means attracting a smaller number of farmers in supporting local biodiversity. This means not capitalising on the maximum gain that could be obtained for enhancing local biodiversity. However, in case of a limited policy implementation budget, when only one intervention could be implemented, the solution could be indeed dictated by the most favourable strategy for biodiversity.

8.5 Conclusion

The outcomes of this chapter show there is potential for both LS/LS strategies to meet the expectations of land users in agricultural systems of the Nilgiris in a complimentary way. The chapter provides empirical evidence of the importance of understanding the attitudinal fabric of a small and otherwise seemingly homogeneous community (Badaga), which is intrinsically linked to the existence of multiple alternative motivations to engage in LS/LS policies. The heterogeneity of preferences among recipients of environmental policies has shown that land use policies require understanding the motivations of individuals to participate in new conservation activities in order to be flexible and adaptive. Finally, the chapter demonstrated that uncovering the latent diversity of perspectives for adoption and the diversity of land use farming preferences are important factors that influence the cost-effective design and implementation of conservation interventions through financial incentive schemes.

The next chapter will look into understanding how the adoption of these three interventions impacts on local biodiversity, production along with households' livelihoods and food security.

Chapter 9

Evaluating the environmental and socioeconomic implications of land use interventions using PLUSES

9.1 Introduction

The effectiveness of LS/LS approaches to conservation, in the face of rising agricultural demands, have been widely debated (Tscharntke et al., 2012, Fischer et al., 2014, Kremen, 2015). While numerous studies have investigated the relationship between food production and biodiversity (e.g. (Phalan et al., 2011), Chandler et al., 2013, Hulme et al., 2013) the relevance of the LS/LS framework to applied scenarios depends on a broader range of factors than has previously been considered. For example, socioeconomic factors play an important role in determining the choice between the two strategies, but only a handful of studies under the LS/LS framework (e.g. Steffan-Dewenter et al., 2007, van Vliet et al., 2012, Lee et al., 2014) have engaged with them. This small pool of studies shows that when they are considered, the choice between the two strategies is less clear than in the outcomes of biodiversity density-yield studies. Focusing on the ecological evidence and demeaning the importance of socioeconomic aspects leads to premature conclusions that can ultimately cause further harm to biodiversity (Phelps et al., 2013).

This chapter focuses on these limitations by proposing to assess how LS/LS interventions compare, not only in terms of food production and biodiversity conservation but also in terms of other socioeconomic factors, such as food security and livelihood aspects. The chapter uses the PLUSES simulator to assess the relative impact of the three LS/LS interventions adopted by the Nilgiris farmers (discussed in Chapter 8) on a range of socioeconomic and environmental factors. This chapter ends Part IV of the thesis, which compares the environmental and the socioeconomic implications of LS/LS interventions under different scenarios.

9.2 Data and Methodology

This chapter uses PLUSES simulator to test the socioeconomic and environmental implications of the uptake of the three LS/LS environmental policy interventions tested in Chapter 8: Wildflower Meadows (Scheme A), Forest Plantation (Scheme B) and Tree Intercropping (Scheme C). To understand the impact of adoption a suite of output metrics are used (Table 9.1).

Results will be presented following the order of the metrics in Table 9.1. The results of one metric group are followed by an interpretation of the observed results. This format has been used to enable the reader to follow the results, as the chapter contains many comparisons between multiple scenarios.

Table 9.1 Data type and ABM output metric.

Metric group	Metric
Land use change	• Land use change by land use type at the landscape level over time (quantitative). • Changes in farm types by land use change (quantitative).
Biodiversity outcomes	• The total number of trees cultivated (quantitative); • The total number of trees by age group (quantitative); • Landscape connectivity and fragmentation: - The number and size of clustered patches/components spared for conservation (quantitative); - Demonstrative maps of fragmentation from villages (qualitative).
Production	• Farm spending (quantitative); • The total numbers of farms that experienced an increase or decrease in production as a result of scheme enrolment (quantitative); • Production changes at the landscape level (quantitative).
Economic outcomes	• Median Income (quantitative); • Gini coefficient based on total income (quantitative); • Households below the poverty line (quantitative)-see Section 4.2 for definition of poverty line
Food security	• The proportion of food retained for household consumption (quantitative); • The percentage of households by food budget groups (quantitative).

As in Chapter 8, the metrics outlined in Table 9.1 are measured at the end of 30 years of simulation and averaged over 20 simulation runs. The metrics are measured for each of the nine agri-environmental scheme scenarios (Table 9.2).

Table 9.2 The nine scenarios tested using PLUSES simulator

No.	Scenario	Description
01	No Schemes	Business-as-usual. Simulation running with no policies interventions in the landscape.
02	A only + No FI	Scheme A land use policy is introduced in the landscape, but it carries no financial incentive. Scheme B and C are switched off.
03	B only + No FI	Scheme B land use policy is introduced in the landscape, but it carries no financial incentive. Scheme A and C are switched off.
04	C only + No FI	Scheme C land use policy is introduced in the landscape, but it carries no financial incentive. Scheme A and B are switched off.
05	All + No FI	All schemes are running in the landscape, but they carry no financial incentive. Land users can select any one of the schemes, two schemes or all three.
06	A only + FI	Scheme A land use policy is introduced in the landscape and it carries a financial incentive. Scheme B and C are switched off.
07	B only + FI	Scheme B land use policy is introduced in the landscape and it carries a financial incentive. Scheme A and C are switched off.
08	C only + FI	Scheme C land use policy is introduced in the landscape and it carries a financial incentive. Scheme A and B are switched off.
09	All + FI	All schemes are running in the landscape and they carry a financial incentive. Land users can select any one of the schemes, two schemes or all three.

One-way analysis of variance (ANOVA) and Tukey's Honest Significant Difference (HSD) test were used to test for statistically significant differences between pairs of metric output means.

To assess how sensitive the output metrics are to changes in model settings, sensitivity testing was performed on a range of indicators (Table 9.3) following the same methodology outlined in Chapter 8 (see *Section 8.2*.).
The results of the sensitivity testing are always presented by comparing the results of the scenario under the baseline value with the other values of the same indicator.

Table 9.3 Table indicating the values of each indicator parameter that were tested against eight output metrics during the sensitivity testing of PLUSES. The baseline value of an indicator is identified by (B).

Output metrics	**Indicator parameters**															
	Initial household balance			Social Influence Threshold		Financial Incentive		Timber sale		Agency buys land		Bonus for connectivity			Production	
	0 (B)	5 times the initial household income	-5 times the initial household income	5 links (B)	0 links	6500 INR per patch for Scheme B. 5000 INR per patch for Schemes A and C (B)	Double the baseline Incentive	Allowed (B)	Not allowed	Allowed (B)	Not allowed	0 INR	1000 INR per patch (B)	4000 INR per patch	A 10% increase for Schemes A and B, a10% decrease for Scheme C (B)	Double the baseline change in production output
Biodiversity outcomes																
Total number of trees cultivated								X	X	X	X					
Age of trees	X	X	X					X	X	X	X					
Landscape connectivity and fragmentation				X	X					X	X	X	X	X		
Economic outcomes																
Income variation						X	X								X	X
Gini coefficient						X	X								X	X
Households below poverty line	X	X	X			X	X								X	X
Food security																
Food retained for consumption						X	X								X	X
Food spending	X	X	X			X	X								X	X

9.3 Land use and land cover change results and interpretation

9.3.1 Land use and land cover change results

9.3.1.1 Land use and land cover change over 30 years of simulation

Land use and land cover (LULC) change is analysed within the boundaries of the villages, as farmers in the model do no interact with the land outside of the village borders. At initialization the modelled landscape is formed of 60.03% forest cover, which is almost entirely under Forest Department protection. Additionally 18.29% of the area is: arable and plantation land, 15.93% rocky land, 2.66% settlements and 3.09% other land uses.

The simulation is run for 30 years with all the interventions present in the landscape. There are important land use changes that can be observed within the boundaries of the villages. The changes observed mostly affect areas categorised as arable and tea plantation land (Table 9.4, Figure 9.1).

Table 9.4 The percentage of the landscape covered by different land use and land cover types at the beginning and end of the simulation. The simulation was run with all schemes available for enrolment and with financial incentives in place to encourage enrolment.

Land use	Initial percentage of LULC	End of simulation percentage of LULC
Tea land: not enrolled in schemes *(Unenrolled Tea)*	90.09	44.88
Agriculture land: not enrolled in schemes (*Unenrolled Agriculture)*	9.91	31.92
Forest land: not enrolled in schemes *(Unenrolled Forest)*	0	3.48
Tea land: enrolled in Scheme A *(A Tea)*	0	0.44
Agriculture land: enrolled in Scheme A *(A Agriculture)*	0	7.85
Forest land: enrolled in Scheme B *(B Forest)*	0	1.49
Tea land: enrolled in Scheme C *(C Tea)*	0	7.66
Agency Forest	0	2.28

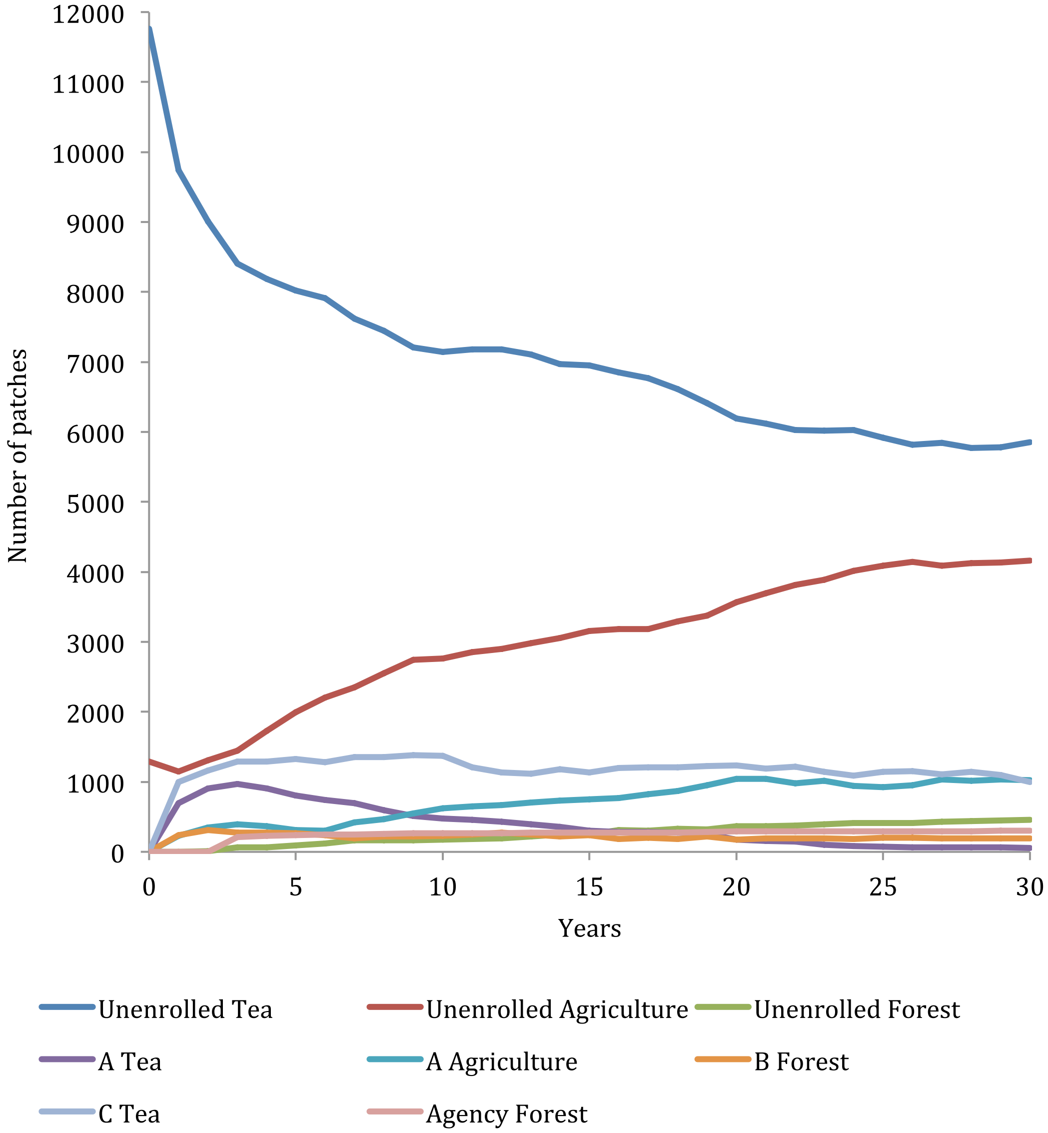


Figure 9.1 The change in the number of patches per LULC type within the landscape over 30 years of simulation. The simulation was run with all schemes available for enrolment and with financial incentives in place. The results refer to the total area within the boundaries of the study villages. "Unenrolled" refers to the land that is owned by farmers and is not enrolled in any of the Schemes.

The most significant change is the increase of cropland and a corresponding loss of tea land. Over the simulated period the area of tea land decreases by 50%, from 11,760 patches (SD=1352) to 5,858 patches (SD=365). During the same period the area of agricultural land increases by 300%, from 1,294 patches (SD=98) to 4,164 patches (SD=267). An important increase is also observed in the extent of forested land. At the start of the simulation no forest cover exists within the village boundaries. After 30 years 946 patches are present, this equates to 7.25% of LULC. Forested land is predominantly found on private land 48% (454 patches, SD=23). An additional 20% of forested land (194 patches, SD=50) also occurs on private land but enrolled under Forest Plantations (Scheme B). The remaining 32% (298 patches, SD=15) of forestland is owned by the Agency.

After 30 years of simulation, tea plantations enrolled in Tree Intercropping (Scheme C) and agricultural land or tea plantations enrolled in Wildflower Meadows (Scheme A) have also increased their area of coverage within the landscape. The land enrolled in Schemes A (8.29%) and C (7.66%) covers areas similar to that of the total forest cover (Table 9.4).

A sustained preference for Scheme A is observed among agricultural farms and for Scheme C among tea growers.

9.3.1.2 Changes in farm types by land use

There are four main types of households in the landscape: landless, vegetable only farms, tea only farms and mixed farms.

Under the *"No Schemes"* scenario, (after 30 years of simulation), landless households account for 35% of all households in the landscape (349.05 households, SD=16.05, n=993). Their main source of income comes from off-farm sources. Of the 644 households that own land the most common type of landholding was mixed farms that own both tea plantations and vegetable land. These mixed farms account for 58% of all farmsteads (371.65 households, SD=18.08). Those that own only tea land (171.80 households, SD=12.44) or only vegetable land (101.10 households, SD=10.52) represent 27% and 15% of the total farmsteads respectively.

The number of vegetable farms does not vary with statistical significance between model initialisation and the simulation's conclusions regardless of the scenario [$F(8, 171)=1.22$, $p=0.273$]). Similarly, there is no statistically significant change in the number of landless households across any of the scenarios tested [$F(8, 171)=0.017$, $p=0.99$].

In contrast the number of tea farms and mixed farms do vary between model initialisation and the simulation's conclusions depending on the implemented scenario. In the *"No Schemes"* scenario a 62% reduction in the number of tea farms is observed over the 30-year simulation (from 463.95, SD=12.65 to 171.8, SD=12.43).

A simultaneous 49% increase in mixed land use farms is observed (from 189.5, SD=8.84 to 371.65, SD=18.08). This change can be observed in the land use maps of all the villages under study (Figure 9.2).

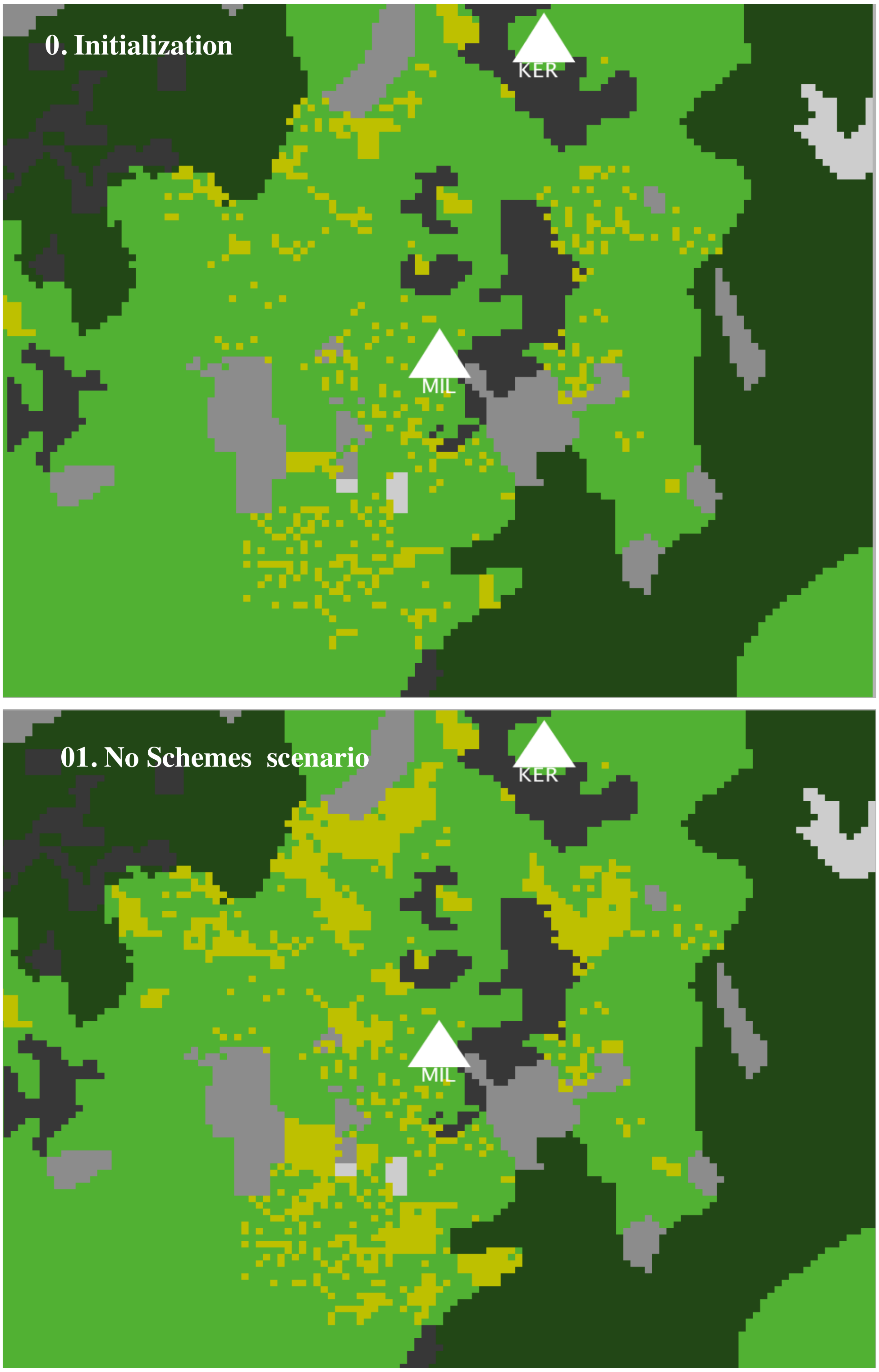


Figure 9.2 An example land use map showing Milidhen village at the models' initialization and conclusion under the "No Schemes" scenario. The land uses are colour coded as follows: tea (light green), agriculture (yellow), forest (dark green) and rocky land (grey).

For owners of tea and mixed farms the introduction of schemes, either individually or simultaneously, without any financial incentives, did not generate a statistically significant change in land use when compared with the change observed under the "*No Schemes*" scenario (Figure 9.3, Table 9.5).

When Scheme A was accompanied by a financial incentive for scheme adoption, statistically significant increases in the conversion of tea farms to mixed farms over that already seen in the *"No Schemes"* scenario was observed (Figure 9.3, Table 9.5). The same pattern of increased conversion of tea land to mixed cultivation land was observed when all the Schemes were available simultaneously and accompanied by a financial incentive, *"All +FI"*. In both cases the conversion of tea only farms to mixed farms resulted in a 17% increase in the number of mixed farms (Figure 9.3, Table 9.5).

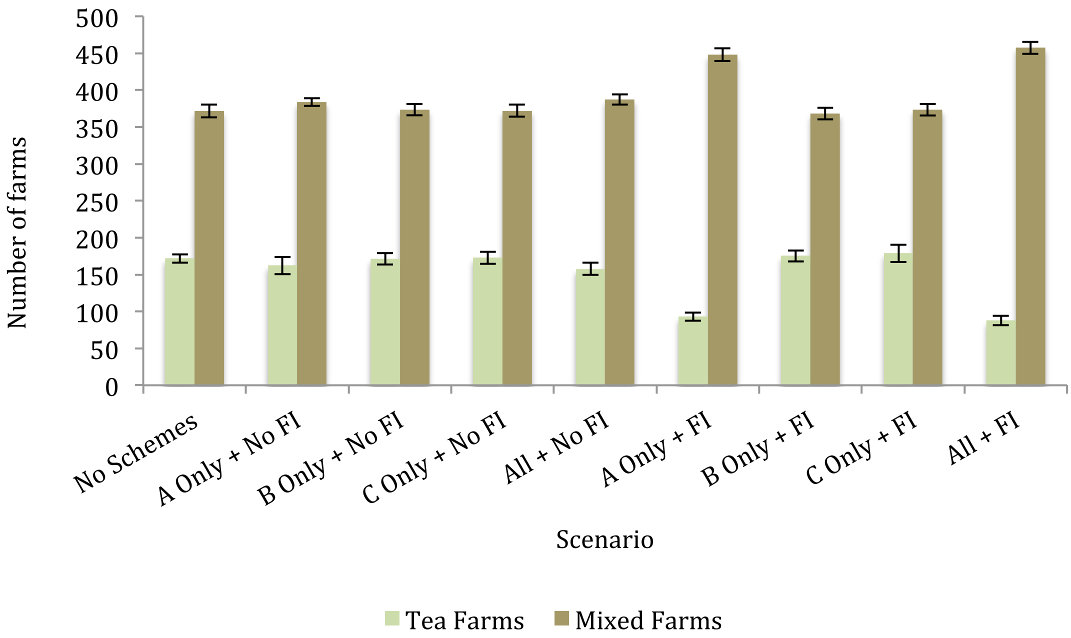


Figure 9.3 The number of households by landholding type owned averaged over 20 simulations at the end of 30 years of simulation predicted by the model under nine scenarios. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

Table 9.5 One-way ANOVA results of the number of landholdings pre and post simulation, by land use type, under nine scenarios. Tukey's HSD post hoc results between pairs of scenario groups are also shown. Statistically significant differences ($p < 0.05$) between pairs of scenarios are shown in bold and marked with an asterisk.

Tea farms ANOVA $F(8, 171) = 110.67, p < 0.001$									
		No Scheme	Scheme A Only + No FI	Scheme B Only + No FI	Scheme C Only + No FI	All Schemes + No FI	Scheme A + FI	Scheme B + FI	Scheme C + FI
Tukey's HSD test	Scheme A Only + No FI	9.35	-						
	Scheme B Only + No FI	0.30	9.05	-					
	Scheme C Only + No FI	0.95	10.30	1.25	-				
	All Schemes + No FI	14.05	4.70	13.75	15.00	-			
	Scheme A Only + FI	**78.9***	**69.55***	**78.6***	**79.85***	**64.85***	-		
	Scheme B Only + FI	3.60	12.95	3.90	2.65	17.65	**82.5***	-	
	Scheme C Only + FI	7.00	16.35	7.30	6.05	**21.05***	**85.9***	3.40	-
	All Schemes + FI	**83.85***	**74.5***	**83.55***	**84.8***	**69.8***	4.95	**87.45***	**90.85***
Mixed farms ANOVA $F(8, 171) = 109.99, p < 0.001$									
		No Scheme	Scheme A Only + No FI	Scheme B Only + No FI	Scheme C Only + No FI	All Schemes + No FI	Scheme A + FI	Scheme B + FI	Scheme C + FI
Tukey's HSD test	Scheme A Only + No FI	12.25	-						
	Scheme B Only + No FI	1.95	10.3	-					
	Scheme C Only + No FI	0.5	11.75	1.45	-				
	All Schemes + No FI	15.5	3.25	13.55	15	-			
	Scheme A Only + FI	**76.45***	**64.2***	**74.5***	**75.95***	**60.95***	-		
	Scheme B Only + FI	3.3	15.55	5.25	3.8	**18.8***	**79.75***	-	
	Scheme C Only + FI	1.7	10.55	0.25	1.2	13.8	**74.75***	5	-
	All Schemes + FI	**85.75***	**73.5***	**83.8***	**85.25***	**70.25***	9.3	**89.05***	**84.05***

9.3.2 Land use and land cover change discussion

In terms of LULC change PLUSES forecasts two important emerging phenomena. The first and most surprising one (which shares similarities with the RPG outcomes) is the rapid conversion of tea land into vegetable land, even in the absence of schemes in the simulation. Studies carried out in the Nilgiris describe the area under agro-horticulture as having reduced by 25% between 1973 and 2009 (Lakshumanan et al., 2012) and a further reduction is reported between 2013 - 2016 (Mamtha et al., 2016). Both studies fail to provide a definition for what type of crops fall under agro-horticulture category but do report specific figure for changes in (the area) of tea plantations. Lakshumanan et al. (2012) reported a 10% decrease in tea plantations area between 1973 and 2009 whilst Mamtha et al. (2016) described an increase of 10% between 2013 and 2016. In contrast the Department of Economics and Statistics (2017) and Horticulture Department (2015) describe the area under tea cultivation as static between 2012 and 2016. These ambiguous results are of limited value for validating the future trends in the area of land covered by tea plantations as predicted by PLUSES.

Whilst absolute published figures on changes to tea plantation area are of limited value, both the model itself and the published literature provide valuable information regarding the trend of converting tea land to agricultural production. In the model, the fact that vegetable only farms are found within the same range throughout all the scenarios, suggests that most of the tea farms do not convert all their tea land to vegetable land. The conversion of tea land to vegetable cultivation, even in the absence of interventions occurs as a result of low tea prices and the higher profitability of agricultural land. Venugopal (2004) and Thiagarajan (2014) note that the conversion of tea land to vegetable crop land in the Nilgiris is expected to accelerate following sustained years of low tea prices.

The pace at which tea land is predicted to be converted to agricultural production by the PLUSES model is probably an exaggeration of the rate expected in reality. The assumptions made in the model, regarding farmers' decision-making around profitability of land and conversion, are the cause of this accelerated process. The assumptions and their implications are detailed in *Section 7.7.1*.

By introducing the individual schemes a further conversion from tea to vegetable land occurs exclusively under Wildflower Meadows (Scheme A) and only when it is supplemented by a financial incentive. This result is difficult to explain. The only likely justification is that Tree Intercropping (Scheme C) adds value to tea land and discourages conversion to vegetable land. A similar outcome was observed in the RPG (see LULC in *Section 6.3.2.2*). Further investigation to better understand this process and inform the local policies is needed.

The second noteworthy outcome of the model is the increase in areas under agroforestry, wildflower meadows and forest plantations. Unlike the RPG, the use of the ABM provides an important dimension; that of understanding the scale of the land enrolled under the three interventions at landscape level. The lands enrolled in each scheme individually cover small areas of similar sizes (around 7-8% of LULC), but when put together these lands cover more than a quarter of the total area of the villages. This has significant implications for policy makers because it demonstrates that by placing the aspiration of the farmers at the core of the decision-making the heterogeneity of habitats might be a key solution in human-modified landscapes, supporting the findings of previous studies carried in Western Ghats (Anand et al., 2010, Garcia et al., 2010, Karanth and DeFries, 2010, Karanth et al., 2016). The findings are relevant and could provide valuable policy information to other similar human-modified landscapes around the world that feature habitat heterogeneity and structural complexity while retaining considerable native forest cover, such as Mexico (Greenberg et al., 1997), the Dominican Republic (Wunderle, 1999) and Colombia (Armbrecht et al., 2005). In Nilgiris, the importance of understanding farmers' individual choices is also supported by the fact that after 30 years of simulation more conservation habitat occurs on private farms than is owned by the Agency. Thus, it is important to focus conservation efforts on both private and state owned conservation land. In the Peruvian Amazon it was shown that private lands growing forest were on average more effective in avoiding deforestation and degradation than state protected areas, showing that local governance can be equally or more effective than centralized state regimes (Schleicher et al., 2017)

A limitation of the model is that it does not simulate the interaction between the villages and the forest found in the protected areas due to limited data availability on the processes that occur in the landscape. Factors such as tourism, house expansion and land abandonment will all play an important part in understanding these interactions (Venugopal, 2004, Chetan et al., 2012, Mamtha et al., 2016), which could lead to both an increase and decrease in the pressure on forests. In the model the forest, currently under protection, remains constant but PLUSES could be expanded in the future to include some of the interactions mentioned.

9.4 Biodiversity conservation outcomes and interpretation

9.4.1 Biodiversity conservation results

9.4.1.1 Total number of trees cultivated

The total number of trees cultivated in the landscape is a combined total of tree numbers from four sources:

i) The total number of trees on farmers' land at the beginning of the simulation;

ii) The total number of trees replanted by farmers on the farm after trees have been harvested and sold for timber;

iii) The trees planted by farmers through enrolment in Schemes B and C;

iv) The trees planted on the land bought by the Agency.

Within the study trees are classified as exotic or native species. The model assumes that when a tree is harvested for timber it is replaced with a sapling of the same species. Therefore under the *"No Schemes"* scenario where no schemes or Agency are present within the landscape to influence the cultivation of trees the total number of trees and the proportion of exotic to native trees in the landscape is the same at model initialization and the simulation's conclusion. Under the *"No Schemes"* scenario 4 times more exotic trees are cultivated in the landscape (26,600 trees, SD = 2,353), than native trees (6,424 trees, SD=1175).

The total number of native trees in the landscape shows a statistically significant increase under all scenarios when compared to the *"No Schemes"* scenario (Figure 9.4, Table 9.6). The total number of exotic trees shows little or no variation across all the different scenarios ($F(8,171)=0.0013$, $p=0.999$). In all instances running the simulation with all schemes simultaneously, with or without a financial incentive, significantly increases the cultivation of native trees when compared with running one scheme at a time (Figure 9.4, Table 9.6).

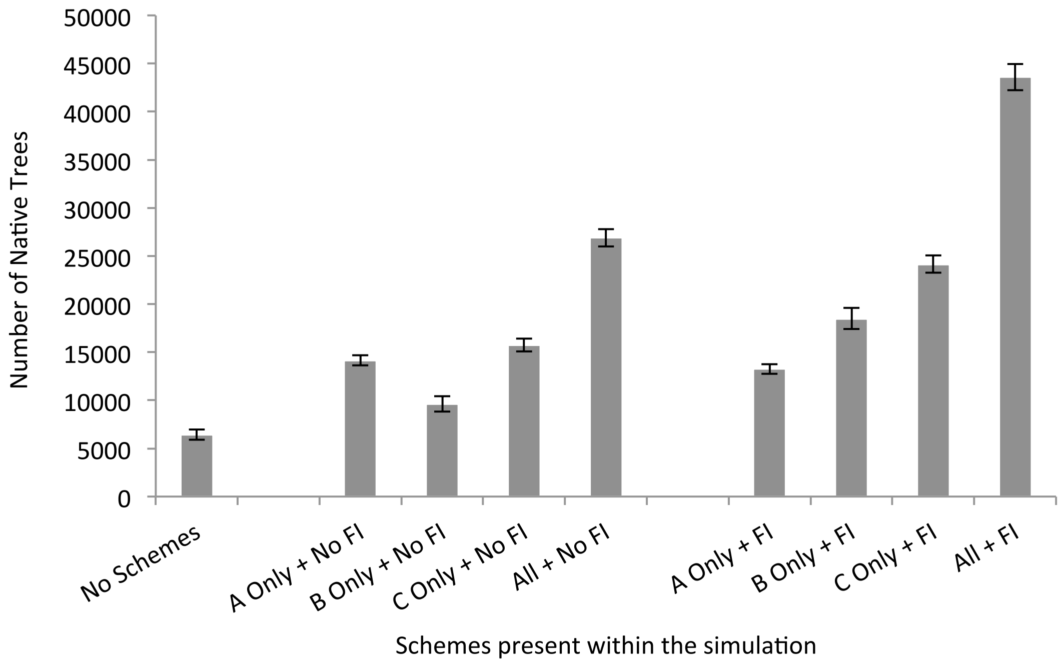


Figure 9.4 The total number of native trees cultivated by landholdings, as predicted by the model under nine scenarios after 30 years of simulation. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

Table 9.6 One-way ANOVA result of total number of native tress cultivated under different simulation scenarios and Tukey's HSD post hoc results between pairs of scenario groups. Statistically significant differences ($p < 0.05$) are shown in bold and marked with an asterisk.

Native trees									
	ANOVA $F(8,171)=749.7, p<0.001$								
Tukey's HSD test		No Scheme	Scheme A Only + No FI	Scheme B Only + No FI	Scheme C Only + No FI	All Schemes + No FI	Scheme A + FI	Scheme B + FI	Scheme C + FI
	Scheme A Only + No FI	7725*	-						
	Scheme B Only + No FI	3199*	4525*	-					
	Scheme C Only + No FI	9307*	1582.1	6107*	-				
	All Schemes + No FI	20477*	12752*	17278*	11170*	-			
	Scheme A Only + FI	6845*	879.5	3646*	2461.6*	13632*	-		
	Scheme B Only + FI	12083*	4358*	8883*	2775.9*	8394*	5238*	-	
	Scheme C Only + FI	17724*	9999*	14524*	8417*	2753.3*	10879*	5641*	-
	All Schemes + FI	37170*	29450*	33980*	27868*	16698*	30329*	25092*	19451*

When a scenario with a financial incentive is compared to the same scenario without a financial incentive a statistically significant increase in native trees is observed in almost all cases (Figure 9.4, Table 9.6). The only exception is for the scenarios where only Scheme A is available (Table 9.6). Under the financial incentive scenarios and all-scheme scenarios the number of trees is expected to grow or have the highest value, because of the higher enrolment and the cumulated effect of the three schemes.

Probably the most noteworthy outcome of this metric is that *"A Only + No FI"*, increases the number of native trees in the landscape significantly more than *"B Only + No FI"*, despite A being a wildflower meadow scheme and B being a forest plantation scheme (Figure 9.4, Table 9.6). This is related to the Agency's behaviour and sensitivity testing revealed how this emergent process occurs. When a landowner is forced to abandon or sell their land, the Agency buys that land and plants the maximum number of native trees possible on that land (up to 200 trees per acre) and this happens more commonly under Scheme A than Scheme B.

Sensitivity testing

Sensitivity testing shows that the number of trees is influenced by:

i) The capacity of the Agency to buy land for conservation;

ii) The restrictions on timber sell.

Sensitivity testing of Agency behaviour was tested for when the Agency is allowed to buy land into conservation and plant trees (baseline) compared with not being allowed. A statistically significant difference in native tree numbers at the conclusion of simulations is observed only under Scheme *"A Only + No FI"* [$t(38) = 19.097$, $p < 0.001$]. The number of native trees in the landscape, at the simulation's conclusion, is halved (from 14,148 trees to 6,400 trees) when the Agency is not permitted to buy and reforest abandoned land. For Scheme *"B Only + No FI"* and Scheme *"C Only + No FI"* an increase is also observed but it is not statistically different from baseline behaviour [$t(38) = 0.251$, $p = 0.803$; $t(38) = 0.774$ p=0.443]. The Agency therefore plants more trees on land bought under Scheme *"A Only + No FI"* than Scheme *"B Only + No FI"* or Scheme *"C Only + No FI"* even though the number of patches bought by the Agency doesn't vary significantly between the three schemes (Figure 9.5).

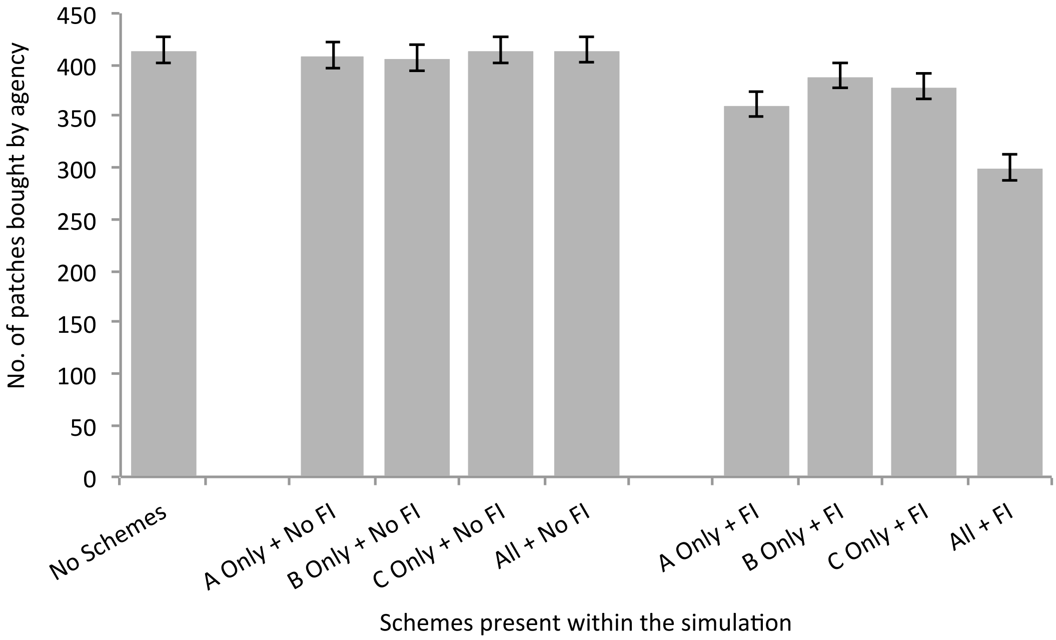


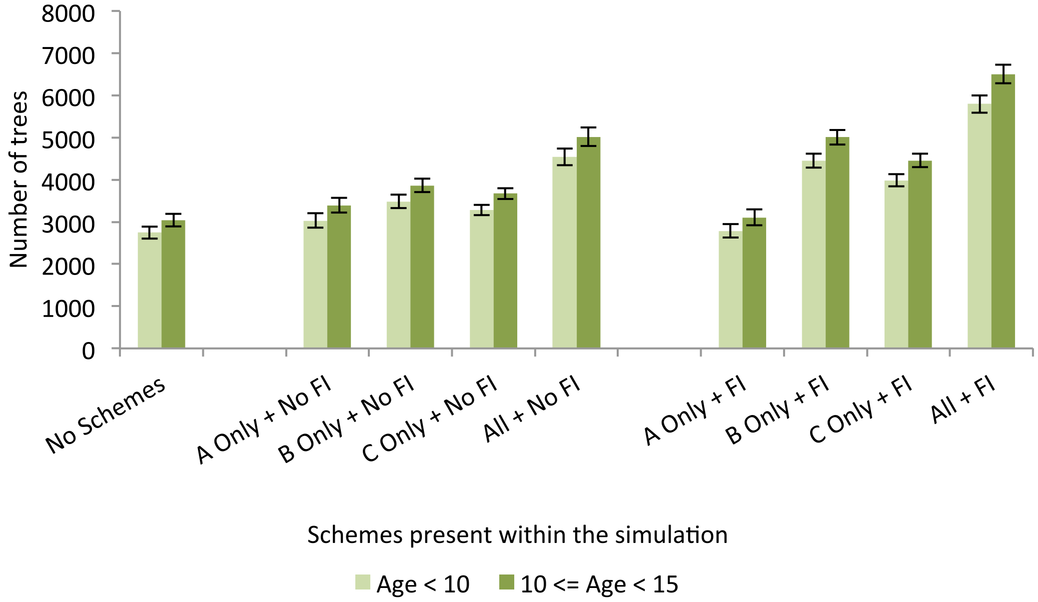
Figure 9.5 Total number of patches bought by the Agency into conservation, as predicted by the model under nine scenarios after 30 years of simulation. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

The ability of landowners to sell timber or not also influences the total number of trees in the landscape. When the schemes carry a financial incentive a statistically significant 9% increase in the number of native trees (from 13,252 trees to 14,543 trees) was observed under Scheme A when the sale of timber was restricted [$t(38)$=3.945, $p < 0.001$]. Schemes B and C showed no statistical difference in the number of native trees between the sale of timber being restricted or permitted [$t(38)$=0.493, p=0.624; $t(38)$=1.465, p=0.151].

9.4.1.2 *Age of trees*

When the simulation runs with the *"No Schemes"* scenario the number of trees over 15 years old (28,858.55 trees, SD=2969.17) is considerably higher than both the number of trees under

10 years old (2,786.95 trees, SD=942.64) and between 10 and 15 years old (3,091.68 trees, SD=1031.23; Figure 9.6).



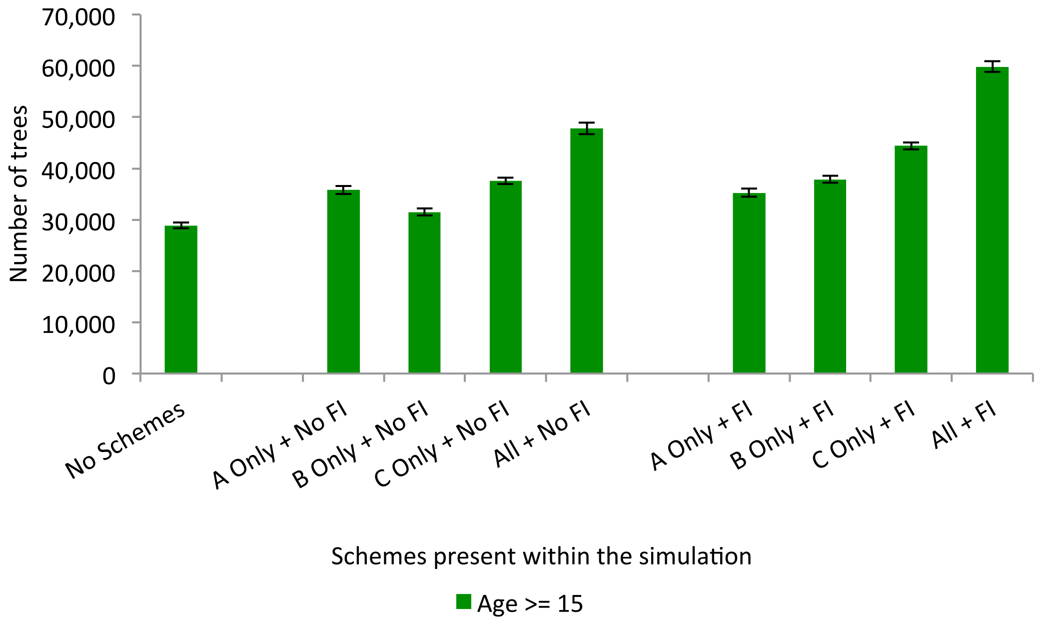


Figure 9.6 The number of trees by age predicted by the model under nine scenarios after 30 years of simulation. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

When individual schemes without financial incentives are introduced into the model the number of trees within the <10 and 10-15 age classes at the end of the simulation increases in comparison with the *"No schemes"* scenario (Figure 9.6). The increase in tree numbers generated by the inclusion of individual schemes without a financial incentive does not show a significant difference between Schemes A, B or C (Table 9.7).

Table 9.7 One-way ANOVA results of the total number of tress, by age group, under different simulation scenarios and Tukey's HSD post hoc results between pairs of scenario groups. Statistically significant differences ($p < 0.05$) are shown in bold and marked with an asterisk.

Trees Aged less than 10 years									
	ANOVA $F(8,171) = 161.02$, $p < 0.001$								
Tukey's HSD test		No Scheme	Scheme A Only + No FI	Scheme B Only + No FI	Scheme C Only + No FI	All Schemes + No FI	Scheme A + FI	Scheme B + FI	Scheme C + FI
	Scheme A Only + No FI	205	-						
	Scheme B Only + No FI	645	440	-					
	Scheme C Only + No FI	208.4	3.4	436.6	-				
	All Schemes + No FI	**1353.8***	**1148.8***	708.8	**1145.4***	-			
	Scheme A Only + FI	91.75	296.75	**736.7***	300.15	**1445.5***	-		
	Scheme B Only + FI	**1396.1***	**1191.1***	**751.1***	**1187.7***	42.3	**1487.8***	-	
	Scheme C Only + FI	**1083.8***	**878.8***	438.9	**875.4***	269.95	**1175.6***	312.25	-
	All Schemes + FI	**3056.7***	**2851.7***	**2411.7***	**2848.3***	**1702.9***	**3148.4***	**1660.6***	**1972.9***
Trees aged 10 years or more but less than 15 years									
	ANOVA $F(8,171) = 165.25$, $p < 0.001$								
Tukey's HSD test		No Scheme	Scheme A Only + No FI	Scheme B Only + No FI	Scheme C Only + No FI	All Schemes + No FI	Scheme A + FI	Scheme B + FI	Scheme C + FI
	Scheme A Only + No FI	233.05	-						
	Scheme B Only + No FI	690.9	457.9	-					
	Scheme C Only + No FI	212.45	20.6	478.5	-				
	All Schemes + No FI	**1488.2***	**1255.1***	**797.3***	**1275.7***	-			
	Scheme A Only + FI	118.4	351.5	**809.3***	330.9	**1606.6***	-		
	Scheme B Only + FI	**1655.1***	**1422.1***	**964.2***	**1442.7***	166.95	**1773.5***	-	
	Scheme C Only + FI	**1146.3***	**913.2***	455.4	**933.8***	341.9	**1264.7***	508.8	-
	All Schemes + FI	**3494***	**3261***	**2802.7***	**3281***	**2005.5***	**3612***	**1838.5***	**2347.4***
Trees age 15 years and over									
	ANOVA $F(8,171) = 217.63$, $p < 0.001$								
Tukey's HSD test		No Scheme	Scheme A Only + No FI	Scheme B Only + No FI	Scheme C Only + No FI	All Schemes + No FI	Scheme A + FI	Scheme B + FI	Scheme C + FI
	Scheme A Only + No FI	**7225***	-						
	Scheme B Only + No FI	2205	**5020***	-					
	Scheme C Only + No FI	**8803***	1577.7	**6598***	-				
	All Schemes + No FI	**18134***	**10909***	**15929***	**9331***	-			
	Scheme A Only + FI	**6584***	640.8	**4379***	2218.5	**11549***	-		
	Scheme B Only + FI	**9461***	2235.7	**7256***	658	**8673***	2876.5	-	
	Scheme C Only + FI	**15856***	**8631***	**13651***	**7053***	2277.8	**9272***	**6395***	-
	All Schemes + FI	**31710***	**24483***	**29503***	**22905***	**13574***	**25123***	**22247***	**15852***

In the absence of a financial incentive for scheme adoptions, in the over 15 years age class, only the inclusion of Scheme A and C increases the number of trees in comparison to the *“No Schemes”* scenario (Figure 9.6). The inclusion of Scheme B generates an increase that is not significantly different to the *“No Schemes”* scenario and is significantly lower than the increase produced by the introduction of Schemes A and C (Table 9.7). The effect of introducing individual schemes, without a financial incentive, to the number of trees 15 years old or more is similar to that seen for the total number of trees, where Scheme B also did not produce any noticeable difference to the no scheme scenario (Table 9.7).

With the exception of Scheme A, adding a financial incentive to the schemes significantly increased the number of trees in each age class in comparison to scenarios where schemes have no financial incentive (Table 9.7).

Sensitivity testing

Sensitivity testing shows that the number of trees by age group is influenced by:

i) The level of initial household balance
ii) Whether timber transactions are permitted or not
iii) The capacity of the Agency to buy land for conservation.

When the initial household balance is set to 5 times the annual income, the number of trees at the end of the simulation in the <10 and 10-15 year old age categories decreases under all three schemes with a financial incentive compared to the baseline setting where initial household balance is set to 0. The extent of the reduction in tree numbers varies across the schemes with *“B Only + FI”* and *“C Only + FI”* generating a 30% decline and *“A Only + FI”* generating a large 400% decline when household balances are increased in the models initial conditions. Trees that are over 15 years old show much smaller decreases of 5-10% under Schemes “*A Only + FI*” and “*C Only + FI*”, and an increase of 9% under Scheme “*B Only + FI*”.

Sensitivity testing also shows that when the sale of timber is restricted within the model a decrease in the number of trees in the <10 and 10-15 year old age categories occurs. A corresponding increase in trees that are over 15 years old within the landscape also occurs under each scenario [*"A Only + FI"* 20% increase*, "B Only + FI"* 13% increase and *"C Only + FI"* 13% increase].

The observed increase is larger under Scheme A, because the total number of trees in the landscape increases under Scheme A when there are restrictions on the sale of timber (see *Section 9.4.1.1*).

The final factor revealed by sensitivity testing to influence the number of trees by age group is the Agency's capacity to buy land for conservation. An agency that buys abandoned land and reforests it produces a simulation in which there are more trees that reach the >15 year old age category; with the scenarios *"A Only + FI"*, *"B Only + FI"* and *"C Only + FI* showing a 29%, 12% and 9% increase in the total number of trees over 15 years old. Once again a larger increase is observed under Scheme A, because of its comparatively higher capacity to increase the total number of trees in the landscape (see *Section 9.4.1.1*).

9.4.1.3 Landscape connectivity and fragmentation

This section assesses the spatial arrangement of patches of land set aside for biodiversity conservation within the modelled landscape and therefore only Schemes A and B are relevant. In calculating the landscape connectivity under the two schemes the forested patches that are owned by farmers (and are not in the schemes) or were set aside for conservation by the Agency were also included. The impact of the Agency under each scheme is reported alongside sensitivity testing, at the end of this section.

The connectivity in the landscape is assessed using two metrics: the number of components (using Normalised Network Metric Value) and the average size of the components. The patches owned by households or by the land agency and converted to forest or enrolled in Wildflower Meadows are referred to as nodes. A network component is any set of nodes for which every member of the scheme has its land connected directly or indirectly to every other member, and no member is connected to a non-member. The metric was standardized by dividing by the total number of nodes in the landscape (n), so that it varies between 1/n (close to 0) and 1 (i.e. Normalised Network Metric Value). Given an equal number of patches set aside for biodiversity a smaller number of components indicates a higher degree of connectivity in the landscape (Figure 9.7).

The average size of the component refers to the mean number of nodes that form a component.

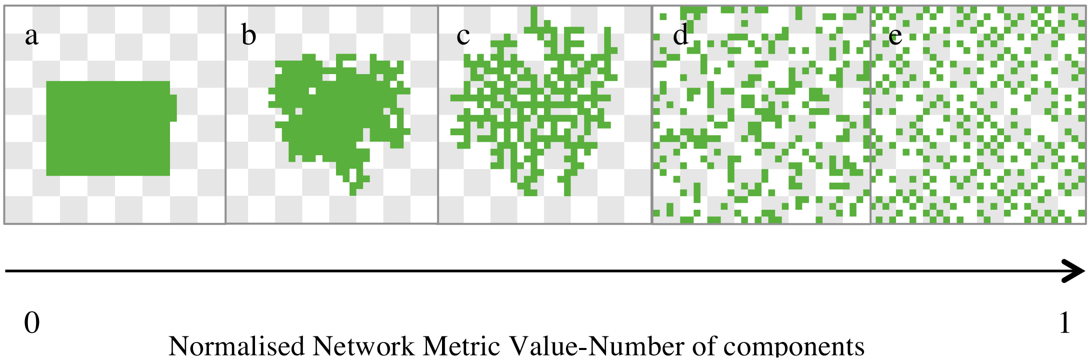
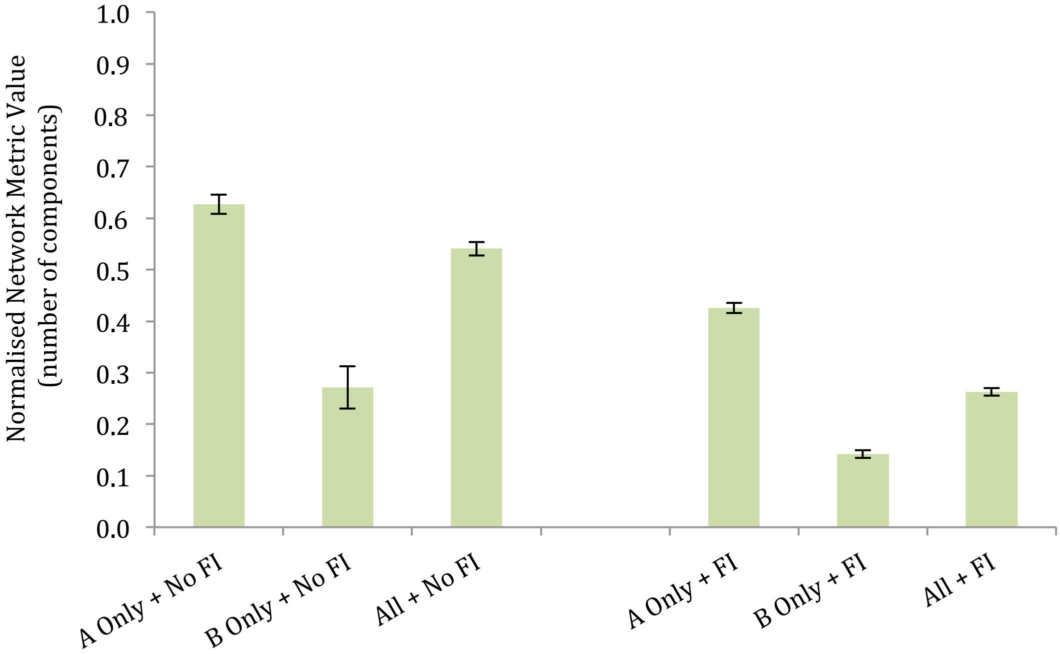


Figure 9.7 Connectivity of the land set aside for conservation

Under Scheme B, with or without a financial incentive, both a smaller number of components and a higher average size were generated compared to Scheme A and All Schemes scenarios (Figure 9.8, Table 9.8). Between Scheme A and All Schemes, the latter generates a smaller number of components with a larger average size when financial incentives are both present and absent (Figure 9.8, Table 9.8).

Patches enrolled under Scheme *"B Only + FI"* are more clustered, resembling the configuration of Figure 9.7b compared to patches enrolled under the *"A Only + FI"* scenario, which are more similar to Figure 9.7d, particularly in Kaggula village (Figure 9.9).



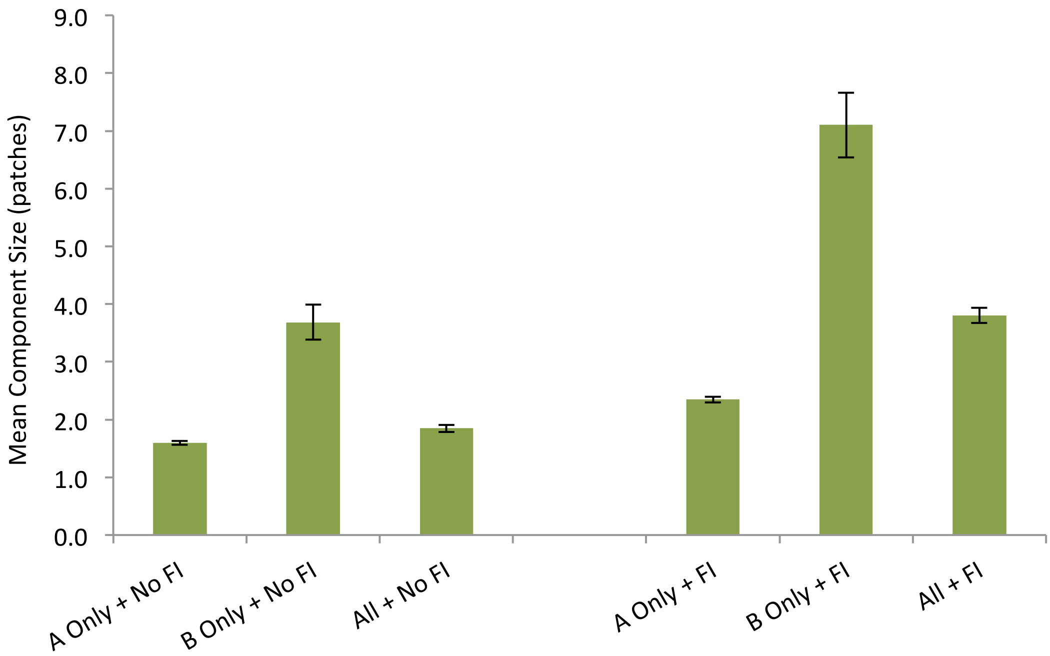


Figure 9.8 Total number of components and the mean component size predicted by the model under six scenarios, after 30 years of simulation. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

Table 9.8 One-way ANOVA results of the number of components and the size of the largest component under different simulation scenarios and Tukey's HSD post hoc results between pairs of scenarios. Statistically significant differences (p < 0.05) are shown in bold and marked with an asterisk.

Normalised Network Metric Value						
	ANOVA *F*(5,114)=369.47, *p*<0.001					
Tukey's HSD test		Scheme A Only + No FI	Scheme B Only + No FI	Schemes A and B + No FI	Scheme A+ FI	Scheme B+ FI
	Scheme A Only + No FI	-				
	Scheme B Only + No FI	**0.35***	-			
	Schemes A and B + No FI	**0.08***	**0.26***	-		
	Scheme A + FI	**0.20***	**0.15***	**0.11***	-	
	Scheme B + FI	**0.48***	**0.12***	**0.39***	**0.28***	-
	Schemes A and B + FI	**0.36***	0.008	**0.27***	**0.16***	**0.12***
Average Component Size						
	ANOVA *F*(5,114)=252.29, *p*<0.001					
Tukey's HSD test		Scheme A Only + No FI	Scheme B Only + No FI	Schemes A and B + No FI	Scheme A+ FI	Scheme B+ FI
	Scheme A Only + No FI	-				
	Scheme B Only + No FI	**2.09***	-			
	Schemes A and B + No FI	0.25	**1.83***	-		
	Scheme A + FI	**0.75***	**1.33***	0.49	-	
	Scheme B + FI	**5.50***	**3.41***	**5.25***	**4.753***	-
	Schemes A and B + FI	**2.20***	0.11	**1.95***	**1.4558***	**3.297***

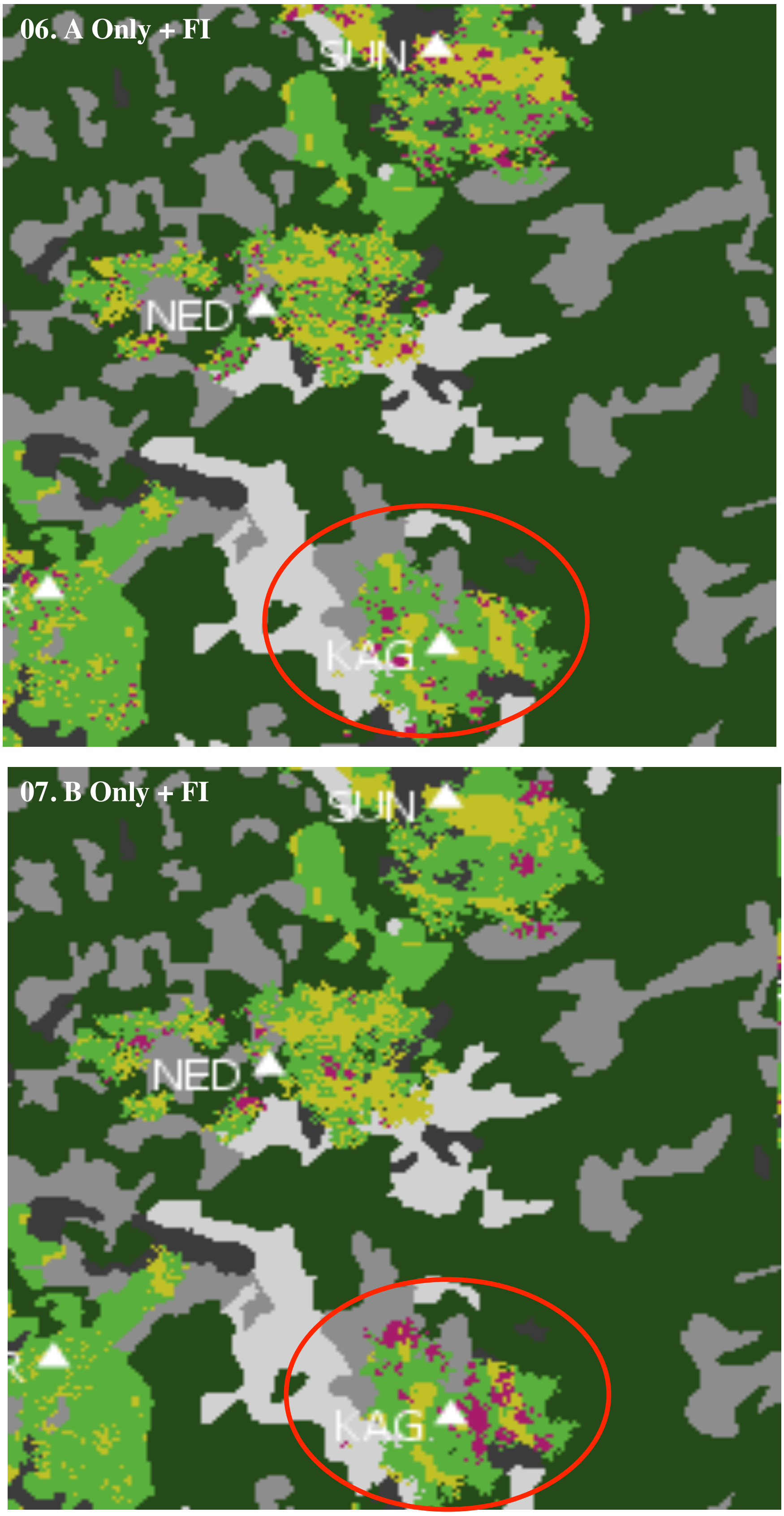


Figure 9.9 Land use maps showing the spatial distribution of patches enrolled under scheme "A Only + FI" and "B Only + FI" covering the areas of Kaggula (KAG), Nedugula (NED) and Sundatty (SUN) villages. Patches enrolled are coloured purple. *Note: The map only refers to the patches enrolled in schemes, not the Agency land.*

Sensitivity testing

To understand the effect of the Agency on landscape connectivity and fragmentation, sensitivity testing assessed the differences in the number and size of components when the model was run with and without the Agency buying land into conservation. In the *"A Only + FI"* scenario both the number and size of components varied significantly under different Agency behaviours [Number of components $t(38)=27.174$, $p < 0.001$; Size of component $t(38)=4.578$, $p<0.001$]. When the Agency buys land into conservation the total number of components increases by about 42% and the average size of the component increases by 17%. Under Scheme *"B Only + FI"* no statistically significant difference in the number of components and the average size of component was observed between the two Agency behaviours [Number of components $t(38)=0.487$, $p=0.628$; Size of component $t(38)=0.773$, $p=0.444$].

Sensitivity testing was also performed on the Social Influence Threshold (SIT) and it was found that it only influences the component size under Scheme "*A Only + FI*". The average size of the largest component increases by about 27% when there is no SIT, compared to the baseline scenario [$t(38)=4.868$, $p < 0.001$].

9.4.2 Biodiversity conservation discussion

The results show that all three interventions generate positive outcomes for biodiversity, but the benefits manifest differently across the schemes. While most of the biodiversity related processes and the metrics used to measure aspects of biodiversity show expected changes, there are some surprising results that were only possible to observe through the use of the ABM.

Firstly, the number of exotic trees in the landscape stays the same across all the scenarios. This indicates that farmers continue to cultivate exotic trees on their land when they sell timber. With the introduction of Forest Plantations and Tree Intercropping (for simplification I will use 'Intercropping'), almost all households that enrol choose to cultivate native trees even if they are given the choice between native or exotic species. This is one of the most surprising outcomes of this research given that plantation economics along with public policies have driven landowners to gradually replace the original diversified cover with exotic shade trees such as Silver Oak (*Grevillea robusta)*, which grows fast and can be easily traded as timber. In the Nilgiris, this led the Forest Department to only provide exotic tree saplings to farmers. The finding is important for policy makers, organisations or public institutions because it demonstrates that local farmers value native biodiversity and there is room to

increase the presence of native trees on the farms. However, some authors (Garcia et al. 2013) draw attention to the perverse outcomes that tree tenure security can have on jungle wood species on farms. Outcomes should also be balanced with the model assumptions around native trees (survival rate and farmers' choice) that are discussed later in this section.
Further, unexpected results were observed in the scenarios without a financial incentive. Here Wildflower Meadows generated an increase in the number of native trees greater than that of Forest Plantations and almost as high as Intercropping. Sensitivity testing showed this emerging process is likely a complex interplay between timber sales, land transactions (abandonment) and land that is dropped out of schemes. The findings suggest that the more communities face financial struggles and are forced into selling timber and ultimately abandoning land, the better opportunities for the conservation of biodiversity. It has been demonstrated that biodiversity conservation can indeed benefit from land abandonment, both locally (Chetan et al., 2012) and globally (e.g. Parrotta et al., 1997, Cramer et al., 2008, Sloan et al., 2016). However, abandonment doesn't lead *per se* to habitat that is of greater biodiversity value (Troiani et al., 2016). As such the presence of the Agency is still important in the landscape to ensure that where land does become available the biodiversity returns are maximised. Given the focus of this study, the social dimension of land abandonment is also important. What happens with the households when they are forced to abandon their lands? Whom do they sell their properties to and what do the new buyers intend for the land? These are important questions that need to be further addressed, as they are equally important in determining the future opportunities or threats for local biodiversity and food production.

Another important and unforeseen outcome emerges when increasing farmers' initial budgets. A substantial decline in the number of trees, especially in younger tree groups, across all three interventions is observed. Households are less likely to cultivate trees, for sale as timber as a potential financial safety net, when they have alternative sources of income to cope with financial pressure. Thus, greater financial wealth across the landscape influences the number of trees in a negative way. This has important implications for the design of the policies in the area. It draws attention on the possible effects of increasing wealth that might act in the detriment of conservation as many studies around the globe have demonstrated (Kaimowitz and Angelsen, 1998, Geist and Lambin, 2002, Kusters et al., 2006, Polimeni, 2012, Jepma, 2014, Busch and Ferretti-Gallon, 2017). It will be necessary for regional development policies to identify such potential negative impacts if biodiversity loss as a result of poverty alleviation is to be avoided.

The findings of this study, regarding the total number of trees and the age of trees need to be understood in relation to some of the assumptions made in the development of the model. Firstly, the model assumes that all new trees planted have a survival rate of 100%. The total number of native trees in the landscape is therefore likely to be inflated compared to what is expected in real life. A study of native trees' survival rate in Western Ghats shows a broad range between 34.4 and 90.3% under different site conditions (Raman et al., 2009). Data of this type was not available in the Nilgiris necessitating the use, in the model, of a survival rate that was uniform across all sites and interventions. This uniformity means that despite the likely elevation in absolute tree numbers, the patterns of tree numbers and age that occur between the three schemes are not affected.

Secondly, native trees are defined in a broad and general sense. There is no distinction made between particular species of jungle wood. In the model it is assumed that farmers have an equal likelihood to plant any native tree species. In reality it is expected that factors such as ease of pruning, depth of roots (which can affect tea plants), the price of timber and speed of growth would have an important influence on farmers' planting decisions. Research aiming to understand if current fast growing and economically viable exotic species can be replaced by native species equivalents is starting to emerge and the outcomes look promising. For example, in Kodagu district of Western Ghats *Acrocarpus fraxinifolius*, a native tree species was found to produce timber at rates equivalent to those of exotic species, *Grevillea robusta* (Nath et al., 2011).

Lastly, the model assumes that for every tree cut, the landowner plants a new one of the same species. This is certainly a strategy applied by the Nilgiris farmers, but the extent to which it manifests across farms has not been documented. The rule applied in the model was selected in order to avoid making more intricate assumptions about the rate of replanting and species choice replanting. The effect of this assumption is that the total number of trees may again be overestimated.

Moving on to connectivity of landscape patches enrolled in the schemes, a predictable increase in connectivity occurs when a financial incentive for enrolment is present. This is a function of more patches being enrolled in the incentivised scenarios, enabling an increase in the average cluster size and the formation of more continuous components.

The most surprising result that has been observed in the ABM shows that the Forest Plantations scheme produces a more connected landscape then both Wildflower Meadows and the All Schemes scenario. This is believed to be the result of the way the Agency manifests in the landscape. The purchase and reforestation of abandoned land by the Agency allows for habitat clusters to form larger areas but also creates more clusters that are isolated from existing habitat. The Agency is dependent on patches becoming available for sale and as a result it has little control over connectivity. A future version of the model could consider a variation in the Agency's buying strategy, in which only those patches that are already connected to a cluster are purchased. This would be of value where agency resources are limited and habitat connectivity is a key priority, for example in scenarios where sensitive species are unwilling to cross non-habitat patches (Green et al., 2005).

Finally, promoting one intervention over the other comes with important trade-offs. Forest Plantations result in greater habitat connectivity in the landscape, while Wildflower Meadows in a larger area set aside for conservation. A decision between the two has to then take into account whether more land set aside for conservation of wildflower meadows and forested patches but disjoined is better than small islands of continuous land spared for forests (Bunyan et al., 2012). The relative value of these options will depend on local conservation objectives and the ecology of target species.

9.5 Production outcomes

9.5.1 Production results

9.5.1.1 Farm budget changes

Based on their farm budget, households are classified in three initial spending groups that take into account the land use and land size of the farms (see Table 7.4).

Under the *"No Schemes"* scenario 43.33% of all landholdings (SD=3.11) are in the high farm-spending group, compared to 30.17% (SD=1.59) and 26.50% (SD=2.14) that have a low or medium-spending budget respectively.

Under the scheme scenarios statistical differences can only be observed when there is an incentive and only for low and high farm-spending groups (Table 9.9). Schemes *"A Only +*

FI", *"C Only + FI "*and *"All + FI"* decrease the number of landholdings in the low farm-spending group compared to *"No Schemes"* by about 3 percentage points, 2 percentage points and 6 percentage points respectively. A comparable increase in landholdings in the high-spending group was observed with *"A Only + FI"* producing a 3 percentage points increase, *"C Only + FI"* a 2 percentage points increase and *"All + FI"* a 5 percentage points increase. For medium spending-group the interventions produce no statistical change [$F(8,171)=2.35$, $p=0.02$].

Table 9.9 One-way ANOVA results of the number of landholdings in low and high farm-spending groups under different simulation scenarios and Tukey's HSD post hoc results between pairs of scenarios. Statistically significant differences ($p < 0.05$) are shown in bold and marked with an asterisk.

Farm spending (Low)									
	ANOVA $F(8,171)=74.24$, $p<0.001$								
Tukey's HSD test		No Scheme	Scheme A Only + No FI	Scheme B Only + No FI	Scheme C Only + No FI	All Schemes + No FI	Scheme A + FI	Scheme B + FI	Scheme C + FI
	Scheme A Only + No FI	0.34	-						
	Scheme B Only + No FI	0.08	0.26	-					
	Scheme C Only + No FI	0.032	0.31	0.05	-				
	All Schemes + No FI	0.51	0.16	0.42	0.48	-			
	Scheme A Only + FI	**3.07***	**3.42***	**3.15***	**3.10***	**3.58***	-		
	Scheme B Only + FI	0.45	0.80	0.54	0.48	0.97	**2.61***	-	
	Scheme C Only + FI	**1.89***	**2.24***	**1.98***	**1.93***	**2.41***	**1.17***	**1.44***	-
	All Schemes + FI	**6.01***	**6.36***	**6.09***	**6.04***	**6.52***	**2.93***	**5.55***	**4.11***
Farm spending (High)									
	ANOVA $F(8,171)=49.27$, $p<0.001$								
Tukey's HSD test		No Scheme	Scheme A Only + No FI	Scheme B Only + No FI	Scheme C Only + No FI	All Schemes + No FI	Scheme A + FI	Scheme B + FI	Scheme C + FI
	Scheme A Only + No FI	0.07	-						
	Scheme B Only + No FI	0.33	0.26	-					
	Scheme C Only + No FI	0.05	0.02	0.28	-				
	All Schemes + No FI	0.53	0.46	0.19	0.48	-			
	Scheme A Only + FI	**3.03***	**3.10***	**3.37***	**3.08***	**3.57***	-		
	Scheme B Only + FI	0.06	0.13	0.40	0.11	0.59	**2.97***	-	
	Scheme C Only + FI	**1.79***	**1.87***	**2.13***	**1.84***	**2.33***	1.23	**1.73***	-
	All Schemes + FI	**5.28***	**5.35***	**5.62***	**5.33***	**5.81***	**2.24***	**5.21***	**3.48***

9.5.1.2 Production change on the farms

Scheme enrolment modified production rates on land that remained under cultivation. In Schemes A and B where some land was set aside for biodiversity conservation the remaining land under cultivation saw a 10% increase in production as part of the scheme effect. Under Scheme C where trees were intercropped the land placed under the scheme saw a 10% decrease in production however no land was removed from production entirely.

Under these conditions about 15% (97.75, SD=8.29) of the total farmsteads (N = 644) who remained in the simulation benefited from an increase in production from enrolling in *"A Only + No FI"*. A smaller proportion, 2.5% of landholdings (16.15, SD=5.20), benefited from adopting *"B Only + No FI"* and 8.2 % of all farmsteads (53.1, SD=5.38) experienced a decline in production under *"C Only + No FI"*.

When a financial incentive is introduced the total number of households benefiting from an increase in production raises to about 48% (309.2, SD=17.28) under Scheme *"A Only +FI"* and to 8.5% (55.05, SD=5.92) under Scheme *"B Only +FI"*. A production decline was observed for about 18.4% (119.2, SD = 6.59) households under Scheme *"C Only +FI"*.

9.5.1.3 Production change at the landscape level

There is no statistically significant change in the aggregated agricultural production at landscape level between any of the nine scenarios tested [$F(8,171) = 1.516, p = 0.155$].

In terms of the aggregated tea production, there is no statistically significant difference between the *"No Schemes"* scenario and the other eight scenarios (Table 9.10). However, there is a statistically significant difference between *"C Only + FI"* and three other scenarios *"All + No FI"*, *"A Only + FI"* and *"B Only + FI"* (Table 9.10). Production under Scheme C is 9% higher than *"A Only + FI"* and *"B Only + FI"* and 10% higher than *"All + No FI"*. Given that less tea farms are converted to agriculture in the landscape under *"C Only + FI"* (see *Section 9.3.1.2*) the production is expected to be higher.

Table 9.10 One-way ANOVA results of total tea production under different simulation scenarios and Tukey's HSD post hoc results between each pair of scenario groups under each scheme. Statistically significant differences ($p < 0.05$) are shown in bold and marked with an asterisk.

Tea production									
	ANOVA $F(8,171)=2.68$, $p=0.01$								
Tukey's HSD test		No Scheme	Scheme A Only + No FI	Scheme B Only + No FI	Scheme C Only + No FI	All Schemes + No FI	Scheme A + FI	Scheme B + FI	Scheme C + FI
	Scheme A Only + No FI	93080	-						
	Scheme B Only + No FI	177460	270540	-					
	Scheme C Only + No FI	44710	137800	132750	-				
	All Schemes + No FI	671500	764600	494100	626800	-			
	Scheme A Only + FI	403800	496900	226320	359100	267730	-		
	Scheme B Only + FI	540000	633100	362600	495300	131480	136250	-	
	Scheme C Only + FI	1616000	1522900	1793500	1660700	**2287500***	**2019800***	**2156100***	-
	All Schemes + FI	463400	370300	640800	508100	1134900	867200	1003400	1152700

9.5.2 Production discussion

One of the most interesting and surprising emergent phenomena observed in the ABM is related to the production at landscape level. To understand its significance it is important to reflect on the outcomes at the farm level. At the farm level, enrolment in Wildflower Meadows is the strategy that benefited production the most compared to the other two strategies. This is because it attracted the highest number of enrollers who benefited from extension services (a measure of scheme enrolment) and an increase in farm spending, which led to a boost in total production. The other two interventions either had a small contribution (Forest Plantations) or decreased production on a considerable number of farms (Intercropping). At landscape level, when the total production from the farms is aggregated, the picture looks different. Sharing or sparing habitat for biodiversity does not affect overall production compared to a business-as-usual scenario. In the case of Wildflower Meadows and Forest Plantations the increase in production on the farm, as a result of enrolment, compensates for the land that was set aside for biodiversity. Under Intercropping, the production decreases as a direct consequence of scheme enrolment but there is an increase in farm spending, which allows farmers to improve (intensify) their yields and compensate for the yield penalties. What this means is that both land sharing and land sparing strategies lead to the same production levels in the landscape. This finding has critical consequences for the framing of the LS/LS debate. Contrary to the LS/LS argument (that wildlife friendly agriculture is lower yielding), land sharing is equally productive to land sparing interventions while improving conditions for biodiversity. First, there is potential to expand the habitat for wildlife without affecting local production. While the results align with previous findings from agricultural systems around the world e.g. Mexican coffee agroecosystems (Gordon et al., 2007) or see meta-analysis by Kremen and Miles (2012), there is still a suite of important questions that arise from this outcome. How much can farmers increase their production in an intercropped system until they no longer are able to compete with a land sparing strategy in terms of total production, thus rendering land sparing a better strategy? If farmers that enroll in land sharing interventions choose to compensate the loss in production through practices, that are harmful to biodiversity, every time there is a yield penalty, then up to what point it is acceptable to do so? At what point is the intended purpose of the policy voided? It is more likely the specific suites of agricultural practices utilized, rather than the yields they produce, which determine how hospitable the shared agricultural landscape would be for elements of biodiversity (Kremen, 2015). Without such an assessment it would be difficult to conclude the extent to which one intervention is more desirable than the other, locally.

9.6 Economic outcomes and discussion

9.6.1 Economic changes

9.6.1.1 Median income variation

Under the *"No Schemes"* scenario the median household income is about 74,000 INR (SD=3,742). Without a financial incentive to join the schemes there is no significant change in households median income between *"A Only + No FI"*, *"B Only + No FI", "C Only + No FI"* or *"All + No FI"* and the *"No Schemes"* scenario (Figure 9.10 Table 9.11). When a financial incentive is introduced median household incomes increase under Scheme *"A Only + FI",* and *"All + FI"* compared with the *"No Schemes"* scenario (Table 9.11).

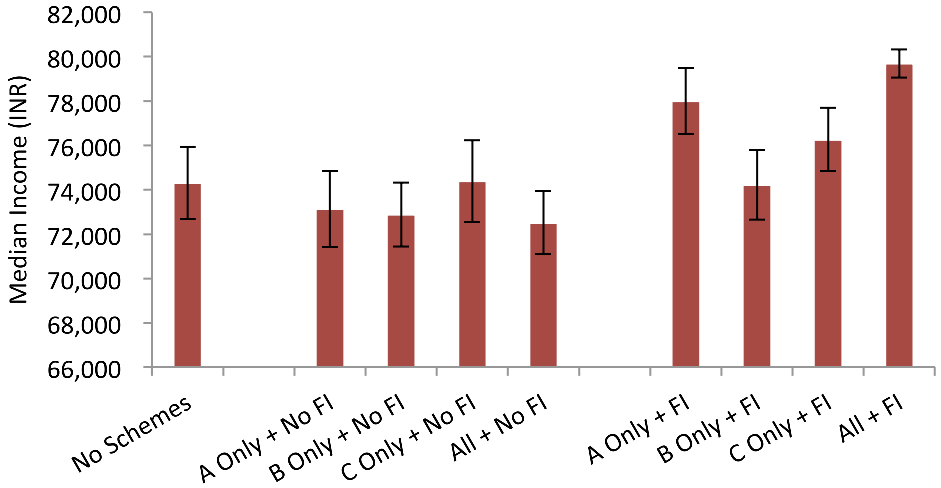


Figure 9.10 Median income at the end of 30 years of simulation, predicted by the model under nine scenarios. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

Table 9.11 One-way ANOVA results of the median income under the nine scenarios and Tukey's HSD post hoc results between pairs of scenarios. Statistically significant differences (p < 0.05) are shown in bold and marked with an asterisk

Median Income									
	ANOVA $F(8, 171)=13.51, p<0.001$								
Tukey's HSD test		No Scheme	Scheme A Only + No FI	Scheme B Only + No FI	Scheme C Only + No FI	All Schemes + No FI	Scheme A + FI	Scheme B + FI	Scheme C + FI
	Scheme A Only + No FI	1168.7	-						
	Scheme B Only + No FI	1421.3	252.62	-					
	Scheme C Only + No FI	87.17	1255.9	1508.5	-				
	All Schemes + No FI	1793.6	624.9	372.3	1880.8	-			
	Scheme A Only + FI	**3698***	**4867***	**5120***	**3611***	**5492***	-		
	Scheme B Only + FI	83.24	1085.5	1338.1	170.41	1710.4	**3782***	-	
	Scheme C Only + FI	1961	3129.7	**3382***	1873.8	**3755***	1737.4	2044.2	-
	All Schemes + FI	**5390***	**6559***	**6811***	**5303***	**7184***	1691.7	**5473***	**3429***

Sensitivity testing

The sensitivity tests show that changes in the size of the incentive for joining a scheme and the changes in production level associated with joining a scheme have small, statistically insignificant influences on the median household income. For example, under Scheme *"C Only+ FI"* doubling the level of incentive only increases the median household income by less than 1% (from 76,631 INR to 76,893 INR; $t(38)=0.699$, $p=0.448$). Under Scheme *"A Only+ FI"* doubling production upon scheme enrolment also increases median household income by less than 1% (from 78,083 INR to 78,500 INR; $t(38)=0.052$, $p=0.958$).

9.6.1.2 Gini coefficient

Trends observed when assessing the impact of the schemes on income inequality showed a similar pattern to those observed for median household income. While variation in Gini coefficient between the "*No Schemes*" scenarios and no incentive schemes were observed, the differences were not statistically significant (Figure 9.11, Table 9.12).

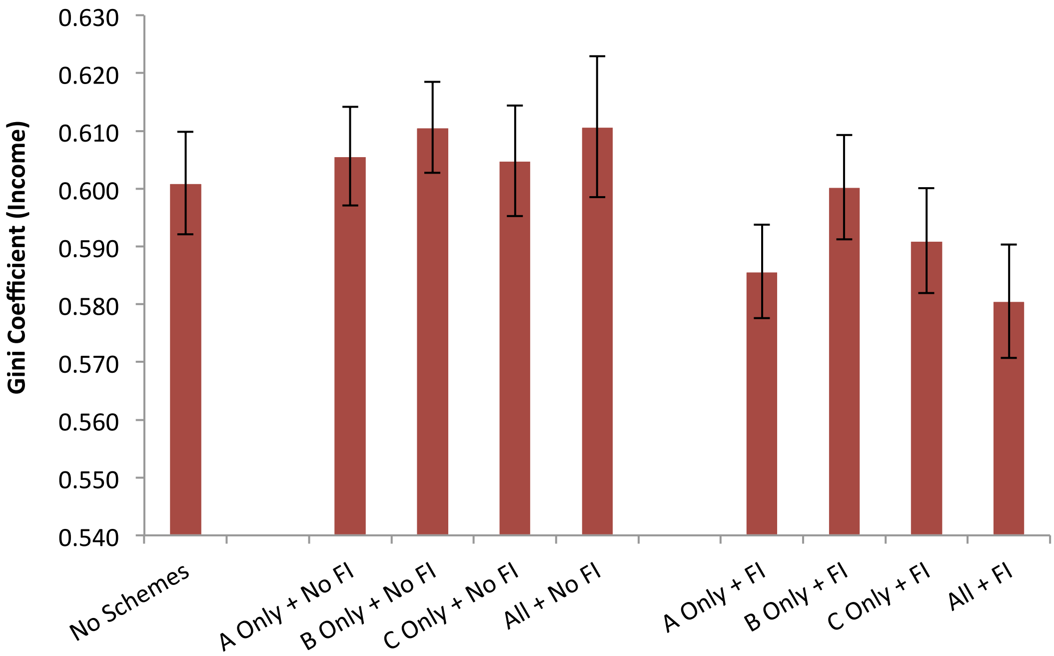


Figure 9.11 Predicted Income inequality, measured by the Gini coefficient under nine scenarios after 30 years of simulation. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

Table 9.12 One-way ANOVA results of Gini coefficient under nine scenarios and Tukey's HSD post hoc results between pairs of scenarios. Statistically significant differences (p < 0.05) are shown in bold and marked with an asterisk

Gini coefficient									
	ANOVA $F(8, 171)=11.14, p<0.001$								
Tukey's HSD test		No Scheme	Scheme A Only + No FI	Scheme B Only + No FI	Scheme C Only + No FI	All Schemes + No FI	Scheme A + FI	Scheme B + FI	Scheme C + FI
	Scheme A Only + No FI	0.0015	-						
	Scheme B Only + No FI	0.0060	0.0045	-					
	Scheme C Only + No FI	0.0025	0.0010	0.0034	-				
	All Schemes + No FI	0.0061	0.0045	0.0001	0.0035	-			
	Scheme A Only + FI	**0.0195***	**0.0211***	**0.0255***	**0.0221***	**0.0256***	-		
	Scheme B Only + FI	0.0017	0.0032	0.0077	0.0042	0.0078	**0.0179***	-	
	Scheme C Only + FI	0.0036	0.0021	0.0024	0.0011	0.0024	**0.0232***	0.0053	-
	All Schemes + FI	**0.0192***	**0.0208***	**0.0252***	**0.0218***	**0.0253***	0.0003	**0.0176***	**0.0229***

When financial incentives to scheme enrolment are introduced *"A Only + FI"* and *"All + FI"* scenarios show a significant reduction in income inequality over the "*No Schemes*" scenario (Table 9.12).

Sensitivity testing

Similarly to the previous metric, median income, the sensitivity tests show that changes in the size of the incentive for joining a scheme and the changes in production level associated with joining a scheme have small, statistically insignificant influences on the Gini coefficient. For example, a 1% increase in income inequality is observed when the size of the incentive is doubled under Scheme *"A Only + FI"* (from 0.586 to 0.593 $t(38)=0.429$, $p=0.680$). Under Scheme *"B Only+ FI"* doubling production upon scheme enrolment increases Gini coefficient by less than 0.5% (from 0.6 to 0.603 $t(38)=0.431$, $p=0.662$).

9.6.1.3 Households below the poverty line left in the system at the end of the simulation

The number of households below the poverty line is only decreased when there is an incentive for scheme enrolment in comparison with the *"No Schemes"* scenario. Statically significant reductions in the number of households below the poverty line compared to the *"No Schemes"* scenario were observed for Schemes *"A Only + FI"* (from 343, SD=14.44 to 320, SD=12.6),*"C Only + FI"* (from 343, SD=14.44 to 329, SD=11.85) and *"All + FI"* (from 343, SD=14.44 to 300, SD=12.97) (Table 9.13).

Table 9.13 One-way ANOVA results of remaining households below poverty line under nine scenarios and Tukey's HSD post hoc results between pairs of scenarios. Statistically significant differences ($p < 0.05$) are shown in bold and marked with an asterisk.

Remaining households below poverty line									
	ANOVA $F(8, 171)=34.45, p<0.001$								
		No Scheme	Scheme A Only + No FI	Scheme B Only + No FI	Scheme C Only + No FI	All Schemes + No FI	Scheme A + FI	Scheme B + FI	Scheme C + FI
Tukey's HSD test	No Schemes	-							
	Scheme A Only + No FI	4.1	-						
	Scheme B Only + No FI	1.95	2.15	-					
	Scheme C Only + No FI	0.05	4.05	1.9	-				
	All Schemes + No FI	4.95	0.85	3	4.9	-			
	Scheme A Only + FI	**23.2***	**27.3***	**25.15***	**23.25***	**28.15***	-		
	Scheme B Only + FI	2	6.1	3.95	2.05	6.95	**21.2***	-	
	Scheme C Only + FI	**13.9***	**18***	**15.85***	**13.95***	**18.85***	9.3	11.9	-
	All Schemes + FI	**42.9***	**47***	**44.85***	**42.95***	**47.85***	**19.7***	**40.9***	**29***

Sensitivity testing

The sensitivity tests show that changes in the size of the incentive for joining a scheme and the changes in production level associated with joining a scheme have statistically insignificant influences on the households below poverty line. For example, there is no change in the total number of households below poverty line under Scheme *"B Only+ FI"* when the size of production is doubled ($t(38)=0.699$, $p=0.99$). Under Scheme *"C Only+ FI"* increasing the incentive to double the amount produces no change either ($t(38)=0.431$, $p=0.99$).

9.6.2 Economic outcomes discussion

Communalities were observed between the three economic outputs measured in the simulation: median income, Gini coefficient and the number of households below the poverty line. Overall, the introduction of the schemes (with no financial incentive) in the landscape had a positive effect on the economy of the households. As the simulation results imply that biodiversity improvements can be made with no consequence on the economy of the household it would appear that both intensifying agriculture and intercropping are desirable options. The LUDAS model of Vietnam (Le et al., 2010) and Lee et al. (2014) model of palm oil in Indonesia are the only two models that have compared the economic outcomes of similar or actual LS/LS land use policies based on a real landscape. Similar to PLUSES, the

Lee et al. (2014) model shows best economic gains are achieved with a mixed LS/LS strategy. In the simulation by Le et al. (2010) intensifying cultivation resulted in damage to the environment through increased agrochemical use, offsetting long-term biodiversity and economic gains. The study suggests that the local economy and environment would likely benefit from alternative agricultural types, such as various forms of agroforestry and conservation farming. Given that PLUSES assumes increasing productivity on the farm comes at no cost for biodiversity the results must be carefully interpreted. Identifying how yield is increased on the farm and its impacts was beyond the scope of this study, but will be a crucial factor in determining desirable local interventions alongside the outcomes of this research.

When a financial incentive is introduced in the landscape the Wildflower Meadows and All Schemes scenario consistently improve the economic status of households across all three economic output metrics. The other two schemes, Forest Plantations and Intercropping show no change or affect only one economic indicator. Forest Plantations produce no change in the median income and total number of households below the poverty line because of low rates of enrolment. Moreover the proportion of households that enrol in schemes varies little across the range of income per person. With no income group disproportionately accessing financial incentives income inequality is not affected.

In contrast Intercropping produces unexpected outcomes. A positive change in household economic status was expected for all metrics because the incentive is larger than the return on investment obtained from tea plantations. However the results show improvements only for the total number of households below the poverty line. This is justified by incentives benefiting more small income households than rich ones. Why a reduction in households below the poverty line and a disproportionate benefit for low-income households does not produce a reduction in income inequality is not clear. Maybe a small number of better-of households are making more gains because of large areas of land enrolled in the scheme, thus keeping the same level of income inequality. The median income shows no difference probably because the effect of the incentive is offset by the 10% decrease in production resulting from enrolment.

The increase in median income and reduction in the number of households below the poverty line observed under the Wildflower Meadows scenario could be explained by the incentive providing a steady, reliable source of income on vegetable farms that are otherwise exposed to more financial insecurity resulting from return on investment fluctuations. In terms of inequality the emergent phenomena are surprising and are not entirely understood. The intervention was expected to increase inequality, not reduce it as the model shows, since a larger number of rich households are benefiting in comparison to small income ones. Integrating a human component makes models very complex and often difficult to disentangle and predict (Nguyen and de Kok, 2007).

Taken one at a time not all interventions experience a statistically significant change in economic status over a business-as-usual scenario but all produce a positive effect. The positive change under All Schemes is the cumulated effect of the schemes running together making it superior to that of Wildflower Meadows alone. A similar trend was again observed in the LUDAS model where the increase in the household income was the result of three combined land use interventions (Le et al., 2010). In LUDAS however the effect of the interventions was not strong enough to shift income inequality. The participatory approach of PLUSES in determining feasible interventions with direct land users may be why the interventions are better adapted to reach the more vulnerable households and decrease inequality, showing the strength of the approach.

9.7 Food security outcomes

9.7.1 Food security results

9.7.1.1 Food spending

Under the "*No Schemes*" scenario 34% of the households in the landscape are food insecure. When schemes are implemented in the model without a financial incentive there is no significant variation in the proportion of household budgets allocated to food in comparison with the "*No Schemes*" scenario [$F(8,171)=1.21$, $p=0.278$].

When financial incentives for scheme enrolment are offered the proportion of money from household budgets that is spent on food significantly increases under Schemes *"A Only +FI"*, *"C Only + FI"* and *"All + FI"* compared to the *"No Schemes"* scenario [$F(8,171)=13.5$, $p<0.001$]. 10% of food insecure households double their spending under Scheme *"A Only +FI"*, 6% double their spending under Scheme *"C Only +FI"* and 15% under *"All +FI"*.

Sensitivity testing

Sensitivity testing shows that the amount of money a household spends on food is not influenced by the size of the financial incentive or the changes in production level associated with joining a scheme. For example, doubling the financial incentive has no impact on the number of food insecure households under Scheme *"A Only +FI"* ($t(38)=0.143$, $p=0.99$). Under Scheme *"B Only +FI"* doubling the production after scheme enrolment also produces no change in the number of food insecure households ($t(38)=0.34$, $p=0.78$).

The amount of money a household spends on food is however influenced by the initial balance. When households start with an initial balance five times their declared income then improvements in food security can be observed under all three schemes but the increases over the *"No Schemes"* scenario are not statistically significant (e.g. *"C Only + FI"* $t(38)=0.21$, $p=0.99$). If households start with an initial debt five times worse than their income then more households are food insecure. Under "*A Only +FI"* the number of food insecure households increased from 31% to 37%, ($t(38)=3.2$, $p<0.01$). Under scenario "*B Only +FI"* an increase in food insecure households from 33% to 40% was observed ($t(38)=0.57$, $p<0.01$), "*C Only +FI"* produced an increase of 32% to 37% ($t(38)=1.56$, $p<0.01$) and "*All +FI"* an increase of 28% to 31% ($t(38)=0.46$, $p<0.01$).

9.7.1.2 Food retained for household consumption

The average food retained for household consumption from the farm does not change with statistical significance between the nine scenarios [$F(8,171)=1.529$, $p=0.15$] (Figure 9.12).

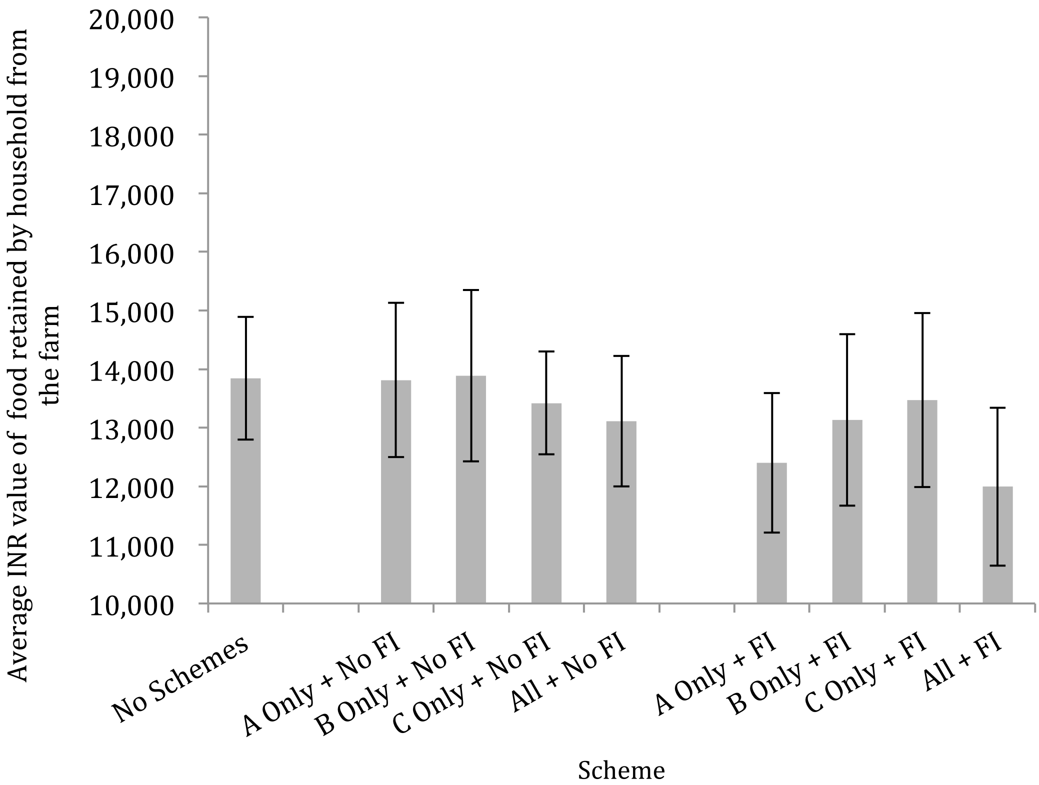


Figure 9.12 Average value of food retained for households' own consumption from their farm as predicted by the model under nine scenarios after 30 years of simulation. Vertical bars indicate the margin of error of the mean values at a 95% confidence interval.

Sensitivity testing

Sensitivity testing shows that the average value of food retained for consumption does not vary with the size of the financial incentive or the change in production resulting from enrolment. For example, when the financial incentive doubles the value of food retained for household consumption under *"A Only +FI"* scenario increased by 5%, a statistically insignificant difference ($t(38)=0.95, p=0.34$). A statistically insignificant 1% increase in value is seen when production on the farm is reduced by 20% under the *"C Only +FI" scenario* ($t(38)=1.67, p=0.102$).

Variation in the value of food retained for household consumption is seen when initial household balances are changed in the model settings. When the initial household balance is five times the declared income there is an increase in the value of food retained for household consumption under the *"B Only +FI"* and *"C Only + FI"* scenarios compared to the baseline scenario (initial household balance=0). Statistically significant increases of 21% were observed for scheme *"A Only +FI"* ($t(38)=3.13$, $p<0.001$) and 25% for scheme *"C Only + FI"* ($t(38)=3.25, p<0.001$).

When the initial debt is five times worse than their income the amount retained for household consumption does not change with statistical significance. For example under *"All +FI"* scenario the amount retained for household consumption decreases by 8% compared to baseline scenario [($t(38)=1.31, p=0.19$].

9.7.2 Food security discussion

The model shows that after 30 years of simulation food insecurity in the landscape will affect about one third of households. This is above the current national average of 15.2% (FAO et al., 2015), but close to the Tamil Nadu prevalence of undernourishment reported as 24.3% (Government of India, 2014). India is a rapidly growing economy and has shown considerable improvements in increasing food security (FAO, 2008, FAO et al., 2015). As a result of further food security policies and activities outside the consideration of the PLUSES model the food security in the Nilgiris may look better in 30 years time than the model predicts. Nevertheless, the prolonged tea crisis in the area, which is expected to continue, could reflect more accurately the future of food security in the Nilgiris landscape that was predicted under PLUSES (meaning higher rates of food insecurity).

The most surprising outcome that emerges from the ABM is that the food security metrics show the introduction of the three land use policies (without financial incentives) does not change the level of food security in the landscape. Whether land is taken out of production and set aside for biodiversity conservation or trees are intercropped on the farms, the food security of the households is not affected. The average value of food retained from farms for household consumption and food spending does not change under Wildflower Meadows and Forest Plantations because there is an increase in production from enrolling in the interventions that compensates for the land that has been spared for nature. Thus, farmers are able to identify new mechanisms to enable meeting the households' food security needs and the conservation of biodiversity. In the case of Tree Intercropping the sale of timber is probably compensating for decreases in production on the farm and as a result no change is observed in spending on food. With the introduction of a financial incentive food security improves across the landscape. Financial incentives for the enrolment in Tree Intercropping and Wildflower Meadows schemes provide a constant and secure source of revenue that acts like a financial safety net enabling an increase in food spending, especially among the most vulnerable households. Households with low agricultural and tea profitability rates are therefore expected to be the main beneficiaries of improved food security. Low enrolment in Forest Plantations is probably the reason why no statistically significant change in food security is produced even when a financial incentive is available.

Sensitivity testing revealed some key processes that manifest in the landscape. Food security was not affected by increases in the financial incentive or production levels. This is likely because the most food insecure households have already benefited at the baseline levels. The level at which financial incentives are expected to produce changes in food security are not straightforward to determine as it varies both by scheme type (Figure 8.3) and land use type (Figure 8.4).

Changes in initial household budgets were seen to influence food security. A reduction in initial budgets reduces food spending, but farmers are able to maintain the same consumption from their own farms. In this case land acts as an important safety net. Surprisingly, an increase in the initial budget leads to agents maintaining their food spending and increasing consumption from their farms. This trend is probably due to a prioritisation of investment in farming which leads to an increase in production (see *Section 9.5.1.1*). It is also possible that households that are food insecure are so poor that they benefit from increased initial budgets for a number of years, but in the long term they cannot support an increase in spending on food and they return to their original budgets.

To conclude, PLUSES simulations indicate that increasing biodiversity on the farms through the introduction of both LS/LS land use policies does not compromise the food security of the households in the landscape. Of the three schemes, Wildflower Meadows and Tree Intercropping have the potential to reduce food insecurity. Similar findings were reported in Cramer et al., (2017), Fischer et al. (2017) and Wittman et al. (2017) where land use interventions that resemble forms of LS/LS where found to harmonize food security and biodiversity conservation. This study provides empirical evidence that shows the importance of bringing social system characteristics back into existing discourses on food security and biodiversity conservation in order to understand how synergies can occur and how policies can capitalize on them. The results support Hanspach et al. (2017)'s critique and call that too often reaserch is focused on trade-offs (e.g. Glamann *et al*. 2017) and though strategies that can benefit both biodiversity and food security exist (e.g. Chappell and LaValle, 2011) they are often neglected, when instead, they need to be brought to the forefront.

PLUSES also shows that farmers found ways to adapt when land was taken out of production or yield penalties were imposed by the schemes. Agents used the new circumstances to their advantage. Under Forest Plantations and Wildflower Meadows these adaptive stratgies may be an artefact of the model, direct compensations for taking land out of production. But, under Tree Intercropping, income diversification through selling of intercropped timber has emerged as a succesful form of risk avoidance and did not compromise biodiversity gains. This form of diversification through tree intercropping is of special relevance not only to the Nilgiris context, but also to many other South and Southeast Asia countries that are faced with similar current agricultural crises (Kumar, 2007). Apart from being an important source of income, trees can represent a valuable source of nutrition, particularly during lean seasons and periods of vulnerability (Balooni, 2003, Puri and Nair, 2004, Dagar et al., 2013, FAO, 2013, Vira et al., 2015, Prabhat et al., 2017). Their direct contribution to food security has been undevalued in this research. Disaggregating the native and exotic categories into specific species of trees would allow a more justified assessment of how they specifically contribute to individual farms' food security. Considering this limitation, Tree Intercropping is expected to bring more benefits in reality then the model was able to capture and as a result become a more desirable intervention to Wildflower Meadows.

9.8 Conclusions

This chapter has analysed the production, environmental and socioeconomic outcomes of pursuing three LS/LS interventions in the Nilgiris landscape using PLUSES, a spatially explicit simulation model. The model shows that all the tested schemes bring biodiversity conservation benefits but that they do so in different ways. Tree Intercropping generates the largest number of trees in the landscape on private farms. Wildflower Meadows spares the most land for conservation, while Forest Plantations creates clusters of forest fragments and scores best in landscape connectivity measures. In terms of production, the results show that under each of the three interventions the same amount of food could be produced even if land was set aside for conservation, or trees were intercropped on farms. The increase in production from joining the interventions or the adaptive strategies farmers used by farmers allowed for this to happen. Finally, the analysis of the socioeconomic impacts of scheme adoption indicates that both LS/LS interventions have a positive effect on the economy and food security of the household. The simulation results reveal that land sparing wildflower meadows brings the best outcomes as an individual intervention. Part V (Chapter 10) will reflect in more depth on the comparative merits and benefits of the three interventions and the policy lessons that can be learned from these outcomes.

PART V

Chapter 10

Conclusions

Understanding the relevance of the land sharing-land sparing framework to real life

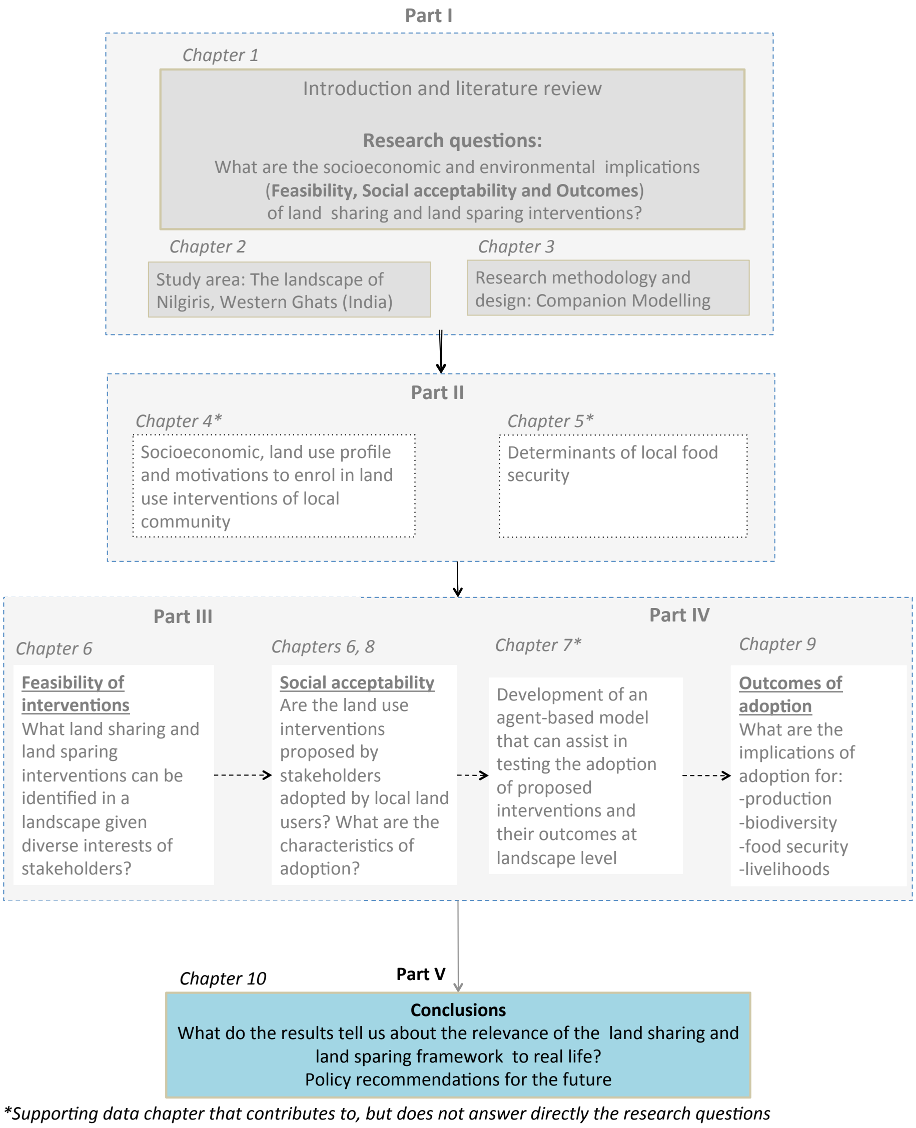


Diagram 1 Summary of research highlighting the questions addressed in Part V

Tropical forests have the highest rates of biodiversity in the world (Groombridge and Jenkins, 2002). Deforestation and forest degradation due to the expansion and intensification of farming are the main threats to their preservation (Hosonuma et al., 2012). Different conservation approaches have been proposed to reduce the impact of agricultural expansion and intensification on biodiversity. The LS/LS framework has emerged as one such approach (Green et al. 2005) and has received increasing attention. While numerous studies (e.g. Anderson-Teixeira et al., 2012, Hulme et al., 2013, Williams et al., 2017) have investigated the relative merits of the two land use strategies through a production lens, it has been argued that the relevance of the framework to real life depends on a much broader set of factors. A key criticism has been that the framework fails to consider the social acceptability of the framework to stakeholders and direct land users or the socioeconomic implications of their advancement in a real-world landscape (Fischer et al., 2014). By proposing ready-made expert solutions without understanding the social ramifications of the two approaches proponents of the framework risk a partial picture that is not grounded in local realities. Such oversights can have profound implications for the conservation of biodiversity on the long run (Phelps et al., 2013, Kremen, 2015, Bennett, 2017).

To address these caveats, this thesis seeks to move beyond the 'productionist' approach by integrating social and economic dimension into the LS/LS framework. The thesis investigates three main aspects:

1. What land use interventions are plausible in a landscape given diverse interests of stakeholders?
2. What is the social acceptability (uptake) of the interventions to direct land users?
3. What are the implications of land users' choices, not only on production and biodiversity but also on local food security and livelihoods?

Finally, the thesis considers the implications of the results of these investigations for the applicability of the LS/LS framework in real life situations.

Answering these questions means crossing disciplinary boundaries in order to analyse the system under study as a complex structure that is governed both by social and ecological processes. Companion Modelling has emerged as an approach specifically designed to address these challenges and it uses a combination of RPGs and ABMs with local stakeholders to enable a shared representation and validation of the social and environmental processes that occur in a system (Chapter 3). In order to understand how land use decisions are shaped in landscapes that can accommodate both LS/LS strategies, the Nilgiris, India was selected as a suitable fieldwork site for its long agricultural history of both intensification and expansion into one of the world's most biodiverse forests. The thesis explains the historical and economic drivers that shape the current landscape and livelihood decisions (Chapter 2) along with a present socioeconomic, land use and food security profile of the study area (Chapter 4 and 5). It then moves on to explore the type of policies stakeholders believe feasible for the reconciliation of agriculture and forest conservation and reveals that both LS/LS interventions are desirable in the landscape (Chapter 6). For them to be adopted by local land users reward schemes were proposed and in order to test their social acceptability (uptake) a RPG and an ABM were developed (Chapter 6 and 7). The ABM allows analysing *ex ante* the results of their hypothetical adoption (Chapter 8) and the implications of their adoption for local livelihoods, food security and environment (Chapter 9) over a 30-year period simulation.

The next section revisits how the key research questions have been tackled, what has been found, and what the findings signify for these questions (*Section 10.1*). Then, the final research question is addressed, the relevance of the LS/LS policy to real life and the practical policy implications (*Section 10.2*). This is followed by a recapitulation of the main contributions of the thesis (*Section 10.3*). The chapter ends with an exposition of limitations and caveats of this research, and policy-relevant future research directions (*Section 10.4*).

10.1 Key findings of the thesis

10.1.1 Feasible LS/LS interventions in the tropics that meet diverse interests of stakeholders

One of the focuses of the study is to understand if LS/LS interventions, that meet the objectives of diverse local stakeholders present in a landscape, could be identified. To date the debate over the relative merits of LS/LS has been ideological in nature, and lacks empirical evidence to demonstrate that scientific recommendations could translate into local policy. Phalan et al. (2016) provides examples of how active land sparing mechanisms can occur in a landscape, but there is negligible proof that these have arisen as a direct result of the scientific evidence. Rather it is more likely that these sparing mechanisms are the result of local development goals and stakeholders' interests (Mertz and Mertens, 2017).

This study explores for the first time whether LS/LS policy recommendations resulting from scientific evidence can translate into policy in a real landscape by meeting the interest of the local stakeholders. Stakeholders were engaged in a participatory process that integrated empirical, technical and scientific knowledge and helped identify suitable land use strategies that align with stakeholders' objectives. A RPG looking at how farmers take land use decisions when environmental policies are introduced in the landscape is used as decision support tool. The process of developing a RPG with the local stakeholders allows them to increase their knowledge and understanding of a system and its dynamics under various conditions. Most importantly it acts as a platform to make stakeholders more aware of each other's goals and to allow negotiations to take place in a less formal format.

The study demonstrates that LS/LS interventions that meet all stakeholders' objectives could be found locally. Three interventions are proposed in the landscape. Two of them resemble a form of land sparing on the farms: sparing land for wildflower meadows or tree plantations while increasing yield on the remaining land. The third one asks farmers to accept yield penalties for intercropping more trees on their farms, a form of land sharing.

The interventions carry three important traits that demonstrate the importance of engaging stakeholders from an early stage of policy development. Firstly, only certain policies meet the interest of relevant stakeholders and from a yield-biodiversity assessment they might not be the optimal solutions. Secondly, the land sparing interventions proposed are different from the classic mechanisms identified by Phalan et al. (2016). Farmers are encouraged to spare land on their farms for nature and to connect the spared areas of land. Whether they are more closely related to land sharing or land sparing is a matter of the landscape scale, the size of the land set aside for biodiversity conservation and the connectivity of the spared land over time. Thirdly, stakeholders proposed different phases in the life cycle of the policies. The pilot stage aims to create forms of interventions that are universal and inclusive and attract as many enrollers as possible. The key is to demonstrate their benefits and success. This will popularize the policy in the landscape, so that in the maturity phase they can attract more land users by better tailoring the interventions to the land users' needs. In this later stage the yield and biodiversity conservation benefits are expected to increase. This study focuses only on the pilot stage.

All these three aspects demonstrate the value and importance of engaging stakeholders in planning of interventions and expanding the LS/LS framework beyond the yield-biodiversity relationship. By doing so, low effectiveness and the emergence of unwanted side effects of environmental and agricultural policies caused by over-simplistic assumptions in the design of policy instruments could be reduced, if not prevented.

10.1.2 Heterogeneous motivations affecting the social acceptability of land use interventions and *ex ante* assessment of their adoption in the landscape

This study also focuses on aspects of decision-making regarding the adoption of proposed LS/LS interventions by direct land users. The study reveals several findings in this regard. Firstly, in the study area there are three main types of motivations that influence farmers' decisions about whether to adopt an intervention on their farm or not, in order of importance: monetary benefits, pro environmental motivations and social norms. Secondly, land use, the type of management preferred on the farm and whether land users accept trees on the farm or not are factors that influence what type of intervention is feasible on individual farms. These factors were detected in the in-depth household survey and also validated by the role-playing game.

When assessing the adoption of the three interventions *ex ante,* it is observed that monetary incentives are the main contributor to farm enrolment. There are some important differences observed between the interventions. Wildflower Meadows is the intervention adopted by the largest number of households, whereas intercropping is adopted on the largest area of land. Forest Plantations are significantly less popular than the other two interventions and only attract a small number of households. The financial level at which the incentive attracts the optimal enrolment also varies between the three interventions. Those that spare land for wildflower meadows are motivated at higher levels of incentives then those that prefer intercropping or spare land for forest plantations. Another difference observed between interventions is that social norms and pro-environmental motivations have different influences on enrolment rate of the three interventions. Social norms play a particularly important role in the enrolment of Wildflower Meadows, whereas pro-environmental interventions are more prevalent among those that prefer Intercropping. Finally, land use influences significantly the choice of schemes. Consistently more tea farms go for Intercropping whereas Wildflower Meadows attracts more vegetable farms. For Forest Plantations, land use is not a strong determinant.

All these traits that characterize enrolment under different interventions have important implications for proposing LS/LS approaches in a landscape. Identifying the main motivations of enrolment could encourage adoption under the different interventions by tailoring the incentives to better meet land users' motivations. This is of particular importance for the pilot phase of a project that needs to demonstrate a wide spread enrolment. An *ex ante* assessment also gives policymakers the chance to observe how financial incentives can be optimized.

Another important implication for policy formulation is that, even if stakeholders are able to identify what they consider feasible interventions, adoption by direct land users is not guaranteed. This is supported by the limited enrolment in Forest Plantations. Prior assessment of policies can give stakeholders time to reflect on how a policy could be improved and what the likelihood is of the intervention being accepted or failing to attract interest. Moreover, it allows for policymakers to observe what hindrances can occur (e.g. tree tenure anxieties) and how they could be mediated over time.

Finally, the research shows that a combination of these strategies can increase participation and adoption in a community with heterogeneous motivations and farming preferences. This is perhaps the most important implication for policy design.

10.1.3 The comparative merits and benefits of adopting LS/LS interventions by direct land users

The third question, about the outcomes of adoption, has important policy implications. The underlying question is whether adding socioeconomic dimensions to the LS/LS framework changes the outcome of what constitutes the optimal land use policy between LS/LS. It has been hypothesised that incorporating other landscape goods such as ecosystem services or food security, into the analysis could shift the nature and outcome of the debate (Adams, 2012).

Table 10.1 A summary of the impact of the three interventions on the study's key metrics when they are tested separately and all together. Results come from PLUSES simulator when the interventions are tested with a financial incentive for enrolment.

Category	Metrics	Wildflower meadows	Tree plantations	Intercropping	All interventions
Social acceptability	Total number of Households enrolled				
	Total land enrolled				
Biodiversity	Number of native trees				
	Number of exotic trees				
	Number of trees > 15 years old				
	Number of trees < 15 years old				
	Number of components			NA	
	Average size of component			NA	
Production	Farm budget				
	Yield farm level				
	Yield landscape				
Economic outcomes	Median income				
	Gini coefficient				
	Number of households below the poverty line				
Food security	Food retained for consumption				
	Food spending				
Incentive	Total cost, including incentives over 30 years (mil. $)	3.05	0.88	3.2	7.13

Legend (The colours signify the direction and magnitude of change a intervention produced by comparison to the baseline scenario, "No Schemes". The change is shown only if there is a statistically significant difference

Deterioration	No change	Subtle improvement--Major improvement			

The findings of this research demonstrate that indeed adding more outcomes on which to assess the comparative merits of the interventions does indeed change the balance in the debate. It adds a level of complexity and creates a less straightforward choice between the two strategies (Table 10.1).

The first key finding is that none of the three interventions can provide optimal outcomes for all the indicators analysed. Secondly, each intervention has indicators on which it scores better when compared to the other two interventions (Table 10.1). Wildflower Meadows has the highest rate of enrolment whilst delivering greater improvements in biodiversity, enhancements to livelihood metrics and greater food security than any other intervention. Nevertheless, after 30 years of simulation, the land that has been spared for conservation under this scheme is very disjoined and scattered in the landscape, reducing its conservation value. By contrast, the Forest Plantations intervention is better at creating larger and more connected areas of secondary habitat. It is however adopted by the least number of enrollers and produces no improvements (or deteriorations) in food security and livelihoods. Intercropping attracts the largest area of land enrolled in an intervention, plants the largest number of native trees in the landscape and produces some improvements in food security and livelihoods. Production decreases at farm level, but surprisingly not at landscape level, which contradicts the assumption that land sharing is lower yielding in comparison to land sparing (Green et al., 2005).

The central question becomes, which of the interventions is more desirable between the three? The answer depends most likely on what the local values and political objectives (rather than scientific) are and what compromises a policymaker is willing to make? Furthermore, using a different set of outcome metrics, for example pollination services, well-being or farm profitability, could make these choice even more complex and ultimately tip the results in favour of a different intervention. This raises questions such as: What objectives most matter, and why? How would a representative list of metrics, that ensures a good spread of relevant factors, based on which policymakers can take decisions, look? And if identified, could the complexity added to the ABM produce results on which to base decisions? These are important questions that need addressing in future research. The effectiveness, limitations, and potential for unintended consequences have yet to be systematically tested.

Under all these uncertainties, there is however one less divisive outcome. By combining the three interventions the model generated the best synergies between production, environmental

and socioeconomic outcomes. Thus, the key to providing landscape level benefits across ecological and societal metrics could lie in continuing to preserve the current protected areas and expand the wildlife habitat while at the same time enhance the effectiveness of biodiversity-friendly farming practices. Agroforestry (Intercropping), forest fragments (Forest Plantations) and protected areas in human-modified landscapes have all been shown to bring important biodiversity benefits and they often complement each other by filling different biodiversity needs (Anand et al., 2010, Sayer et al., 2013, Lasco et al., 2014, Zomer et al., 2014, Schroth and Ruf, 2014, Mitchell et al., 2014, Karanth et al., 2016, Rahman et al., 2017). Classified as a threatened habitat, the Nilgiris grassland (Wildflower Meadows) harbour species of conservation concern and can't be substituted by other habitats (Kumar, 1993, Shanavas et al., 2016). Such matrices are favourable to biodiversity and are shown to support human livelihoods and food security without leading to yield penalties in the Nilgiris. Lee et al. (2014) reached a similar conclusion and showed that a hybrid LS/LS approach can generate the best economic outcomes for local communities engaged in plantation agriculture at forest fringes. In the Nilgiris the area was shown to have high potential to increase yields beyond the 10% target set in the agent-based model, however the problem that still remains is what happens under prolonged periods of agriculture unprofitability?
Finally, the limited budgets of the implementing agencies will be an important determinant in influencing the choice of the land use strategies selected. Future research would benefit from a more in-depth analysis of the cost-effectiveness of different combinations of strategies.

The next section looks at how the LS/LS framework is equipped for a real world landscape and proposes ways to move forward in the debate.

10.2 Implications for framework design and implementation - the policy perspective

This section aims to bring together the different lessons learned about the LS/LS framework when it moves beyond the yield-biodiversity relationship and considers socioeconomic factors. Three main points that can aid research and policy to move forward are addressed. First, I explore the dangers of moving from science to policy too quickly and discuss how the framework should either remain in the academic domain or be upgraded to enable more true-to-life policy recommendations (*Section 10.2.1*). Second, I discuss why engaging stakeholders matters in the formulation of feasible interventions (*Section 10.2.2*). Lastly, I consider why testing adoption of policies with direct land users prior to their implementation can provide valuable insight for the final formulation of the policies (*Section 10.2.3*). The section ends with possible ways of identifying motivations for adoption and how policies can be adapted to respond to the heterogeneity of motivations.

10.2.1 From science to policy. A missing link.

The findings presented in this thesis suggest that land use policies that go beyond the assessment of production efficiency and biodiversity conservation by incorporating other factors such as livelihood and food security add a more nuanced view in understanding the merits and limitations of the LS/LS approaches. With this additional information the LS/LS framework can move in two main directions. The first direction would be to continue to focus on optimizing food production and biodiversity conservation while acknowledging the trade-offs, potential risks and implications for food security, livelihoods and other aspects such as ecosystem services or well-being. In following such a path, generating policy recommendations risks overly simplifying complex contexts and can expose biodiversity to even greater dangers (Kremen, 2015). Poorly defined policies based on recommendations from partial understanding risk being distorted to serve entrenched interests, such as big food production companies (Phelps et al., 2013).

The alternative would be to change the focus of the LS/LS debate towards a more human-environment centred framework. This would involve acknowledging that the framework deals with a complex system of multiple interactions, which bridges natural and social sciences. It opens an avenue to deal with interrelationships between, for example, agricultural practices, intensification, expansion, yields, biodiversity, land-use patterns, deforestation, reforestation, environmental policies, and local and global food security. Most importantly it will allow engaging with different stakeholders to select which of these matter most to them, as different actors have different objectives. If the framework were repositioned thus it can be argued that it would transition into a socio-ecological system. In this case the focus can be placed on finding synergies that can meet several objectives and as such it better aligns with the Sustainable Development Goals and responds to the recent calls of doing so (Bennett, 2017, Fischer et al., 2017, Law et al 2017).

10.2.2 Stakeholders' engagement, a valuable resource

The results show that understanding the objectives of stakeholders engaged in land use decision-making plays a central role in formulating feasible land use strategies like LS/LS. Almost all strategies proposed in the landscape resemble the interventions highlighted by Phalan et al. (2016). However, out of them only one type of policy could reconcile the interests of all stakeholders, economic incentives. Moreover they vary considerably from the optimal solutions proposed by the advocates of the framework. Policy tends to favour scientific results that are in line with overall political goals as a century of policy of shifting cultivation in Southeast Asia has shown (Fox et al., 2009, Padoch and Pinedo-Vasquez, 2010, Mertz and Bruun, 2017). While this might be one of the important reasons that influenced the choice of interventions it was also shown that the apparently optimal yield-biodiversity solutions were simply not well adapted to respond to the local needs.

For example, from a land sparing perspective the optimal solution in the Nilgiris landscape would be to maximize production on existing farms while preventing further expansion into existing protected areas. However, discussions with local stakeholders revealed that such an approach would be futile. Low market prices, a decrease in soil fertility on farms and a wide spread reliance on a single unprofitable crop are among factors that lead to land abandonment and make intensification unattractive to local farmers. Furthermore, the Forest Department considers that there is no imminent threat to protected areas from small-scale agriculture directly. On the contrary, an expansion of regrowth forest has been observed. The real threat to biodiversity comes from farmers having limited livelihood alternatives with unforeseen impacts on the environment. The conclusion is that engaging stakeholders from an early stage can aid the formulation of policies that are better adapted to the local social-cultural, environmental and economic context that transcends a simple production efficiencies evaluation and that stand a better chance of materializing.

To scale up the results and understand the dangers of taking a narrow line of investigation that omits the socioeconomic factors, parallels could be made to other regions of the globe. Similarly to the Nilgiris and India more broadly, countries like China, Vietnam, El Salvador, Costa Rica and Chile experience a major trend of forest regrowth with simultaneous increase in food production (Mather, 2007, Lambin and Meyfroidt, 2010, 2011, Hecht, 2014). But is this evidence for land sparing in response to agricultural intensification? As shown in this study a simple production efficiencies outlook would fail to pick up more nuanced processes. Forest growth can be the results of smallholder farmers abandoning their lands (Grau and

Aide, 2008). For biodiversity, land abandonment might result in conservation opportunities, but again it is important to ask whether forest regrowth is resulting in large regions of contiguous forest (land-sparing landscapes) or many forest fragments in high settlement densities (land-sharing landscapes), which is most likely the case as demonstrated in Latin America (Hecht, 2014).

This takes us back to the original point; failure to pick up these nuances would most probably lead to inadequate translation of science into policy practice. But, it is also important to highlight that while in the Nilgiris case stakeholder engagement has proved valuable practice, this is not always true. Stakeholders' engagement also carries risks of creating more conflicts and as such it is not always the most convenient and helpful approach (Young et al., 2013).

10.2.3 From feasible interventions to actual adoption

The last point made is that once suitable policies have been identified for the local context and stakeholders have reached consensus, LS/LS policies are not guaranteed to succeed. It was shown that out of the three direct interventions proposed, only two of them were actually accepted more widely by direct land users and farms that enrolled in the individual schemes had generally different characteristics. Thus, for the LS/LS framework to stand a better chance of succeeding and to be more cost-effective it needs to acknowledge the heterogeneity of motivations and farming preferences and characteristics that stimulate land users' enrolment. As the findings demonstrate, acknowledging the diversity of motivations can help identify those who are more likely to adopt according to intrinsic interests (that are likely to be 'kindled' by non-monetary rewards) and those who may need monetary incentives to participate. Also it can help identify those that reject or accept certain farming practices, such as having trees on the farm or not.

Identifying these motivations and how policies can be adapted to respond to them could be done in several ways. One way may be to pre-assess the specific contexts where the intervention is to be made. The RPG and the ABM proved valuable and effective approaches to understand heterogeneity and the likely uptake of the interventions. The RPG in particular was a valuable tool that offered insight in the land use strategies processes that span on the farm that were otherwise difficult to capture in a conventional survey. Knowing these strategies, a policy maker can envisage who is more likely to adopt a certain intervention and why. Identifying the barriers to adoption is equally important. Such was the case with the social networks, where it was observed that enrolment could significantly rise with an increase in social influence. To be effective in the long term a policy must assess and ensure that such factors do not become a barrier within a given context. In a similar study (Zabala, 2015) it was proposed that an inventory of factors can be used as a check-list for a case-by-case rapid assessment of the preconditions for adoption and to address potential barriers before doing so becomes impracticable. This can be done on expert assessment or key informant interviews for example.

Another method of adjusting LS/LS policies (or any type of land use policies) to diverse motivations is to propose a set of typologies, which do not need to be sophisticated. For example, policymakers can imagine typologies based on diffusion, such as innovators and followers, and adjust rewards to their specific motivations (Zabala et al., 2017). Alternatively, instead of assuming that all households follow a utility-driven behaviour, the policymaker can expect several other typologies each of whom is mostly determined by monetary gains, social norms or non-monetary intrinsic motivations.

Once policy makers have access to this information there are several instruments that can be developed to respond to the heterogeneity of needs. Among these instruments, payments are but one. For example, rewards can be given to innovators in the form of acknowledging their services to their wider community and promoting them as mentors. Another approach would be to design an adaptive and dynamic programme in several steps (Hayes, 2012). In the first stage the programme would focus on the proven benefits of the practice and importance for the environment. In this case it is expected that farmers with non-monetary intrinsic motivations would volunteer. In a second stage financial rewards could be introduced for all to accelerate participation. If the programme budget is limited to a single instrument, the one expected to be most effective may be selected. Alternatively all these instruments may be used simultaneously or separately, depending on what the programme developer knows about the context where the intervention is to be made.

10.3 Research contributions of the thesis and limitations

The thesis contributes to fill an important gap in understanding the viability of interventions that aim to integrate or separate food production and biodiversity conservation by focusing on three aspects: stakeholders, direct beneficiaries and the socioeconomic and environmental implications of proposed interventions. The environmental implications of the two land use strategies have been well researched and continue to attract considerable research interest; the remaining aspects have received little attention. The literature critiquing the framework strongly emphasized expanding the scope of research to address this deficiency but there is a

lack of evidence to demonstrate the importance of the under investigated subjects to the debate. The first contribution of the research is therefore to expand the framework under which sharing and sparing interventions were compared, by adding a triad of social dimensions.
Agroforestry, forest plantations and wildflower meadows are presented as promising approaches to conciliate food production and biodiversity conservation but the understanding of their adoption in tea plantations and vegetable fields is limited. This research empirically and quantitatively analyses the outcomes of hypothetical interventions to encourage the three interventions among smallholders. Thus, this thesis contributes to the findings of the limited pool of studies doing this type of research and provides a more thorough understanding by considering adoption as a process driven not only by financial motivations but also by intrinsic motivations.

Overall, the thesis has three main contributions to knowledge, of empirical, theoretical and methodological natures. These are highlighted in order of findings.

First, involving the local stakeholders in identifying symbiotic food production and biodiversity conservation land use policies yields new empirical insight into what constitutes suitable LS/LS policies in a real-world landscape. This is the first study in which stakeholders were directly involved and contributed to formulation of LS/LS policies in a bottom-up approach. Interventions that reconcile stakeholders' goals are less vulnerable to failure and carry less risks of being rejected or deterred post implementation. Though data-collection intensive, future LS/LS studies can critically benefit from implementing this participatory approach.

Second, the analysis on farmers' motivations and farming practices preferences reveals how the two influence the choice between the LS/LS strategies. This empirical evidence is the first to integrate farmers' motivations and preferences in explaining adoption of LS/LS policies. Results suggest the need to better tailor the interventions on farmers' motivations but also to preview some of the hindrances that can occur (e.g. tree tenure controversies). This contribution is complemented with a time-efficient and in-depth approach to collect data, based on a combination of household survey and RPG. The study acknowledges though that measuring motivations and farmers preferences was done in a crude and simplistic way mostly for the mere purpose of demonstrating the importance of considering this aspect in the LS/LS debate. Other *state of the art* studies (e.g. Zabala et al., 2017) that looked at these aspects have paired, for example, game-like procedures with Q methodology.

Third, the ABM developed is one of the few land use simulators able to test policy adoption prior to its actual implementation based on social, economic and environmental decision-making factors. It is the only simulator to date to include aspects of food security and landscape connectivity in a LS/LS research context. The breadth of factors included allows a more realistic representation of the complexity of human decision-making, based on which policy decisions are made, increasing the reliability of results. Furthermore, being able to compare and contrast between the outcomes of different policies considering such a wide range of factors enables decision makers to understand the potential synergies, trade-offs, opportunities and unanticipated risks at a finer scale and, as a result, plan better and more cost-effective. This new scientific simulator has already attracted interest among practitioners and researchers and it will be made available as an open source. The use of the ODD protocol to describe the model makes it transparent and easy to replicate in other contexts where land use policies are to be assessed. This approach could be used to compare strategies across sites and countries, throughout historical trajectories or to forecast policy scenarios. I recommend that the ABM should be taken as a learning tool that facilitates discussions and draws attention on possible opportunities or unintended consequences that might arise under different policy scenarios. The ABM was constructed on a series of assumptions that limits the capacity of the simulator to make definite policy recommendations (see limitations in Chapters 7, 8 and 9). To improve the simulation more research is needed to address the individual assumptions.

10.4 Future direction

Building on the outcomes of this research, further lines of enquiry are identified. The first one refers to specific niches that can shed instrumental knowledge about how participation in policies can be enhanced and further analysed. The last two are directly tied to alternative or improved methodologies.

If the aim is to encourage long-term enrolment, analysing what drives previous adopters to drop out of interventions can give key insights about adoption barriers (Mekoya et al., 2008, Greiner and Gregg, 2011). In doing so valuable information for improving the policies can be obtained. Land users can have a restrained degree of motivation, knowledge and of moral drive but when putting thoughts into actions, the hindrances are decisive. Supplementary incentives are crucial to overcome these situations. Thus, finding what considerations led to pulling out from an intervention is logically necessary in order to be able to identify how to encourage long-term adoption. In turn, knowing what these obstacles are may be critical to envision whether the incentives considered will achieve optimal outcomes.

Second, the study has not focused on how yield improvements can be achieved in the landscape once the interventions are adopted on the farm. The change in the yield is conditioned by enrolment. Land sparing interventions aid higher yields on the farms whereas land sharing leads to lower yields. I consider that focusing only on the yield continuum, without further consideration of how the changes in yield are achieved and how they impact on biodiversity, perpetuates one of the main problems related to the LS/LS framework. Namely that nature friendly farming or land sharing will continue to be associated with low yields without necessarily being true to how 'wildlife friendly' the practice is. It is more likely to be specific agricultural practices, rather than the yields they produce, that determine how hospitable the shared agricultural landscape would be for elements of biodiversity (Kremen, 2015). In this case intercropping could affect yields but it could also out-produce conventional systems or be equally productive or profitable, while improving conditions for biodiversity and other ecosystem services (Meylan et al., 2017, Nesper et al., 2017). Therefore, future research should focus on understanding which practices could lead to positive yield changes with the least negative impact on the biodiversity on the farm. Do certain practices enhance yields, profits and biodiversity? Do other practices enhance biodiversity without affecting yields or profits? (Donald and Evans, 2006, Prescott et al., 2015). This would elucidate the important relationships while providing scope for management interventions under the different interventions proposed (Steffan-Dewenter et al., 2007, Clough et al., 2011).

Finally, as emphasized in Chapter 7 (*Section 7.7.1*) future research could be directed to enhancing PLUSES so that it becomes a richer socio-ecological simulator, which is a more sophisticated field of modelling. This would enable improved predictions and would answer the recent calls of researchers engaged in the LS/LS debate that advocate for a socio-ecological approach in dealing with the relationship between food production and biodiversity (Fischer et al., 2017). This would require focus to be placed on further developing the interactions between social, economical and environmental components. For example, the model would benefit from a better understanding of how farmers' choices of inputs affect yields and soil fertility and how in turn these changes affect farmers' food security and livelihood decisions over time. Nevertheless, the model is the first attempt and a valuable 'reality check' that captured the complexities of reaching policy decisions when food security and livelihoods consideration are integrated in the LS/LS framework. More importantly it paved the way for future research by demonstrating the inclusion of social science expertise could considerably enhance both the usefulness of formal models and the effectiveness of policies. For policy recommendations to be meaningful to local contexts they should be jointly framed by scientists and stakeholders in a participatory and interdisciplinary process, that is, constructing new forms of knowledge that move beyond disciplinary boundaries and include collaborations between scientific and nonscientific actors in substantive work.

References

Abdullah, Zhou, D., Shah, T., Ali, S., Ahmad, W., Din, I.U., Ilyas, A., 2017. Factors affecting household food security in rural northern hinterland of Pakistan. J. Saudi Soc. Agric. Sci. https://doi.org/10.1016/j.jssas.2017.05.003

ACCORD, 2017. Development programmes. Action for Community Organization, Rehabilitation and Development [WWW Document]. URL http://www.adivasi.net/history.php

Adams, W.M., 2012. Feeding the next billion: hunger and conservation. Oryx 46, 157–158. https://doi.org/10.1017/S0030605312000397

Ahmed, S., Stepp, J.R., Orians, C., Griffin, T., Matyas, C., Robbat, A., Cash, S., Xue, D., Long, C., Unachukwu, U., Buckley, S., Small, D., Kennelly, E., 2014. Effects of Extreme Climate Events on Tea (Camellia sinensis) Functional Quality Validate Indigenous Farmer Knowledge and Sensory Preferences in Tropical China. PLoS ONE 9. https://doi.org/10.1371/journal.pone.0109126

Ahnström, J., Höckert, J., Bergeå, H.L., Francis, C.A., Skelton, P., Hallgren, L., 2009. Farmers and nature conservation: What is known about attitudes, context factors and actions affecting conservation? Renew. Agric. Food Syst. 24, 38–47. https://doi.org/10.1017/S1742170508002391

Aiking, H., 2011. Future protein supply. Trends Food Sci. Technol., New challenges in food preservation. 22, 112–120. https://doi.org/10.1016/j.tifs.2010.04.005

Akpan, E.O., 2009. Oil resource management and food insecurity in Nigeria, in: European Report on Development (ERD) Conference in Accra, Ghana. Citeseer, pp. 21–23.

Alexandratos, N., 2009. World food and agriculture to 2030/50: highlights and views from mid-2009. In: How to feed the World in 2050. Proceedings of a technical meeting of experts, Rome, Italy, 24–26 June 2009, pp 1–32. Food and Agriculture Organization of the United Nations (FAO).

Alexandratos, N., 1999. World food and agriculture: Outlook for the medium and longer term. Proc. Natl. Acad. Sci. 96, 5908–5914. https://doi.org/10.1073/pnas.96.11.5908

Ali, A., Khan, M.A., 2013. Livestock ownership in ensuring rural household food security in Pakistan. J. Anim. Plant Sci. 23, 313–318.

Altieri, M.A., 2002. Agroecology: the science of natural resource management for poor farmers in marginal environments. Agric. Ecosyst. Environ. 93, 1–24. https://doi.org/10.1016/S0167-8809(02)00085-3

Altieri, M.A., 1999. The ecological role of biodiversity in agroecosystems. Agric. Ecosyst. Environ. 74, 19–31. https://doi.org/10.1016/S0167-8809(99)00028-6

Amaza, P.S., Umeh, J.C., Helsen, J., Adejobi, A.O., 2006. Determinants and Measurements of Food Insecurity in Nigeria: Some Empirical Policy Guide (No. 25357), 2006 Annual Meeting, August 12-18, 2006, Queensland, Australia. International Association of Agricultural Economists.

An, L., 2012. Modeling human decisions in coupled human and natural systems: Review of agent-based models. Ecol. Model., Modeling Human Decisions 229, 25–36. https://doi.org/10.1016/j.ecolmodel.2011.07.010

Anand, M.O., Krishnaswamy, J., Kumar, A., Bali, A., 2010. Sustaining biodiversity conservation in human-modified landscapes in the Western Ghats: Remnant forests matter. Biol. Conserv., Conserving complexity: Global change and community-scale interactions. Tropical forest biodiversity in a human-modified world: a multi-region assessment 143, 2363–2374. https://doi.org/10.1016/j.biocon.2010.01.013

Andersen, D.F., Vennix, J.A.M., Richardson, G.P., Rouwette, E.A.J.A., 2007. Group Model Building: Problem Structuring, Policy Simulation and Decision Support. J. Oper. Res. Soc. 58, 691–694.
Anderson-Teixeira, K.J., Duval, B.D., Long, S.P., DeLucia, E.H., 2012. Biofuels on the landscape: Is "land sharing" preferable to "land sparing"? Ecol. Appl. 22, 2035–2048. https://doi.org/10.1890/12-0711.1
Angelsen, A., Kaimowitz, D., 2001. Agricultural Technologies and Tropical Deforestation. CABI.
Angelsen, A., Larsen, H.O., Lund, J.F., Smith-Hall, C., Wunder, S., (eds.), 2011. Measuring livelihoods and environmental dependence: Methods for research and fieldwork. Earthscan Publications, Oxford, U.K.
Armbrecht, I., Rivera, L., Perfecto, I., 2005. Reduced Diversity and Complexity in the Leaf-Litter Ant Assemblage of Colombian Coffee Plantations. Conserv. Biol. 19, 897–907. https://doi.org/10.1111/j.1523-1739.2005.00062.x
Asghar, Z., Muhammad, A., 2013. Socio-economic Determinants of Household Food Insecurity in Pakistan [WWW Document]. https://mpra.ub.uni-muenchen.de/21510/1/MPRA_paper_21510.pdf
Ashraf, J., Pandey, R., Jong, W. de, Nagar, B., 2015. Factors Influencing Farmers' Decisions to Plant Trees on Their Farms in Uttar Pradesh, India. Small-Scale For. 14, 301–313. https://doi.org/10.1007/s11842-015-9289-7
Asseng, S., Dray, A., Perez, P., Su, X., 2010. Rainfall–human–spatial interactions in a salinity-prone agricultural region of the Western Australian wheat-belt. Ecol. Model. 221, 812–824. https://doi.org/10.1016/j.ecolmodel.2009.12.001
ATREE, CEPF, 2013. Five Year Assessment of the CEPF Investment in the Western Ghats region of the Western Ghats and Sri Lanka Biodiversity Hotspot. Ashoka Trust for Research in Ecology and the Environment, and Critical Ecosystem Partnership Fund.
Ausubel, J.H., Wernick, I.K., Waggoner, P.E., 2013. Peak Farmland and the Prospect for Land Sparing. Popul. Dev. Rev. 38, 221–242. https://doi.org/10.1111/j.1728-4457.2013.00561.x
Balbi, S., Giupponi, C., Perez, P., Alberti, M., 2013. A spatial agent-based model for assessing strategies of adaptation to climate and tourism demand changes in an alpine tourism destination. Environ. Model. Softw., Thematic Issue on Spatial Agent-Based Models for Socio-Ecological Systems 45, 29–51. https://doi.org/10.1016/j.envsoft.2012.10.004
Bali, A., Kumar, A., Krishnaswamy, J., 2007. The mammalian communities in coffee plantations around a protected area in the Western Ghats, India. Biol. Conserv. 139, 93–102. https://doi.org/10.1016/j.biocon.2007.06.017
Balke, T., Gilbert, N., 2014. How Do Agents Make Decisions? A Survey. J. Artif. Soc. Soc. Simul. 17, 13.
Balmford, A., Green, R., Phalan, B., 2015. Land for Food & Land for Nature? Daedalus 144, 57–75. https://doi.org/10.1162/DAED_a_00354
Balmford, A., Green, R., Phalan, B., 2012. What conservationists need to know about farming. Proc. R. Soc. B Biol. Sci. 279, 2714–2724. https://doi.org/10.1098/rspb.2012.0515
Balooni, K., 2003. Economics of wastelands afforestation in India, a review. New For. 26, 101–136. https://doi.org/10.1023/A:1024494010538
Bandhu, P., 2017. Adivasis of the Nilgiri Upper Plateau - South Asia Study Centre. South Asia Study Cent.
Barnaud, C., Le Page, C., Dumrongrojwatthana, P., Trébuil, G., 2013. Spatial representations are not neutral: Lessons from a participatory agent-based modelling process in a land-

use conflict. Environ. Model. Softw., Thematic Issue on Spatial Agent-Based Models for Socio-Ecological Systems 45, 150–159. https://doi.org/10.1016/j.envsoft.2011.11.016
Barreteau, O., Abrami, G., 2007. Variable time scales, agent-based models, and role-playing games: The PIEPLUE river basin management game. Simul. Gaming 38, 364–381. https://doi.org/10.1177/1046878107300668
Barreteau, O., Antona, M., d'Aquino, P., Aubert, S., Boissau, S., Bousquet, F., Dare, W., Etienne, M., Le Page, C., Mathevet, R., Trébuil, G., Weber, J., 2003. Our Companion Modelling Approach. J. Artif. Soc. Soc. Simul. 6.
Barretto, A.G.O.P., Berndes, G., Sparovek, G., Wirsenius, S., 2013. Agricultural intensification in Brazil and its effects on land-use patterns: an analysis of the 1975–2006 period. Glob. Change Biol. 19, 1804–1815. https://doi.org/10.1111/gcb.12174
Barthel, S., Crumley, C., Svedin, U., 2013. Bio-cultural refugia—Safeguarding diversity of practices for food security and biodiversity. Glob. Environ. Change 23, 1142–1152. https://doi.org/10.1016/j.gloenvcha.2013.05.001
Bashir, M.K., Schilizzi, S., 2013. Determinants of rural household food security: a comparative analysis of African and Asian studies. J. Sci. Food Agric. 93, 1251–1258. https://doi.org/10.1002/jsfa.6038
Baudron, F., Giller, K.E., 2014. Agriculture and nature: Trouble and strife? Biol. Conserv. 170, 232–245. https://doi.org/10.1016/j.biocon.2013.12.009
Bawa, K.S., Krishnaswamy, J., Karanth, K.U., Kumar, N.S., Rao, M., 2007. Western Ghats & Sri Lanka Biodiversity Hotspot. Western Ghats Region. Critical Ecosystem Partenrship Fund (CEPF).
Baylis, K., Peplow, S., Rausser, G., Simon, L., 2008. Agri-environmental policies in the EU and United States: A comparison. Ecol. Econ., Payments for Environmental Services in Developing and Developed Countries 65, 753–764. https://doi.org/10.1016/j.ecolecon.2007.07.034
Becu, N., Sangkapitux, C., Neef, A., Kitchaicharoen, J., Elstner, P., 2006. Participatory simulation sessions to support collective decision: the case of water allocation between a Thai and a Hmong village in northern Thailand. Presented at the International Symposium "Towards Sustainable Livelihoods and Ecosystems in Mountainous Regions," Chiang Mai, Thailand.
Bell, A., 2011. Environmental Licensing and Land Aggregation: An Agent-Based Approach to Understanding Ranching and Land Use in Rural Rondônia. Ecol. Soc. 16. https://doi.org/10.5751/ES-03947-160131
Bennett, A.F., Radford, J.Q., Haslem, A., 2006. Properties of land mosaics: Implications for nature conservation in agricultural environments. Biol. Conserv. 133, 250–264. https://doi.org/10.1016/j.biocon.2006.06.008
Bennett, E.M., 2017. Changing the agriculture and environment conversation. Nat. Ecol. Evol. 1, 0018. https://doi.org/10.1038/s41559-016-0018
Bernoulli, D., 1954. Exposition of a New Theory on the Measurement of Risk. Econometrica 22, 23–36. https://doi.org/10.2307/1909829
Berry, N.J., Phillips, O.L., Lewis, S.L., Hill, J.K., Edwards, D.P., Tawatao, N.B., Ahmad, N., Magintan, D., Khen, C.V., Maryati, M., Ong, R.C., Hamer, K.C., 2010. The high value of logged tropical forests: lessons from northern Borneo. Biodivers. Conserv. 19, 985–997. https://doi.org/10.1007/s10531-010-9779-z
Besley, T., Burgess, R., 2000. Land Reform, Poverty Reduction, and Growth: Evidence from India. Q. J. Econ. 115, 389–430. https://doi.org/10.1162/003355300554809

Bhagwat, S.A., Willis, K.J., Birks, H.J.B., Whittaker, R.J., 2008. Agroforestry: a refuge for tropical biodiversity? Trends Ecol. Evol. 23, 261–267. https://doi.org/10.1016/j.tree.2008.01.005
Bickel, G., Nord, M., Price, C., Hamilton, W., Cook, J., 2000. Guide to Measuring Household Food Security, Revised 2000. U.S. Department of Agriculture, Food and Nutrition Service, Alexandria VA.
Boero, R., Squazzoni, F., 2005. Does Empirical Embeddedness Matter? Methodological Issues on Agent-Based Models for Analytical Social Science [WWW Document]. URL http://jasss.soc.surrey.ac.uk/8/4/6.html (accessed 10.5.17).
Bogale, A., 2012. Vulnerability of smallholder rural households to food insecurity in Eastern Ethiopia. Food Secur. 4, 581–591. https://doi.org/10.1007/s12571-012-0208-x
Bolker, B.M., Brooks, M.E., Clark, C.J., Geange, S.W., Poulsen, J.R., Stevens, M.H.H., White, J.-S.S., 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends Ecol. Evol. 24, 127–135. https://doi.org/10.1016/j.tree.2008.10.008
Bone, C., Dragićević, S., 2010. Simulation and validation of a reinforcement learning agent-based model for multi-stakeholder forest management. Comput. Environ. Urban Syst. 34, 162–174. https://doi.org/10.1016/j.compenvurbsys.2009.10.001
Bontkes, T.S., Keulen, H. van, 2003. Modelling the dynamics of agricultural development at farm and regional level. Agric. Syst. 76, 379–396. https://doi.org/10.1016/S0308-521X(02)00128-2
Borlaug, N., 2007. Feeding a Hungry World. Science 318, 359–359. https://doi.org/10.1126/science.1151062
Borrini-Feyerabend, G., Pimbert, M., Farvar, M.T., Kotari, A., Renard, Y., 2004. Sharing power. Learning-by-doing in co-management of natural resources throughout the world. IIED and IUCN/ CEESP/ CMWG, Cenesta, Tehran.
Bose, A., Vira, B., Garcia, C., 2016. Does environmental certification in coffee promote “business as usual”? A case study from the Western Ghats, India. Ambio 45, 946–955. https://doi.org/10.1007/s13280-016-0796-3
Bouamrane, M., Spierenburg, M., Agrawal, A., Boureima, A., Cormier-Salem, M.-C., Etienne, M., Le Page, C., Levrel, H., Mathevet, R., 2016. Stakeholder engagement and biodiversity conservation challenges in social-ecological systems: some insights from biosphere reserves in western Africa and France. Ecol. Soc. 21. https://doi.org/10.5751/ES-08812-210425
Boulanger, P.-M., Bréchet, T., 2005. Models for policy-making in sustainable development: The state of the art and perspectives for research. Ecol. Econ. 55, 337–350. https://doi.org/10.1016/j.ecolecon.2005.07.033
Bousquet, F., Le Page, C., 2004. Multi-agent simulations and ecosystem management: a review. Ecol. Model. 176, 313–332. https://doi.org/10.1016/j.ecolmodel.2004.01.011
Brady, M., Sahrbacher, C., Kellermann, K., Happe, K., 2012. An agent-based approach to modeling impacts of agricultural policy on land use, biodiversity and ecosystem services. Landsc. Ecol. 27, 1363–1381. https://doi.org/10.1007/s10980-012-9787-3
Breen, R.L., 2006. A Practical Guide to Focus-Group Research. J. Geogr. High. Educ. 30, 463–475. https://doi.org/10.1080/03098260600927575
Bremer, L.L., Farley, K.A., Lopez-Carr, D., 2014. What factors influence participation in payment for ecosystem services programs? An evaluation of Ecuador’s SocioPáramo program. Land Use Policy 36, 122–133. https://doi.org/10.1016/j.landusepol.2013.08.002
Brindha, B., Prashanthi Devi, M., 2014. Landscape Heterogeneity mapping for Access to Tribal health care in Nilgiris District of Tamil Nadu, India, in: ISPRS - International

Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Presented at the ISPRS Technical Commission VIII Symposium (Volume XL-8) -;12 December 2014, Hyderabad, India, Copernicus GmbH, pp. 177–183. https://doi.org/10.5194/isprsarchives-XL-8-177-2014

Brugha, R., Varvasovszky, Z., 2000. Stakeholder analysis: a review. Health Policy Plan. 15, 239–246. https://doi.org/10.1093/heapol/15.3.239

Bruner, A.G., Gullison, R.E., Rice, R.E., Fonseca, G.A.B. da, 2001. Effectiveness of Parks in Protecting Tropical Biodiversity. Science 291, 125–128. https://doi.org/10.1126/science.291.5501.125

Bryson, J.M., 2004. What to do when Stakeholders matter. Public Manag. Rev. 6, 21–53. https://doi.org/10.1080/14719030410001675722

Bunyan, M., Bardhan, S., Jose, S., 2012. The Shola (Tropical Montane Forest)-Grassland Ecosystem Mosaic of Peninsular India: A Review. Am. J. Plant Sci. 03, 1632. https://doi.org/10.4236/ajps.2012.311198

Busch, J., Ferretti-Gallon, K., 2017. What Drives Deforestation and What Stops It? A Meta-Analysis. Rev. Environ. Econ. Policy 11, 3–23. https://doi.org/10.1093/reep/rew013

Butsic, V., Radeloff, V.C., Kuemmerle, T., Pidgeon, A.M., 2012. Analytical Solutions to Trade-Offs between Size of Protected Areas and Land-Use Intensity. Conserv. Biol. 26, 883–893. https://doi.org/10.1111/j.1523-1739.2012.01887.x

Caillault, S., Mialhe, F., Vannier, C., Delmotte, S., Kêdowidé, C., Amblard, F., Etienne, M., Bécu, N., Gautreau, P., Houet, T., 2013. Influence of incentive networks on landscape changes: A simple agent-based simulation approach. Environ. Model. Softw., Thematic Issue on Spatial Agent-Based Models for Socio-Ecological Systems 45, 64–73. https://doi.org/10.1016/j.envsoft.2012.11.003

Campo, P.C., Mendoza, G.A., Guizol, P., Villanueva, T.R., Bousquet, F., 2009. Exploring management strategies for community-based forests using multi-agent systems: A case study in Palawan, Philippines. J. Environ. Manage. 90, 3607–3615. https://doi.org/10.1016/j.jenvman.2009.06.016

Carmona, G., Varela-Ortega, C., Bromley, J., 2013. Supporting decision making under uncertainty: Development of a participatory integrated model for water management in the middle Guadiana river basin. Environ. Model. Softw. 50, 144–157. https://doi.org/10.1016/j.envsoft.2013.09.007

Carney, D., 1999. Livelihoods Approaches Compared: a Brief Comparison of the Livelihoods Approaches of the UK Department for International Development (Dfid), Care, Oxfam and the United Nations Development Programme. Department for International Development.

Carson, R.T., Groves, T., 2007. Incentive and informational properties of preference questions. Environ. Resour. Econ. 37, 181–210. https://doi.org/10.1007/s10640-007-9124-5

Carter, J., Gronow, J., 2005. Recent experience in collaborative forest management: a review paper. Cent. Int. For. Res. https://doi.org/10.17528/cifor/001791

Castella, J.-C., Lestrelin, G., Hett, C., Bourgoin, J., Fitriana, Y.R., Heinimann, A., Pfund, J.-L., 2013. Effects of Landscape Segregation on Livelihood Vulnerability: Moving From Extensive Shifting Cultivation to Rotational Agriculture and Natural Forests in Northern Laos. Hum. Ecol. 41, 63–76. https://doi.org/10.1007/s10745-012-9538-8

Ceddia, M.G., Bardsley, N.O., Gomez-y-Paloma, S., Sedlacek, S., 2014. Governance, agricultural intensification, and land sparing in tropical South America. Proc. Natl. Acad. Sci. 111, 7242–7247. https://doi.org/10.1073/pnas.1317967111

Census of India, 2011. District census handbook Nilgiris. Directorate of Census Operations, Tamil Nadu.

CGIAR, n.d. Using game and participatory modelling approaches to guide and test policies. Consultative Group for International Agricultural Research [WWW Document]. Clim.-Smart Agric. Guide. URL https://csa.guide/csa/using-game-and-participatory-modelling-approaches-to-guide-and-test-policies (accessed 12.6.17).
Chambers, R., 2006. Participatory Mapping and Geographic Information Systems: Whose Map? Who is Empowered and Who Disempowered? Who Gains and Who Loses? Electron. J. Inf. Syst. Dev. Ctries. 25.
Chand, R., Prasanna, P.A.L., Singh, A., 2011. Farm Size and Productivity: Understanding the Strengths of Smallholders and Improving Their Livelihoods. Econ. Polit. Wkly. 46, 5–11.
Chandler, R.B., King, D.I., Raudales, R., Trubey, R., Chandler, C., Arce Chávez, V.J., 2013. A Small-Scale Land-Sparing Approach to Conserving Biological Diversity in Tropical Agricultural Landscapes. Conserv. Biol. 27, 785–795. https://doi.org/10.1111/cobi.12046
Chandran, M.D.S., 1997. On the ecological history of the Western Ghats. Curr. Sci. 73, 146–155.
Chappell, M.J., LaValle, L.A., 2011. Food security and biodiversity: can we have both? An agroecological analysis. Agric. Hum. Values 28, 3–26. https://doi.org/10.1007/s10460-009-9251-4
Chaudhary, A., Pfister, S., Hellweg, S., 2016. Spatially Explicit Analysis of Biodiversity Loss Due to Global Agriculture, Pasture and Forest Land Use from a Producer and Consumer Perspective. Environ. Sci. Technol. 50, 3928–3936. https://doi.org/10.1021/acs.est.5b06153
Chaudhary, A., Verones, F., de Baan, L., Hellweg, S., 2015. Quantifying Land Use Impacts on Biodiversity: Combining Species–Area Models and Vulnerability Indicators. Environ. Sci. Technol. 49, 9987–9995. https://doi.org/10.1021/acs.est.5b02507
Chen, X., Lupi, F., An, L., Sheely, R., Viña, A., Liu, J., 2012. Agent-based modeling of the effects of social norms on enrollment in payments for ecosystem services. Ecol. Model., Modeling Human Decisions 229, 16–24. https://doi.org/10.1016/j.ecolmodel.2011.06.007
Chetan, H.C., Siddhartha, K., Ganesh, T.G., 2012. Biodiversity regain in abandoned tea plantations. Curr. Sci. 102, 1089–1090.
Chetana, H.C., 2013. Assessing the ecological processes in abandoned tea plantations and its implication for Ecological Restoration in the Western Ghats, India. Manipal, Ashoka Trust for Research in Ecology and the Environment, Bangalore.
Chiron, F., Chargé, R., Julliard, R., Jiguet, F., Muratet, A., 2014. Pesticide doses, landscape structure and their relative effects on farmland birds. Agric. Ecosyst. Environ. 185, 153–160. https://doi.org/10.1016/j.agee.2013.12.013
Cialdella, N., Carvalho, S., Vaz, V., Barbosa, T., Thâles, M., Mourão, M., Poccard-Chapuis, R., Tourrand, J.-F., 2015. Do political changes aimed at reducing Amazonian deforestation contribute to ecological intensification? Cah. Agric. 24, 246–254. https://doi.org/10.1684/agr.2015.0761
Cincotta, R.P., Wisnewski, J., Engelman, R., 2000. Human population in the biodiversity hotspots. Nature 404, 990–992. https://doi.org/10.1038/35010105
Cinner, J. E, Daw, T., McClanahan, T. r., 2009. Socioeconomic Factors that Affect Artisanal Fishers' Readiness to Exit a Declining Fishery. Conserv. Biol. 23, 124–130. https://doi.org/10.1111/j.1523-1739.2008.01041.x
CL, 2017. Collaborative Learning [WWW Document]. URL http://www.gdrc.org/kmgmt/c-learn/ (accessed 11.11.17).

Clements, T., John, A., Nielsen, K., An, D., Tan, S., Milner-Gulland, E.J., 2010. Payments for biodiversity conservation in the context of weak institutions: Comparison of three programs from Cambodia. Ecol. Econ., Special Section - Payments for Environmental Services: Reconciling Theory and Practice 69, 1283–1291. https://doi.org/10.1016/j.ecolecon.2009.11.010

Clough, Y., Barkmann, J., Juhrbandt, J., Kessler, M., Wanger, T.C., Anshary, A., Buchori, D., Cicuzza, D., Darras, K., Putra, D.D., Erasmi, S., Pitopang, R., Schmidt, C., Schulze, C.H., Seidel, D., Steffan-Dewenter, I., Stenchly, K., Vidal, S., Weist, M., Wielgoss, A.C., Tscharntke, T., 2011. Combining high biodiversity with high yields in tropical agroforests. Proc. Natl. Acad. Sci. 108, 8311–8316. https://doi.org/10.1073/pnas.1016799108

Coates, J., 2013. Build it back better: Deconstructing food security for improved measurement and action. Glob. Food Secur. 2, 188–194. https://doi.org/10.1016/j.gfs.2013.05.002

Coates, J., Swindale, A., Bilinsky, P., 2007. Household Food Insecurity Access Scale (HFIAS) for Measurement of Food Access: Indicator Guide | Food and Nutrition Technical Assistance Project (FANTA). USAID, Washington, DC.

Collas, L., Green, R.E., Ross, A., Wastell, J.H., Balmford, A., 2017. Urban development, land sharing and land sparing: the importance of considering restoration. J. Appl. Ecol. https://doi.org/10.1111/1365-2664.12908

Conway, G., 2012. One Billion Hungry: Can We Feed the World? Cornell University Press, Ithaca, NY.

Conway, G.R., Barbie, E.B., 1988. After the Green Revolution: Sustainable and equitable agricultural development. Futures, Special Issue Sustainable Development 20, 651–670. https://doi.org/10.1016/0016-3287(88)90006-7

Cordeiro, A. de A.C., Coelho, S.D., Ramos, N.C., Meira-Neto, J.A.A., 2017. Agroforestry systems reduce invasive species richness and diversity in the surroundings of protected areas. Agrofor. Syst. 1–11. https://doi.org/10.1007/s10457-017-0095-4

Cowlishaw, G., 1999. Predicting the Pattern of Decline of African Primate Diversity: an Extinction Debt from Historical Deforestation. Conserv. Biol. 13, 1183–1193. https://doi.org/10.1046/j.1523-1739.1999.98433.x

CPRC, 2009. Hunger, Under-Nutrition and Food Security in India (No. Working Paper 44). Chronic poverty research center. Indian Institute of Public Administration.

Cramer, V.A., Hobbs, R.J., Standish, R.J., 2008. What's new about old fields? Land abandonment and ecosystem assembly. Trends Ecol. Evol. 23, 104–112. https://doi.org/10.1016/j.tree.2007.10.005

Crawley, M.J., 2012. The R Book, 2nd ed. Wiley.

Crawley, M.J., 2002. Statistical Computing: An Introduction to Data Analysis using S-Plus. John Wiley & Sons.

Critical Ecosystem Partnership Fund (CEPF), 2017. Western Ghats and Sri Lanka [WWW Document]. URL http://www.cepf.net/resources/hotspots/Asia-Pacific/Pages/Western-Ghats-and-Sri-Lanka.aspx

Crona, B., 2006. Supporting and Enhancing Development of Heterogeneous Ecological Knowledge among Resource Users in a Kenyan Seascape. Ecol. Soc. 11. https://doi.org/10.5751/ES-01712-110132

Crooks, A., Castle, C., Batty, M., 2008. Key challenges in agent-based modelling for geo-spatial simulation. Comput. Environ. Urban Syst., GeoComputation: Modeling with spatial agents 32, 417–430. https://doi.org/10.1016/j.compenvurbsys.2008.09.004

Crooks, A.T., Heppenstall, A.J., 2012. Introduction to Agent-Based Modelling, in: Agent-Based Models of Geographical Systems. Springer, Dordrecht, pp. 85–105. https://doi.org/10.1007/978-90-481-8927-4_5

Cumming, G.S., 2016. The relevance and resilience of protected areas in the Anthropocene. Anthropocene 13, 46–56. https://doi.org/10.1016/j.ancene.2016.03.003
D'Aquino, P., Bah, A., 2013. A bottom-up participatory modelling process for a multi-level agreement on environmental uncertainty management in West Africa. J. Environ. Plan. Manag. 56, 271–285. https://doi.org/10.1080/09640568.2012.665361
Dagar, J.C., Singh, A.K., Arunachalam, A., 2013. Agroforestry Systems in India: Livelihood Security & Ecosystem Services. Springer Science & Business Media.
Dahanukar, N., Raut, R., Bhat, A., 2004. Distribution, Endemism and Threat Status of Freshwater Fishes in the Western Ghats of India. J. Biogeogr. 31, 123–136.
Daily, G.C., 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press.
Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J., Shallenberger, R., 2009. Ecosystem services in decision making: time to deliver. Front. Ecol. Environ. 7, 21–28. https://doi.org/10.1890/080025
Daniels, R.J.R., Hegde, M., Gadgil, M., 1990. Birds of the man-made ecosystems: the plantations. Proc. Anim. Sci. 99, 79–89. https://doi.org/10.1007/BF03186376
D'Aquino, P., Le Page, C., Bousquet, F., Bah, A., 2002. A novel mediating participatory modelling : The "self-design" process to accompany collective decision making. Int. J. Agric. Resour. Gov. Ecol. 2, 59–74.
Darnhofer, I., Walder, P., 2014. Farmer Types and Motivation, in: Thompson, P.B., Kaplan, D.M. (Eds.), Encyclopedia of Food and Agricultural Ethics. Springer Netherlands, pp. 710–715. https://doi.org/10.1007/978-94-007-0929-4_86
Darragh, H.S., Emery, S.B., 2017. What Can and Can't Crowding Theories Tell Us about Farmers' 'Environmental' Intentions in Post-Agri-Environment Scheme Contexts? Sociol. Rural. n/a-n/a. https://doi.org/10.1111/soru.12159
Deadman, P., Robinson, D., Moran, E., Brondizio, E., 2004. Colonist Household Decisionmaking and Land-Use Change in the Amazon Rainforest: An Agent-Based Simulation. Environ. Plan. B Plan. Des. 31, 693–709. https://doi.org/10.1068/b3098
DEFRA, 2016. Farm Accounts in England – Results from the Farm Business Survey 2015/16. Depratment for Environment, Food and Rural Affairs, UK.
Delzeit, R., Zabel, F., Meyer, C., Václavík, T., 2017. Addressing future trade-offs between biodiversity and cropland expansion to improve food security. Reg. Environ. Change 17, 1429–1441. https://doi.org/10.1007/s10113-016-0927-1
Demmer, U., 2014. The Poetics and Politics of Practical reason: Indigenous Identity, Ritual Discourse, and the Postcolonial State in the Northern Nilgiris (South India). Asian Ethnol. 73, 111–137.
DeNeve, K.M., Heppner, M.J., 1997. Role play simulations: The assessment of an active learning technique and comparisons with traditional lectures. Innov. High. Educ. 21, 231–246. https://doi.org/10.1007/BF01243718
Department of Economics and Statistics, 2017. District Statistical Handbook-The Nilgiris 2015-2016. Department of Economics and Statistics, The Nilgiris, Tamil Nadu, India.
DFID, 1997. Eliminating World Poverty: A Challenge for the 21st Century. White Paper on International Development. Department for International Development, HMSO, London.
Diedrich, A., Upham, P., Levidow, L., van den Hove, S., 2011. Framing environmental sustainability challenges for research and innovation in European policy agendas. Environ. Sci. Policy 14, 935–939. https://doi.org/10.1016/j.envsci.2011.07.012
Doglioni, A., Primativo, F., Laucelli, D., Monno, V., Khu, S.-T., Giustolisi, O., 2009. An integrated modelling approach for the assessment of land use change effects on wastewater infrastructures. Environ. Model. Softw., Special issue on simulation and

modelling in the Asia-Pacific regionSI: ASIMMOD 24, 1522–1528. https://doi.org/10.1016/j.envsoft.2009.06.006
Dolinska, A., 2017. Bringing farmers into the game. Strengthening farmers' role in the innovation process through a simulation game, a case from Tunisia. Agric. Syst. 157, 129–139. https://doi.org/10.1016/j.agsy.2017.07.002
Donald, P.F., 2004. Biodiversity Impacts of Some Agricultural Commodity Production Systems. Conserv. Biol. 18, 17–38. https://doi.org/10.1111/j.1523-1739.2004.01803.x
Donald, P.F., Evans, A.D., 2006. Habitat connectivity and matrix restoration: the wider implications of agri-environment schemes. J. Appl. Ecol. 43, 209–218. https://doi.org/10.1111/j.1365-2664.2006.01146.x
Dressler, W., de Koning, J., Montefrio, M., Firn, J., 2016. Land sharing not sparing in the "green economy": The role of livelihood bricolage in conservation and development in the Philippines. Geoforum 76, 75–89. https://doi.org/10.1016/j.geoforum.2016.09.003
Dressler, W.H., Wilson, D., Clendenning, J., Cramb, R., Keenan, R., Mahanty, S., Bruun, T.B., Mertz, O., Lasco, R.D., 2017. The impact of swidden decline on livelihoods and ecosystem services in Southeast Asia: A review of the evidence from 1990 to 2015. Ambio 46, 291–310. https://doi.org/10.1007/s13280-016-0836-z
Drèze, J., 1990. Widows in rural India. Discussion Paper No. 26 Development Economics Research Programme, London School of Economics
Ducrot, R., Paassen, A. van, Barban, V., Daré, W., Gramaglia, C., 2015. Learning integrative negotiation to manage complex environmental issues: example of a gaming approach in the peri-urban catchment of São Paulo, Brazil. Reg. Environ. Change 15, 67–78. https://doi.org/10.1007/s10113-014-0612-1
Dudley, N., Alexander, S., 2017. Agriculture and biodiversity: a review. Biodiversity 0, 1–5. https://doi.org/10.1080/14888386.2017.1351892
Dumrongrojwatthana, P., Page, C.L., Gajaseni, N., Trébuil, G., 2011. Co-constructing an agent-based model to mediate land use conflict between herders and foresters in northern Thailand. J. Land Use Sci. 6, 101–120. https://doi.org/10.1080/1747423X.2011.558596
Edwards, D., Hodgson, J.A., Hamer, K.C., Mitchell, S.L., Ahmad, A.H., Cornell, S.J., Wilcove, D.S., 2010. Wildlife-friendly oil palm plantations fail to protect biodiversity effectively. Conserv. Lett. 3, 236–242. https://doi.org/10.1111/j.1755-263X.2010.00107.x
Edwards, D.P., Gilroy, J.J., Woodcock, P., Edwards, F.A., Larsen, T.H., Andrews, D.J.R., Derhé, M.A., Docherty, T.D.S., Hsu, W.W., Mitchell, S.L., Ota, T., Williams, L.J., Laurance, W.F., Hamer, K.C., Wilcove, D.S., 2014. Land-sharing versus land-sparing logging: reconciling timber extraction with biodiversity conservation. Glob. Change Biol. 20, 183–191. https://doi.org/10.1111/gcb.12353
Eloy, L., Méral, P., Ludewigs, T., Pinheiro, G.T., Singer, B., 2012. Payments for ecosystem services in Amazonia. The challenge of land use heterogeneity in agricultural frontiers near Cruzeiro do Sul (Acre,Brazil). J. Environ. Plan. Manag. 55, 685–703. https://doi.org/10.1080/09640568.2011.621021
Emery, S.B., Franks, J.R., 2012. The potential for collaborative agri-environment schemes in England: can a well-designed collaborative approach address farmers' concerns with current schemes? J. Rural Stud. 218–231. https://doi.org/10.1016/j.jrurstud.2012.02.004
Etienne, M., 2010. Companion Modelling - A Participatory Approach to Support Sustainable Development. Springer.

Etienne, M., Du, T., Pollard, S., 2008. ARDI: a co-construction method for participatory modelling in natural resources management. Proc. IEMSS Congr. 2, 866–873.
Etienne, M., Du Toit, D., Pollard, S., 2011. ARDI: A Co-construction Method for Participatory Modeling in Natural Resources Management. Ecol. Soc. 16. https://doi.org/10.5751/ES-03748-160144
Ewers, R.M., Scharlemann, J.P.W., Balmford, A., Green, R.E., 2009. Do increases in agricultural yield spare land for nature? Glob. Change Biol. 15, 1716–1726. https://doi.org/10.1111/j.1365-2486.2009.01849.x
Falconer, K., Saunders, C., 2002. Transaction costs for SSSIs and policy design. Land Use Policy 19, 157–166. https://doi.org/10.1016/S0264-8377(02)00007-8
FAO, 2017a. The future of food and agriculture: Trends and challenges. Rome.
FAO, 2017b. FAOSTAT [WWW Document]. URL http://www.fao.org/faostat/en/#country/100 (accessed 11.19.17).
FAO, 2014a. FAO Country Profiles: India [WWW Document]. Food Agric. Organ. U. N. URL http://www.fao.org/countryprofiles/index/en/?iso3=ZWE (accessed 11.19.17).
FAO, 2014b. Agroecology for food Security and nutrition - Proceedings of the FAO International Symposium. Case Stusy 21. Food and Agriculture Organisation of the United Nations, Rome.
FAO, 2013a. Ethiopia food security scale focus group report and recommendations. Food and Agriculture Organisation of the United Nations.
FAO, 2013b. Towards the assessment of Trees Outside Forests, Assessment Working paper 183. Food and Agriculture Organisation of the United Nations.
FAO, 2009. World Summit on Food Security: World Summit. Food and Agriculture Organisation of the United Nations, Rome.
FAO, 2008. The State of Food Insecurity in the World 2008.
FAO, 2001. Food Balance Sheets - A Handbook [WWW Document]. URL http://www.fao.org/docrep/003/X9892E/X9892E00.htm (accessed 12.1.17).
FAO, 1997. Agriculture food and nutrition for Africa - A resource book for teachers of agriculture. Food and Agriculture Organisation of the United Nations. Agriculture and Consumer Protection Department., Rome.
FAO, 1996. Rome Declaration on World Food Security and World Food Summit Plan of Action [WWW Document]. URL http://www.fao.org/docrep/003/w3613e/w3613e00.htm (accessed 9.1.17).
FAO, CIFOR, IFRI, World Bank, 2016. National socioeconomic surveys in forestry: guidance and survey modules for measuring the multiple roles of forests in household welfare and livelihoods, by R.K. Bakkegaard, A. Agrawal, I. Animon, N. Hogarth, D. Miller, L. Persha, E. Rametsteiner, S. Wunder and A. Zezza. FAO Forestry Paper No. 179. Food and Agriculture Organization of the United Nations, Center for International Forestry Research, International Forestry Resources and Institutions Research Network, and World Bank.
FAO, IFAD, WFP, 2015. The State of Food Insecurity in the World 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress. Rome, Italy.
FAO, World Bank, 2017. Population density (people per sq. km of land area) | Data [WWW Document]. URL https://data.worldbank.org/indicator/EN.POP.DNST?locations=IN (accessed 11.19.17).
Fedoroff, N.V., Battisti, D.S., Beachy, R.N., Cooper, P.J.M., Fischhoff, D.A., Hodges, C.N., Knauf, V.C., Lobell, D., Mazur, B.J., Molden, D., Reynolds, M.P., Ronald, P.C., Rosegrant, M.W., Sanchez, P.A., Vonshak, A., Zhu, J.-K., 2010. Radically Rethinking Agriculture for the 21st Century. Science 327, 833–834. https://doi.org/10.1126/science.1186834

Feleke, S.T., Kilmer, R.L., Gladwin, C.H., 2005. Determinants of food security in Southern Ethiopia at the household level. Agric. Econ. 33, 351–363. https://doi.org/10.1111/j.1574-0864.2005.00074.x

Felker-Kantor, E., Wood, C.H., 2012. Female-headed households and food insecurity in Brazil. Food Secur. 4, 607–617. https://doi.org/10.1007/s12571-012-0215-y

Ferrier, S., Powell, G.V.N., Richardson, K.S., Manion, G., Overton, J.M., Allnutt, T.F., Cameron, S.E., Mantle, K., Burgess, N.D., Faith, D.P., Lamoreux, J.F., Kier, G., Hijmans, R.J., Funk, V.A., Cassis, G.A., Fisher, B.L., Flemons, P., Lees, D., Lovett, J.C., Rompaey, V., R, R.S.A., 2004. Mapping More of Terrestrial Biodiversity for Global Conservation Assessment. BioScience 54, 1101–1109. https://doi.org/10.1641/0006-3568(2004)054[1101:MMOTBF]2.0.CO;2

Filatova, T., Verburg, P.H., Parker, D.C., Stannard, C.A., 2013. Spatial agent-based models for socio-ecological systems: Challenges and prospects. Environ. Model. Softw., Thematic Issue on Spatial Agent-Based Models for Socio-Ecological Systems 45, 1–7. https://doi.org/10.1016/j.envsoft.2013.03.017

Fischer, J., Abson, D.J., Bergsten, A., French Collier, N., Dorresteijn, I., Hanspach, J., Hylander, K., Schultner, J., Senbeta, F., 2017a. Reframing the Food–Biodiversity Challenge. Trends Ecol. Evol. 32, 335–345. https://doi.org/10.1016/j.tree.2017.02.009

Fischer, J., Abson, D.J., Butsic, V., Chappell, M.J., Ekroos, J., Hanspach, J., Kuemmerle, T., Smith, H.G., von Wehrden, H., 2014. Land Sparing Versus Land Sharing: Moving Forward. Conserv. Lett. 7, 149–157. https://doi.org/10.1111/conl.12084

Fischer, J., Lindenmayer, D.B., 2007. Landscape modification and habitat fragmentation: a synthesis. Glob. Ecol. Biogeogr. 16, 265–280. https://doi.org/10.1111/j.1466-8238.2007.00287.x

Fischer, J., Meacham, M., Queiroz, C., 2017b. A plea for multifunctional landscapes. Front. Ecol. Environ. 15, 59–59. https://doi.org/10.1002/fee.1464

Fisher, R.J., 1993. Social Desirability Bias and the Validity of Indirect Questioning. J. Consum. Res. 20, 303–315. https://doi.org/10.1086/209351

Flint, E.P., 1998. Deforestation and land use in Northern India with a focus on Sal (Shorea robusta) forests 1880–1980, in: Nature and the Orient: The Environmental History of South and Southeast Asia. Oxford University Press, New Delhi, India.

Fortman, L., 1985. The tree tenure factor in agroforestry with particular reference to Africa. Agrofor. Syst. 2, 229–251. https://doi.org/10.1007/BF00147036

Foster, A.D., Behrma, J.R., Rosenzweig, M.R., 1999. Population Growth, Technical Change, and Forest Degradation. Dep. Econ. Brown Univ.

Fox, J., Fujita, Y., Ngidang, D., Peluso, N., Potter, L., Sakuntaladewi, N., Sturgeon, J., Thomas, D., 2009. Policies, Political-Economy, and Swidden in Southeast Asia. Hum. Ecol. 37, 305–322. https://doi.org/10.1007/s10745-009-9240-7

Franklin, J.F., Lindenmayer, D.B., 2009. Importance of matrix habitats in maintaining biological diversity. Proc. Natl. Acad. Sci. 106, 349–350. https://doi.org/10.1073/pnas.0812016105

Frelat, R., Lopez-Ridaura, S., Giller, K.E., Herrero, M., Douxchamps, S., Djurfeldt, A.A., Erenstein, O., Henderson, B., Kassie, M., Paul, B.K., Rigolot, C., Ritzema, R.S., Rodriguez, D., Asten, P.J.A. van, Wijk, M.T. van, 2016. Drivers of household food availability in sub-Saharan Africa based on big data from small farms. Proc. Natl. Acad. Sci. 113, 458–463. https://doi.org/10.1073/pnas.1518384112

Frongillo, E.A., Olson, C.M., Rauschenbach, B.S., Kendall, A., 1997. Nutritional consequences of food insecurity in a rural New York state County. Institute for Research on Poverty, University of Wisconsin–Madison.

Garcia, C., 2014. ComMod Role-Playing Games. Objectieves, chracteristics, conception stages. Companion Modelling Spring School. Switzerland
Garcia, C.A., Bhagwat, S.A., Ghazoul, J., Nath, C.D., Nanaya, K.M., Kushalappa, C.G., Raghuramulu, Y., Nasi, R., Vaast, P., 2010. Biodiversity Conservation in Agricultural Landscapes: Challenges and Opportunities of Coffee Agroforests in the Western Ghats, India. Conserv. Biol. 24, 479–488. https://doi.org/10.1111/j.1523-1739.2009.01386.x
Garcia, C.A., Konerira, N.M., Kalla, J., Dray, A., Waeber, P.O., Delay, M., Le Page, C., Raghuramulu, Y., Kushalappa, C.G., Vaast, P., 2013. Understanding farmers: Using role playing games to explore futures of landscape management in the western Ghats (India). 50th Anniv. Meet. Assoc. Trop. Biol. Conserv. Organ. Trop. Stud.
García-Barrios, L., García-Barrios, R., Cruz-Morales, J., Smith, J., 2015. When death approaches: reverting or exploiting emergent inequity in a complex land-use table-board game. Ecol. Soc. 20. https://doi.org/10.5751/ES-07372-200213
Gardner, T.A., Barlow, J., Chazdon, R., Ewers, R.M., Harvey, C.A., Peres, C.A., Sodhi, N.S., 2009. Prospects for tropical forest biodiversity in a human-modified world. Ecol. Lett. 12, 561–582. https://doi.org/10.1111/j.1461-0248.2009.01294.x
Geist, H.J., Lambin, E.F., 2002. Proximate Causes and Underlying Driving Forces of Tropical DeforestationTropical forests are disappearing as the result of many pressures, both local and regional, acting in various combinations in different geographical locations. BioScience 52, 143–150. https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2
Ghazoul, J., 2007. Challenges to the Uptake of the Ecosystem Service Rationale for Conservation. Conserv. Biol. 21, 1651–1652. https://doi.org/10.1111/j.1523-1739.2007.00758.x
Gibbs, H.K., Ruesch, A.S., Achard, F., Clayton, M.K., Holmgren, P., Ramankutty, N., Foley, J.A., 2010. Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. Proc. Natl. Acad. Sci. 107, 16732–16737. https://doi.org/10.1073/pnas.0910275107
Gibson, L., Lynam, A.J., Bradshaw, C.J.A., He, F., Bickford, D.P., Woodruff, D.S., Bumrungsri, S., Laurance, W.F., 2013. Near-Complete Extinction of Native Small Mammal Fauna 25 Years After Forest Fragmentation. Science 341, 1508–1510. https://doi.org/10.1126/science.1240495
Gigerenzer, G., Selten, R., 2001. Bounded Rationality: The Adaptive Toolbox. MIT Press, Cambridge, Massachusetts, USA.
Gill, A.R., Khan, R.E.., 2010. Determinants of Food Security in Rural Areas of Pakistan. SSRN Work. Pap. Ser.
Gilroy, J.J., Edwards, F.A., Medina Uribe, C.A., Haugaasen, T., Edwards, D.P., 2014. Surrounding habitats mediate the trade-off between land-sharing and land-sparing agriculture in the tropics. J. Appl. Ecol. 51, 1337–1346. https://doi.org/10.1111/1365-2664.12284
Glamann, J., Hanspach, J., Abson, D.J., Collier, N., Fischer, J., 2017. The intersection of food security and biodiversity conservation: a review. Reg. Environ. Change 17, 1303–1313. https://doi.org/10.1007/s10113-015-0873-3
Gockowski, J., Afari-Sefa, V., Sarpong, D.B., Osei-Asare, Y.B., Agyeman, N.F., 2013. Improving the productivity and income of Ghanaian cocoa farmers while maintaining environmental services: what role for certification? Int. J. Agric. Sustain. 11, 331–346. https://doi.org/10.1080/14735903.2013.772714

Gordon, C., Manson, R., Sundberg, J., Cruz-Angón, A., 2007. Biodiversity, profitability, and vegetation structure in a Mexican coffee agroecosystem. Agric. Ecosyst. Environ. 118, 256–266. https://doi.org/10.1016/j.agee.2006.05.023
Gordon, T.J., 1992. The methods of futures research. Ann. Am. Acad. Pol. Soc. Sci. 522, 25–35.
Goswami, M., 2006. Emerging entrepreneurship in tea plantation a study of small tea growers of Assam. Gauhati.
Gotts, N.M., Polhill, J.G., 2010. Size matters: large-scale replications of experiments with fearlus. Adv. Complex Syst. 13, 453–467. https://doi.org/10.1142/S0219525910002670
Government of India, 2014. Report of the Expert Group to Review the Methodology for Measurement of Poverty. Planning Commission, Government of India, India.
Government of India, 2012. List of Scheduled Castes - Scheduled Caste Welfare: Ministry of Social Justice and Empowerment [WWW Document]. URL https://web.archive.org/web/20120913050030/http://socialjustice.nic.in:80/sclist.php (accessed 11.21.17).
Government of India, 2009. Report of the Expert Group to Review the Methodology for Estimation of Poverty. Planning Commission, Government of India, India.
Government of Tamil Nadu, 2017. Tamil Nadu State Human Devlopment Report 2017. Academic Foundation, New Delhi, India.
Graeub, B.E., Chappell, M.J., Wittman, H., Ledermann, S., Kerr, R.B., Gemmill-Herren, B., 2016. The State of Family Farms in the World. World Dev. 87, 1–15. https://doi.org/10.1016/j.worlddev.2015.05.012
Grau, H., Aide, M., 2008. Globalization and Land-Use Transitions in Latin America. Ecol. Soc. 13. https://doi.org/10.5751/ES-02559-130216
Grau, H.R., Gasparri, N.I., Aide, T.M., 2008. Balancing food production and nature conservation in the Neotropical dry forests of northern Argentina. Glob. Change Biol. 14, 985–997. https://doi.org/10.1111/j.1365-2486.2008.01554.x
Grau, R., Kuemmerle, T., Macchi, L., 2013. Beyond 'land sparing versus land sharing': environmental heterogeneity, globalization and the balance between agricultural production and nature conservation. Curr. Opin. Environ. Sustain., Human settlements and industrial systems 5, 477–483. https://doi.org/10.1016/j.cosust.2013.06.001
Gray, D.E., 2009. Doing Research in the Real World. SAGE.
Green, R.E., Cornell, S.J., Scharlemann, J.P.W., Balmford, A., 2005. Farming and the Fate of Wild Nature. Science 307, 550–555. https://doi.org/10.1126/science.1106049
Greenberg, R., Bichier, P., Sterling, J., 1997. Bird Populations in Rustic and Planted Shade Coffee Plantations of Eastern Chiapas, México. Biotropica 29, 501–514. https://doi.org/10.1111/j.1744-7429.1997.tb00044.x
Gregory, P.J., Ingram, J.S.I., Brklacich, M., 2005. Climate change and food security. Philos. Trans. R. Soc. Lond. B Biol. Sci. 360, 2139–2148. https://doi.org/10.1098/rstb.2005.1745
Greiner, R., 2015. Motivations and attitudes influence farmers' willingness to participate in biodiversity conservation contracts. Agric. Syst. 137, 154–165. https://doi.org/10.1016/j.agsy.2015.04.005
Greiner, R., Gregg, D., 2011. Farmers' intrinsic motivations, barriers to the adoption of conservation practices and effectiveness of policy instruments: Empirical evidence from northern Australia. Land Use Policy 28, 257–265. https://doi.org/10.1016/j.landusepol.2010.06.006
Grimble, R., Wellard, K., 1997. Stakeholder methodologies in natural resource management: a review of principles, contexts, experiences and opportunities. Agric. Syst., Socio-

economic Methods in Renewable Natural Resources Research 55, 173–193. https://doi.org/10.1016/S0308-521X(97)00006-1
Grimm, V., Berger, U., DeAngelis, D.L., Polhill, J.G., Giske, J., Railsback, S.F., 2010. The ODD protocol: A review and first update. Ecol. Model. 221, 2760–2768. https://doi.org/10.1016/j.ecolmodel.2010.08.019
Groeneveld, J., Müller, B., Buchmann, C.M., Dressler, G., Guo, C., Hase, N., Hoffmann, F., John, F., Klassert, C., Lauf, T., Liebelt, V., Nolzen, H., Pannicke, N., Schulze, J., Weise, H., Schwarz, N., 2017. Theoretical foundations of human decision-making in agent-based land use models – A review. Environ. Model. Softw. 87, 39–48. https://doi.org/10.1016/j.envsoft.2016.10.008
Groombridge, B., Jenkins, M.D., 2002. World Atlas of Biodiversity: earth's living resources in the 21st century. Prepared by UNEP Worl Conservation Monitoring Centre. University of California Press, Berkley, USA.
Groot, A., Maarleveld, M., 2000. Demystifying Facilitation in Participatory Development. International Institute for Environment and Development.
Gundersen, C., Gruber, J., 2001. The dynamic determinants of food insufficiency, in: Second Food Security Measurement and Research Conference. Food Assistance and Nutrition Research Report, pp. 11–2.
Guo, B., 2011. Household Assets and Food Security: Evidence from the Survey of Program Dynamics. J. Fam. Econ. Issues 32, 98–110. https://doi.org/10.1007/s10834-010-9194-3
Gutiérrez-Vélez, V.H., DeFries, R., Pinedo-Vásquez, M., Uriarte, M., Padoch, C., Walter Baethgen, Fernandes, K., Lim, Y., 2011. High-yield oil palm expansion spares land at the expense of forests in the Peruvian Amazon. Environ. Res. Lett. 6, 044029. https://doi.org/10.1088/1748-9326/6/4/044029
Hallsworth, E., 1982. The effects of government policy in forest management in the Himalayan & Slwalik region of Uttar Pradesh, India, in: Socio-Economlc Effects and Constraints in Tropical Forest Management. Wiley-Blackwell, pp. 65–72.
Hammond, R.A., 2015. Considerations and Best Practices in Agent-Based Modeling to Inform Policy. National Academies Press (US).
Hannah, L., Midgley, G., Andelman, S., Araújo, M., Hughes, G., Martinez-Meyer, E., Pearson, R., Williams, P., 2007. Protected area needs in a changing climate. Front. Ecol. Environ. 5, 131–138. https://doi.org/10.1890/1540-9295(2007)5[131:PANIAC]2.0.CO;2
Happe, K., Kellermann, K., Balmann, A., 2006. Agent-based Analysis of Agricultural Policies: an Illustration of the Agricultural Policy Simulator AgriPoliS, its Adaptation and Behavior. Ecol. Soc. 11. https://doi.org/10.5751/ES-01741-110149
Hasanah, A., Mendolia, S., Yerokhin, O., 2017. Labour Migration, Food Expenditure, and Household Food Security in Eastern Indonesia. Econ. Rec. 93, 122–143. https://doi.org/10.1111/1475-4932.12344
Hayes, T.M., 2012. Payment for ecosystem services, sustained behavioural change, and adaptive management: peasant perspectives in the Colombian Andes. Environ. Conserv. 39, 144–153. https://doi.org/10.1017/S0376892912000045
Hecht, S.B., 2014. Forests lost and found in tropical Latin America: the woodland 'green revolution.' J. Peasant Stud. 41, 877–909. https://doi.org/10.1080/03066150.2014.917371
Heidemann, F., 2006. Akka Bakka: Religion, Politik und duale Souveränität der Badaga in den Nilgiri Süd-Indiens. Lit, Berlin; Münster.
Henderson, I.G., Holland, J.M., Storkey, J., Lutman, P., Orson, J., Simper, J., 2012. Effects of the proportion and spatial arrangement of un-cropped land on breeding bird abundance

in arable rotations. J. Appl. Ecol. 49, 883–891. https://doi.org/10.1111/j.1365-2664.2012.02166.x
Hendriks, S.L., 2005. The challenges facing empirical estimation of household food (in)security in South Africa. Dev. South. Afr. 22, 103–123. https://doi.org/10.1080/03768350500044651
Hertel, T.W., Ramankutty, N., Baldos, U.L.C., 2014. Global market integration increases likelihood that a future African Green Revolution could increase crop land use and CO2 emissions. Proc. Natl. Acad. Sci. 111, 13799–13804. https://doi.org/10.1073/pnas.1403543111
Hockings, P., 2012. Encyclopaedia of the Nilgiri Hills. Manohar Publishers and Distributors, New Delhi, India.
Hockings, P., 1989. Blue Mountains-the Ethnography and Biogeography of a South Indian Region. Oxford University Press, New Delhi, India.
Hoddinott, J.F., Yohannes, Y., 2002. Dietary diversity as a food security indicator. FCND Discussion Paper No. 136
Hodgson, J.A., Kunin, W.E., Thomas, C.D., Benton, T.G., Gabriel, D., 2010. Comparing organic farming and land sparing: optimizing yield and butterfly populations at a landscape scale. Ecol. Lett. 13, 1358–1367. https://doi.org/10.1111/j.1461-0248.2010.01528.x
Homan, R.N., Windmiller, B.S., Reed, J.M., 2004. Critical Thresholds Associated with Habitat Loss for Two Vernal Pool-Breeding Amphibians. Ecol. Appl. 14, 1547–1553. https://doi.org/10.1890/03-5125
Horticulture Department, 2015. Archive documents obtained during interview: Area and production of crops 2011-2012.
Hosonuma, N., Herold, M., Sy, V.D., Fries, R.S.D., Brockhaus, M., Verchot, L., Arild Angelsen, Romijn, E., 2012. An assessment of deforestation and forest degradation drivers in developing countries. Environ. Res. Lett. 7, 044009. https://doi.org/10.1088/1748-9326/7/4/044009
Hulme, M.F., Vickery, J.A., Green, R.E., Phalan, B., Chamberlain, D.E., Pomeroy, D.E., Nalwanga, D., Mushabe, D., Katebaka, R., Bolwig, S., Atkinson, P.W., 2013. Conserving the Birds of Uganda's Banana-Coffee Arc: Land Sparing and Land Sharing Compared. PLoS ONE 8, e54597. https://doi.org/10.1371/journal.pone.0054597
Hydén, L.-C., Bülow, P.H., 2003. Who's talking: drawing conclusions from focus groups—some methodological considerations. Int. J. Soc. Res. Methodol. 6, 305–321. https://doi.org/10.1080/13645570210124865
IFAD-UNEP, 2013. Smallholders, Food Security and the Environment. Rome.
IFP, 2017. IDF diabetes atlas - Contry Profile, India. International Diabetes Federation.
IIPS, 2006. India National Family Health Survey. Int. Inst. Popul. Sci.
IMF, 2017. World Economic Outlook - Real GDP growth. Country profile India. International Monetary Fund.
Isaac, M., Erickson, B., Quashie-Sam, S., Timmer, V., 2007. Transfer of Knowledge on Agroforestry Management Practices: the Structure of Farmer Advice Networks. Ecol. Soc. 12. https://doi.org/10.5751/ES-02196-120232
Jackson, L., Bawa, K., Pascual, U., Perrings, C., 2005. Agrobiodiversity: A New Science Agenda for Biodiversity in Support of Sustainable Agroecosystems. Divers. Rep. No 4 40 Pp Paris.
Jadin, I., Meyfroidt, P., Lambin, E.F., 2016. International trade, and land use intensification and spatial reorganization explain Costa Rica's forest transition. Environ. Res. Lett. 11, 035005. https://doi.org/10.1088/1748-9326/11/3/035005

Janssen, M.A., Ostrom, E., 2006. Chapter 30 Governing Social-Ecological Systems, in: Judd, L.T. and K.L. (Ed.), Handbook of Computational Economics. Elsevier, pp. 1465–1509. https://doi.org/10.1016/S1574-0021(05)02030-7
Jaquet, S., Shrestha, G., Kohler, T., Schwilch, G., 2016. The Effects of Migration on Livelihoods, Land Management, and Vulnerability to Natural Disasters in the Harpan Watershed in Western Nepal. Mt. Res. Dev. 36, 494–505. https://doi.org/10.1659/MRD-JOURNAL-D-16-00034.1
Jenkins, C.N., Pimm, S.L., Joppa, L.N., 2013. Global patterns of terrestrial vertebrate diversity and conservation. Proc. Natl. Acad. Sci. 110, E2602–E2610. https://doi.org/10.1073/pnas.1302251110
Jepma, C.J., 2014. Tropical Deforestation: A Socio-economic Approach. Routledge.
Jóhannesdóttir, L., Alves, J., Gill, J., Gunnarsson, T., 2017. Reconciling biodiversity conservation and agricultural expansion in the subarctic environment of Iceland. Ecol. Soc. 22. https://doi.org/10.5751/ES-08956-220116
Johansson, Ö., Rauset, G.R., Samelius, G., McCarthy, T., Andrén, H., Tumursukh, L., Mishra, C., 2016. Land sharing is essential for snow leopard conservation. Biol. Conserv. 203, 1–7. https://doi.org/10.1016/j.biocon.2016.08.034
Johnson, K.A., Polasky, S., Nelson, E., Pennington, D., 2012. Uncertainty in ecosystem services valuation and implications for assessing land use tradeoffs: An agricultural case study in the Minnesota River Basin. Ecol. Econ. 79, 71–79. https://doi.org/10.1016/j.ecolecon.2012.04.020
Jolibert, C., Wesselink, A., 2012. Research impacts and impact on research in biodiversity conservation: The influence of stakeholder engagement. Environ. Sci. Policy 22, 100–111. https://doi.org/10.1016/j.envsci.2012.06.012
Jones, A.D., Ngure, F.M., Pelto, G., Young, S.L., 2013. What Are We Assessing When We Measure Food Security? A Compendium and Review of Current Metrics. Adv. Nutr. Int. Rev. J. 4, 481–505. https://doi.org/10.3945/an.113.004119
Jones, L., Ludi, E., Beautement, P., Broenner, C., Bachofen, C., 2013. New approaches to promoting Flexible and Forward-looking Decision Making: insights from complexity science, climate change adaptation and 'serious gaming.' Africa Climate Change Resilience Alliance.
Kaimowitz, D., Angelsen, A., 1998. Economic models of tropical deforestation: a review. CIFOR, Bogor, Indonesia. https://doi.org/10.17528/cifor/000341
Kakuru, O.V., Doreen, M., Wilson, M., 2014. Adoption of On-Farm Tree Planting in Kibaale District, Western Uganda. J. Sustain. For. 33, 87–98. https://doi.org/10.1080/10549811.2013.776965
Karali, E., Brunner, B., Doherty, R., Hersperger, A., Rounsevell, M., 2014. Identifying the Factors That Influence Farmer Participation in Environmental Management Practices in Switzerland. Hum. Ecol. 42, 951–963. https://doi.org/10.1007/s10745-014-9701-5
Karanth, K.K., DeFries, R., 2010. Conservation and management in human-dominated landscapes: Case studies from India. Biol. Conserv., Conservation and management in human-dominated landscapes: Case studies from India 143, 2865–2869. https://doi.org/10.1016/j.biocon.2010.05.002
Karanth, K.K., Sankararaman, V., Dalvi, S., Srivathsa, A., Parameshwaran, R., Sharma, S., Robbins, P., Chhatre, A., 2016. Producing Diversity: Agroforests Sustain Avian Richness and Abundance in India's Western Ghats. Front. Ecol. Evol. 4. https://doi.org/10.3389/fevo.2016.00111
Kassie, M., Ndiritu, S.W., Stage, J., 2014. What Determines Gender Inequality in Household Food Security in Kenya? Application of Exogenous Switching Treatment Regression. World Dev. 56, 153–171. https://doi.org/10.1016/j.worlddev.2013.10.025

Keenan, D.P., Olson, C., Hersey, J.C., Parmer, S.M., 2001. Measures of food insecurity/security. J. Nutr. Educ. 33 Suppl 1, S49-58.
Kehoe, L., Romero-Muñoz, A., Polaina, E., Estes, L., Kreft, H., Kuemmerle, T., 2017. Biodiversity at risk under future cropland expansion and intensification. Nat. Ecol. Evol. 1, 1129. https://doi.org/10.1038/s41559-017-0234-3
Kennedy, G., Ballard, T., Dop, M.C., 2013. Guidelines for measuring household and individual dietary diversity. (pp. 60): Food and Agriculture Organization of the United Nations and European Union.
Kennedy, W.G., 2012. Modelling Human Behaviour in Agent-Based Models, in: Agent-Based Models of Geographical Systems. Springer, Dordrecht, pp. 167–179. https://doi.org/10.1007/978-90-481-8927-4_9
Keystone Foundation, 2007. Honey Trails in the Blue Mountains. Coonoor Printing Press, The Nilgiris, Tamil Nadu, India.
Khan, Z., Midega, C., Pittchar, J., Pickett, J., Bruce, T., 2011. Push—pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa. Int. J. Agric. Sustain. 9, 162–170. https://doi.org/10.3763/ijas.2010.0558
Khera, R., 2011. India's Public Distribution System: Utilisation and Impact. J. Dev. Stud. 47, 1038–1060. https://doi.org/10.1080/00220388.2010.506917
Kleijn, D., Sutherland, W.J., 2003. How effective are European agri-environment schemes in conserving and promoting biodiversity? J. Appl. Ecol. 40, 947–969. https://doi.org/10.1111/j.1365-2664.2003.00868.x
Kok, K., Biggs, R. (Oonsie), Zurek, M., 2007. Methods for Developing Multiscale Participatory Scenarios: Insights from Southern Africa and Europe. Ecol. Soc. 12. https://doi.org/10.5751/ES-01971-120108
Koning, A.A., Moore, J., Suttidate, N., Hannigan, R., McIntyre, P.B., 2017. Aquatic Ecosystem Impacts of Land Sharing Versus Sparing: Nutrient Loading to Southeast Asian Rivers. Ecosystems 20, 393–405. https://doi.org/10.1007/s10021-016-0032-9
Korfmacher, K.S., 2001. The politics of participation in watershed modeling. Environ. Manage. 27, 161–176.
Kremen, C., 2015. Reframing the land-sparing/land-sharing debate for biodiversity conservation. Ann. N. Y. Acad. Sci. 1355, 52–76. https://doi.org/10.1111/nyas.12845
Kremen, C., Miles, A., 2012. Ecosystem Services in Biologically Diversified versus Conventional Farming Systems: Benefits, Externalities, and Trade-Offs. Ecol. Soc. 17. https://doi.org/10.5751/ES-05035-170440
Kumar, B.M., 2007. Agroforestry: the new old paradigm for Asian food security. J. Trop. Agric. 44, 1–14.
Kumar, M.A., Mudappa, D., Raman, T.R.S., 2010. Asian Elephant *Elephas Maximus* Habitat Use and Ranging in Fragmented Rainforest and Plantations in the Anamalai Hills, India. Trop. Conserv. Sci. 3, 143–158. https://doi.org/10.1177/194008291000300203
Kumar, M.D., Sivamohan, M.V.K., Narayanamoorthy, A., 2012. The food security challenge of the food-land-water nexus in India. Food Secur. 4, 539–556. https://doi.org/10.1007/s12571-012-0204-1
Kumar, S., 1993. Survey and Mapping of Shola Forests and Grasslands in the Upper Nilgiri Plateau and Assessment of Human Utilization of the Vegetation. World Wide Fund for Nature- India.
Kumar, S.V., Bhagavanulu, D.V.S., 2008. Effect of deforestation on landslides in Nilgiris district — A case study. J. Indian Soc. Remote Sens. 36, 105. https://doi.org/10.1007/s12524-008-0011-5
Kumari, S., 2015. Status of Nilgiri Biosphere in 2015. Int. J. Ecosyst. 5, 91–98.

Kummer, D.M., Turner, B.L., 1994. The Human Causes of Deforestation in Southeast Asia. BioScience 44, 323–328. https://doi.org/10.2307/1312382
Kusters, K., Achdiawan, R., Belcher, B., Ruiz Pérez, M., 2006. Balancing Development and Conservation? An Assessment of Livelihood and Environmental Outcomes of Nontimber Forest Product Trade in Asia, Africa, and Latin America. Ecol. Soc. 11, 20.
Lakshumanan, C., Pradeep Kishore, V., Viveganandan, S., Krishnakumar, P., Muthusankar, G., 2012. Landuse / Land cover dynamics study in Nilgiris district part of Western Ghats, Tamilnadu. Int. J. Geomat. Geosci. 2.
Lambin, E.F., Meyfroidt, P., 2011. Global land use change, economic globalization, and the looming land scarcity. Proc. Natl. Acad. Sci. 108, 3465–3472. https://doi.org/10.1073/pnas.1100480108
https://doi.org/10.1073/pnas.1100480108
Lambin, E.F., Meyfroidt, P., 2010. Land use transitions: Socio-ecological feedback versus socio-economic change. Land Use Policy, Forest transitions 27, 108–118. https://doi.org/10.1016/j.landusepol.2009.09.003
Lamers, M., Ottow, B., Francois, G., von Korff, Y., 2010. Beyond Dry Feet? Experiences from a Participatory Water-Management Planning Case in The Netherlands. Ecol. Soc. 15. https://doi.org/10.5751/ES-03204-150114
Läpple, D., Van Rensburg, T., 2011. Adoption of organic farming: Are there differences between early and late adoption? [WWW Document]. Ecol. Econ. URL http://orgprints.org/22497/ (accessed 11.1.17).
Lasco, R.D., Delfino, R.J.P., Catacutan, D.C., Simelton, E.S., Wilson, D.M., 2014. Climate risk adaptation by smallholder farmers: the roles of trees and agroforestry. Curr. Opin. Environ. Sustain., Sustainability challenges 6, 83–88. https://doi.org/10.1016/j.cosust.2013.11.013
Laurance, W.F., Sayer, J., Cassman, K.G., 2014. Agricultural expansion and its impacts on tropical nature. Trends Ecol. Evol. 29, 107–116. https://doi.org/10.1016/j.tree.2013.12.001
Law, E.A., Bryan, B.A., Meijaard, E., Mallawaarachchi, T., Struebig, M.J., Watts, M.E., Wilson, K.A., 2017. Mixed policies give more options in multifunctional tropical forest landscapes. J. Appl. Ecol. 54, 51–60. https://doi.org/10.1111/1365-2664.12666
Law, E.A., Wilson, K.A., 2015. Providing Context for the Land-Sharing and Land-Sparing Debate. Conserv. Lett. 8, 404–413. https://doi.org/10.1111/conl.12168
Le Page, C., Becu, N., Bommel, P., Bousquet, F., 2010. Participatory Agent-Based Simulation for Renewable Resource Management: The Role of the Cormas Simulation Platform to Nurture a Community of Practice. J. Artif. Soc. Soc. Simul. 15, 10.
Le, Q.B., 2005. Multi-agent system for simulation of land-use and land-cover change: a theoretical framework and its first implementation for an upland watershed in the Central Coast of Vietnam. Ecol. Dev. Ser. Ed. Paul G Vlek Manfred Denich Christopher Martius Charles Rodgers Nick Van Giesen 29.
Le, Q.B., Park, S.J., Vlek, P.L.G., 2010. Land Use Dynamic Simulator (LUDAS): A multi-agent system model for simulating spatio-temporal dynamics of coupled human–landscape system: 2. Scenario-based application for impact assessment of land-use policies. Ecol. Inform. 5, 203–221. https://doi.org/10.1016/j.ecoinf.2010.02.001
Lee, D.R., Barrett, C.B., 2001. Tradeoffs or Synergies? Agricultural Intensification, Economic Development and the Environment. CABI Publishing, New York.
Lee, J.S.H., Garcia-Ulloa, J., Ghazoul, J., Obidzinski, K., Koh, L.P., 2014. Modelling environmental and socio-economic trade-offs associated with land-sparing and land-

sharing approaches to oil palm expansion. J. Appl. Ecol. n/a-n/a. https://doi.org/10.1111/1365-2664.12286
Levins, R., 1966. The strategy of model building in population biology. Am. Sci. 54.
Limon, G., Fournié, G., Lewis, E.G., Dominguez-Salas, P., Leyton-Michovich, D., Gonzales-Gustavson, E.A., Gonzalez, A.E., Cabezas, A.H., Pinto, J., Rushton, J., Guitian, J., 2017. Using mixed methods to assess food security and coping strategies: a case study among smallholders in the Andean region. Food Secur. 9, 1019–1040. https://doi.org/10.1007/s12571-017-0713-z
Litosseliti, L., 2003. Using Focus Groups in Research. A&C Black.
Loopstra, R., Tarasuk, V., 2013. Severity of Household Food Insecurity Is Sensitive to Change in Household Income and Employment Status among Low-Income Families. J. Nutr. 143, 1316–1323. https://doi.org/10.3945/jn.113.175414
Loos, J., Abson, D.J., Dorresteijn, I., Fischer, J., 2016. Sustainable Landscapes in Central Romania: A social-ecological study on the future of Southern Transylvania. Pensoft.
Lund, J.F., Shackleton, S., Luckert, M., 2011. Getting Quality Data., in: Measuring Livelihoods and Environmental Dependence: Methods for Research and Fieldwork. Earthscan Publications, Oxford, U.K.
Macal, C.M., 2016. Everything you need to know about agent-based modelling and simulation. J. Simul. 10, 144–156. https://doi.org/10.1057/jos.2016.7
Macchi, L., Grau, H.R., Phalan, B., 2016. Agricultural production and bird conservation in complex landscapes of the dry Chaco. J. Land Use Sci. 11, 188–202. https://doi.org/10.1080/1747423X.2015.1057244
Macdonald, D., Loveridge, A. (Eds.), 2010. The Biology and Conservation of Wild Felids. Oxford University Press, Oxford, New York.
Mace, G.M., Norris, K., Fitter, A.H., 2012. Biodiversity and ecosystem services: a multilayered relationship. Trends Ecol. Evol. 27, 19–26. https://doi.org/10.1016/j.tree.2011.08.006
Machina, M.J. (Ed.), 2008. Expected utility hypothesis. In: Durlauf, S.N.B., L.E. (Eds.), The New Palgrave Dictionary of Economics, 2 ed. Palgrave Macmillan. Nature Publishing Group, Basingstoke, pp. 130–138. https://doi.org/10.1057/9780230226203.0526
Mahood, S.P., Lees, A.C., Peres, C.A., 2012. Amazonian countryside habitats provide limited avian conservation value. Biodivers. Conserv. 21, 385–405. https://doi.org/10.1007/s10531-011-0188-8
Mamtha, R., Jasmine niketha, M., Geetha, P., 2016. Analysis of Deforestation and Land Use Changes in Kotagiri Taluk of Nilgiris District. Indian J. Sci. Technol. 9. https://doi.org/10.17485/ijst/2016/v9i44/105326
Mango, N., Zamasiya, B., Makate, C., Nyikahadzoi, K., Siziba, S., 2014. Factors influencing household food security among smallholder farmers in the Mudzi district of Zimbabwe. Dev. South. Afr. 31, 625–640. https://doi.org/10.1080/0376835X.2014.911694
Manner, M., Gowdy, J., 2010. The evolution of social and moral behavior: Evolutionary insights for public policy. Ecol. Econ., Special Section: Coevolutionary Ecological Economics: Theory and Applications 69, 753–761. https://doi.org/10.1016/j.ecolecon.2008.04.021
Martin, A., 2017. Just Conservation: Biodiversity, Wellbeing and Sustainability (Paperback) - Routledge. Routledge.
Martin, A., Sherington, J., 1997. Participatory research methods—Implementation, effectiveness and institutional context. Agric. Syst., Socio-economic Methods in Renewable Natural Resources Research 55, 195–216. https://doi.org/10.1016/S0308-521X(97)00007-3

Maskell, L.C., Crowe, A., Dunbar, M.J., Emmett, B., Henrys, P., Keith, A.M., Norton, L.R., Scholefield, P., Clark, D.B., Simpson, I.C., Smart, S.M., 2013. Exploring the ecological constraints to multiple ecosystem service delivery and biodiversity. J. Appl. Ecol. 50, 561–571. https://doi.org/10.1111/1365-2664.12085

Mather, A.S., 2007. Recent Asian Forest Transitions in Relation to Forest-Transition Theory. Int. For. Rev. 9, 491–502. https://doi.org/10.1505/ifor.9.1.491

Matson, P.A., Vitousek, P.M., 2006. Agricultural Intensification: Will Land Spared from Farming be Land Spared for Nature? Conserv. Biol. 20, 709–710. https://doi.org/10.1111/j.1523-1739.2006.00442.x

Matthews, R., 2006. The People and Landscape Model (PALM): Towards full integration of human decision-making and biophysical simulation models. Ecol. Model. 194, 329–343. https://doi.org/10.1016/j.ecolmodel.2005.10.032

Matthews, R.B., Gilbert, N.G., Roach, A., Polhill, J.G., Gotts, N.M., 2007. Agent-based land-use models: a review of applications. Landsc. Ecol. 22, 1447–1459. https://doi.org/10.1007/s10980-007-9135-1

Mayer, I.S., 2009. The Gaming of Policy and the Politics of Gaming: A Review. Simul. Gaming 40, 825–862. https://doi.org/10.1177/1046878109346456

McLaughlin, D.W., 2011. Land, Food, and Biodiversity. Conserv. Biol. 25, 1117–1120. https://doi.org/10.1111/j.1523-1739.2011.01768.x

MEA, 2005. Ecosystems and Human Well-being: Synthesis. Millennium Ecosystem Assessment. Island Press, Washington, DC.

Mekoya, A., Oosting, S.J., Fernandez-Rivera, S., Zijpp, A.J.V. der, 2008. Farmers' perceptions about exotic multipurpose fodder trees and constraints to their adoption. Agrofor. Syst. 73, 141–153. https://doi.org/10.1007/s10457-007-9102-5

Mendenhall, C.D., Karp, D.S., Meyer, C.F.J., Hadly, E.A., Daily, G.C., 2014. Predicting biodiversity change and averting collapse in agricultural landscapes. Nature 509, 213–217. https://doi.org/10.1038/nature13139

Menon, S., Bawa, K.S., 1997. Applications of geographic information systems, remote-sensing, and a landscape ecology approach to biodiversity conservation in the Western Ghats. Curr. Sci. 73, 134–145.

Merckx, T., Feber, R.E., Riordan, P., Townsend, M.C., Bourn, N.A.D., Parsons, M.S., Macdonald, D.W., 2009. Optimizing the biodiversity gain from agri-environment schemes. Agric. Ecosyst. Environ. 130, 177–182. https://doi.org/10.1016/j.agee.2009.01.006

Mertz, O., Bruun, T.B., 2017. Shifting cultivation policies in Southeast Asia. A need to work with, rather than against, smallholder farmers. Shifting Cultiv. Policies Balanc. Environ. Soc. Sustain. 81–96.

Mertz, O., Mertens, C.F., 2017. Land Sparing and Land Sharing Policies in Developing Countries – Drivers and Linkages to Scientific Debates. World Dev. 98, 523–535. https://doi.org/10.1016/j.worlddev.2017.05.002

Meyfroidt, P., Carlson, K.M., Fagan, M.E., Gutiérrez-Vélez, V.H., Macedo, M.N., Curran, L.M., DeFries, R.S., Dyer, G.A., Gibbs, H.K., Lambin, E.F., Morton, D.C., Robiglio, V., 2014. Multiple pathways of commodity crop expansion in tropical forest landscapes. Environ. Res. Lett. 9, 074012. https://doi.org/10.1088/1748-9326/9/7/074012

Meylan, L., Gary, C., Allinne, C., Ortiz, J., Jackson, L., Rapidel, B., 2017. Evaluating the effect of shade trees on provision of ecosystem services in intensively managed coffee plantations. Agric. Ecosyst. Environ. 245, 32–42. https://doi.org/10.1016/j.agee.2017.05.005

Milner-Gulland, E.J., 2012. Interactions between human behaviour and ecological systems. Phil Trans R Soc B 367, 270–278. https://doi.org/10.1098/rstb.2011.0175
Ministry of Environment and Forest, 2015. The Nilgiris Biosphere Reserve [WWW Document]. URL http://www.cpreec.org/pubbook-nilgiris.htm (accessed 11.22.17).
Ministry of Environment and Forests, 2013. Report of the High Level Working Group on Western Ghats. Kasturirangan comission. Government of India.
Ministry of Environment and Forests, 2011. Report of the Western Ghats Ecology Expert Panel. Madhav Gadgil Commission. Government of India.
Mitchell, M.G.E., Bennett, E.M., Gonzalez, A., 2014. Forest fragments modulate the provision of multiple ecosystem services. J. Appl. Ecol. 51, 909–918. https://doi.org/10.1111/1365-2664.12241
Mockshell, J., Kamanda, J., 2017. Beyond the Agroecological and Sustainable Agricultural Intensification Debate: Is Blended Sustainability the Way Forward? Deutsches Institut für Entwicklungspolitik, Bonn.
MoEF, 1988. National Forest Policy. Ministry of Environment, Forests and Climate Change.
Mohandass, D., Davidar, P., 2010. The relationship between area, and vegetation structure and diversity in montane forest (shola) patches in southern India. Plant Ecol. Divers. 3, 67–76. https://doi.org/10.1080/17550874.2010.492843
Montoya-Molina, S., Giraldo-Echeverri, C., Montoya-Lerma, J., Chará, J., Escobar, F., Calle, Z., 2016. Land sharing vs. land sparing in the dry Caribbean lowlands: A dung beetles' perspective. Appl. Soil Ecol. 98, 204–212. https://doi.org/10.1016/j.apsoil.2015.10.017
Moreno, N., Quintero, R., Ablan, M., Barros, R., Dávila, J., Ramírez, H., Tonella, G., Acevedo, M.F., 2007. Biocomplexity of deforestation in the Caparo tropical forest reserve in Venezuela: An integrated multi-agent and cellular automata model. Environ. Model. Softw., The Implications of Complexity for Integrated Resources 22, 664–673. https://doi.org/10.1016/j.envsoft.2005.12.022
Müller, B., Bohn, F., Dreßler, G., Groeneveld, J., Klassert, C., Martin, R., Schlüter, M., Schulze, J., Weise, H., Schwarz, N., 2013. Describing human decisions in agent-based models – ODD + D, an extension of the ODD protocol. Environ. Model. Softw. 48, 37–48. https://doi.org/10.1016/j.envsoft.2013.06.003
Murthy, I.K., Dutta, S., Varghese, V., Joshi, P., Kumar, P., 2016. Impact of Agroforestry Systems on Ecological and Socio- Economic Systems: A Review. Glob. J. Sci. Front. Res. 11.
Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858. https://doi.org/10.1038/35002501
Myers, S.S., Smith, M.R., Guth, S., Golden, C.D., Vaitla, B., Mueller, N.D., Dangour, A.D., Huybers, P., 2017. Climate Change and Global Food Systems: Potential Impacts on Food Security and Undernutrition. Annu. Rev. Public Health 38, 259–277. https://doi.org/10.1146/annurev-publhealth-031816-044356
Nagendra, H., 2008. Do Parks Work? Impact of Protected Areas on Land Cover Clearing. AMBIO J. Hum. Environ. 37, 330–337. https://doi.org/10.1579/06-R-184.1
Naivinit, W., Le Page, C., Trébuil, G., Gajaseni, N., 2010. Participatory agent-based modeling and simulation of rice production and labor migrations in Northeast Thailand. Environ. Model. Softw., Thematic Issue - Modelling with Stakeholders 25, 1345–1358. https://doi.org/10.1016/j.envsoft.2010.01.012
Nalina, P., Meenambal, T., Sridhar, R.S., Nalina, P., Meenambal, T., Sridhar, R.S., 2014. Land Use Land Cover Dynamics of Nilgiris District, India Inferred From Satellite Imageries. Am. J. Appl. Sci. 11, 455–461. https://doi.org/10.3844/ajassp.2014.455.461

Narayanamoorthy, A., 2006. State of India's Farmers. Econ. Polit. Wkly. 41, 471–473.
Nath, C.D., Pélissier, R., Ramesh, B.R., Garcia, C., 2011. Promoting native trees in shade coffee plantations of southern India: comparison of growth rates with the exotic *Grevillea robusta*. Agrofor. Syst. 83, 107–119. https://doi.org/10.1007/s10457-011-9401-8
National Audubon Society, 2011. Tools of Engagement: A Toolkit for Engaging People in Conservation. National Audubon Society. U.S. Fish and Wildlife Service; Environmental Education and Training Partnership; TogetherGreen.
National Informatics Centre, 2011. Agricultural Census. State T1 Size Class/Size Group Table3. 2010-2011 [WWW Document]. URL http://agcensus.dacnet.nic.in/SL/StateT1sizetable4.aspx (accessed 11.28.17).
Nayar, T.S., Beegam, A.R., Sibi, M., 2014. Flowering Plants of the Western Ghats, India. Bot. J. Linn. Soc. 179, 756–757. https://doi.org/10.1111/boj.12356
Nesper, M., Kueffer, C., Krishnan, S., Kushalappa, C.G., Ghazoul, J., 2017. Shade tree diversity enhances coffee production and quality in agroforestry systems in the Western Ghats. Agric. Ecosyst. Environ. 247, 172–181. https://doi.org/10.1016/j.agee.2017.06.024
Nguyen, T.G., de Kok, J.L., 2007. Systematic testing of an integrated systems model for coastal zone management using sensitivity and uncertainty analyses. Environ. Model. Softw. 22, 1572–1587. https://doi.org/10.1016/j.envsoft.2006.08.008
Nolan, J., Parker, D., Van Kooten, G.C., Berger, T., 2009. An Overview of Computational Modeling in Agricultural and Resource Economics. Can. J. Agric. Econ. Can. Agroeconomie 57, 417–429. https://doi.org/10.1111/j.1744-7976.2009.01163.x
Noltze, M., Stefan, S., Matin, Q., 2013. Impacts of Natural Resource Management Technologies on Agricultural Yield and Household Income: The System of Rice Intensification in Timor Leste. Ecol. Econ. 59–68. https://doi.org/10.1016/j.ecolecon.2012.10.009.
Norris, K., 2008. Agriculture and biodiversity conservation: opportunity knocks. Conserv. Lett. 1, 2–11. https://doi.org/10.1111/j.1755-263X.2008.00007.x
Odenbaugh, J., 2003. Complex Systems, Trade-Offs, and Theoretical Population Biology: Richard Levin's "Strategy of Model Building in Population Biology" Revisited. Philos. Sci. 70, 1496–1507. https://doi.org/10.1086/377425
OGC, 2007. Managing Successful Programmes PDF: 2nd impression. Office of Government Commerce, TSO.
Olsson, P., Folke, C., Berkes, F., 2004. Adaptive Comanagement for Building Resilience in Social–Ecological Systems. Environ. Manage. 34, 75–90. https://doi.org/10.1007/s00267-003-0101-7
Omer, A., Pascual, U., Russell, N.P., 2007. Biodiversity Conservation and Productivity in Intensive Agricultural Systems. J. Agric. Econ. 58, 308–329. https://doi.org/10.1111/j.1477-9552.2007.00091.x
Oreskes, N., 2004. Science and public policy: What's proof got to do with it? Environ. Sci. Policy 7, 369–383. https://doi.org/10.1016/j.envsci.2004.06.002
Owusu, V., Abdulai, A., Abdul-Rahman, S., 2011. Non-farm work and food security among farm households in Northern Ghana. Food Policy 36, 108–118. https://doi.org/10.1016/j.foodpol.2010.09.002
Padoch, C., Pinedo-Vasquez, M., 2010. Saving Slash-and-Burn to Save Biodiversity. Biotropica 42, 550–552. https://doi.org/10.1111/j.1744-7429.2010.00681.x

Pak, V.M., Brieva, C.D., 2010. Designing and implementing a Role-Playing Game: A tool to explain factors, decision making and landscape transformation. Environ. Model. Softw., Thematic Issue - Modelling with Stakeholders 25, 1322–1333. https://doi.org/10.1016/j.envsoft.2010.03.015
Paracchini, M.-L., Petersen, J.-E., Hoogeveen, Y., Bamps, C., Burfield, I., Van Swaay, C., 2008. High Nature Value Farmland in Europe - An Estimate of the Distribution Patterns on the Basis of Land Cover and Biodiversity Data (EUR - Scientific and Technical Research Reports). OPOCE. https://doi.org/10.2788/8891
Parappurathu, S., Kumar, A., Bantilan, M.C.S., Joshi, P.K., 2015. Food consumption patterns and dietary diversity in eastern India: evidence from village level studies (VLS). Food Secur. 7, 1031–1042. https://doi.org/10.1007/s12571-015-0493-2
Parker, A., Tritter, J., 2006. Focus group method and methodology: current practice and recent debate. Int. J. Res. Method Educ. 29, 23–37. https://doi.org/10.1080/01406720500537304
Parker, D.C., Manson, S.M., Janssen, M.A., Hoffmann, M.J., Deadman, P., 2003. Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review. Ann. Assoc. Am. Geogr. 93, 314–337. https://doi.org/10.1111/1467-8306.9302004
Parrotta, J.A., Turnbull, J.W., Jones, N., 1997. Catalyzing native forest regeneration on degraded tropical lands. For. Ecol. Manag. 99, 1–7. https://doi.org/10.1016/S0378-1127(97)00190-4
Patel, R., 2013. The Long Green Revolution. J. Peasant Stud. 40, 1–63. https://doi.org/10.1080/03066150.2012.719224
Patel, R., 2012. Stuffed and Starved: The Hidden Battle for the World Food System - Revised and Updated. Melville House Publishing.
Perfecto, I., Vandermeer, J., 2010. The agroecological matrix as alternative to the land-sparing/agriculture intensification model. Proc. Natl. Acad. Sci. 107, 5786–5791. https://doi.org/10.1073/pnas.0905455107
Perfecto, I., Vandermeer, J., 2008. Biodiversity conservation in tropical agroecosystems: a new conservation paradigm. Ann. N. Y. Acad. Sci. 1134, 173–200. https://doi.org/10.1196/annals.1439.011
Perrings, C., Jackson, L., Bawa, K., Brussaard, L., Brush, S., Gavin, T., Papa, R., Pascual, U., De Ruiter, P., 2006. Biodiversity in Agricultural Landscapes: Saving Natural Capital without Losing Interest. Conserv. Biol. 20, 263–264. https://doi.org/10.1111/j.1523-1739.2006.00390.x
Phalan, B., Balmford, A., Green, R.E., Scharlemann, J.P.W., 2011a. Minimising the harm to biodiversity of producing more food globally. Food Policy, The challenge of global food sustainability 36, S62–S71. https://doi.org/10.1016/j.foodpol.2010.11.008
Phalan, B., Bertzky, M., Butchart, S.H.M., Donald, P.F., Scharlemann, J.P.W., Stattersfield, A.J., Balmford, A., 2013. Crop Expansion and Conservation Priorities in Tropical Countries. PLOS ONE 8, e51759. https://doi.org/10.1371/journal.pone.0051759
Phalan, B., Green, R.E., Dicks, L.V., Dotta, G., Feniuk, C., Lamb, A., Strassburg, B.B.N., Williams, D.R., Ermgassen, E.K.H.J. zu, Balmford, A., 2016. How can higher-yield farming help to spare nature? Science 351, 450–451. https://doi.org/10.1126/science.aad0055
Phalan, B., Onial, M., Balmford, A., Green, R.E., 2011b. Reconciling Food Production and Biodiversity Conservation: Land Sharing and Land Sparing Compared. Science 333, 1289–1291. https://doi.org/10.1126/science.1208742
Phelps, J., Carrasco, L.R., Webb, E.L., Koh, L.P., Pascual, U., 2013. Agricultural intensification escalates future conservation costs. Proc. Natl. Acad. Sci. 110, 7601–7606. https://doi.org/10.1073/pnas.1220070110

Piha, H., Luoto, M., Merilä, J., 2007. Amphibian occurrence is influenced by current and historic landscape characteristics. Ecol. Appl. Publ. Ecol. Soc. Am. 17, 2298–2309.
Polhill, J.G., Gimona, A., Gotts, N.M., 2013. Nonlinearities in biodiversity incentive schemes: A study using an integrated agent-based and metacommunity model. Environ. Model. Softw., Thematic Issue on Spatial Agent-Based Models for Socio-Ecological Systems 45, 74–91. https://doi.org/10.1016/j.envsoft.2012.11.011
Polhill, J.G., Izquierdo, L., Gotts, N., 2008a. FEARLUS 1-1-5 User Guide.
Polhill, J.G., Parker, D., Brown, D., Grimm, V., 2008b. Using the ODD Protocol for Describing Three Agent-Based Social Simulation Models of Land-Use Change. J. Artif. Soc. Soc. Simul. 11.
Polimeni, J.M., 2012. The Jevons Paradox and the Myth of Resource Efficiency Improvements. Earthscan.
Power, A.G., 2010. Ecosystem services and agriculture: tradeoffs and synergies. Philos. Trans. R. Soc. B Biol. Sci. 365, 2959–2971. https://doi.org/10.1098/rstb.2010.0143
Prabhakar, R., 2005. Resource, Use, Culture And Ecological Change: A Case Study Of The Nilgiri Hills Of Southern India [WWW Document]. URL http://etd.ncsi.iisc.ernet.in/handle/2005/143 (accessed 6.26.17).
Prabhat, T., Rakesh, K., Lalit, T., Anand, S., 2017. Agroforestry for Sustainable Rural Livelihood : A Review. Int. J. Pure Appl. Biosci. 5, 299–309.
Prescott, G.W., Edwards, D.P., Foster, W.A., 2015. Retaining biodiversity in intensive farmland: epiphyte removal in oil palm plantations does not affect yield. Ecol. Evol. 5, 1944–1954. https://doi.org/10.1002/ece3.1462
Pretty, J., 2008. Agricultural sustainability: concepts, principles and evidence. Philos. Trans. R. Soc. Lond. B Biol. Sci. 363, 447–465. https://doi.org/10.1098/rstb.2007.2163
Price, O.F., Woinarski, J.C.Z., Robinson, D., 1999. Very large area requirements for frugivorous birds in monsoon rainforests of the Northern Territory, Australia. Biol. Conserv. 91, 169–180. https://doi.org/10.1016/S0006-3207(99)00081-6
Pritchard, B., Neilson, J., 2009. Value Chain struggles:Institutions and Governance in the Plantation Districts of South India. Wiley-Blackwell, Oxford, UK.
Puri, S., Nair, P.K.R., 2004. Agroforestry research for development in India: 25 years of experiences of a national program. Agrofor. Syst. 61–62, 437–452. https://doi.org/10.1023/B:AGFO.0000029014.66729.e0
PwC, 2017. The World in 2050. PricewaterhouseCoopers.
Queiroz, C., Beilin, R., Folke, C., Lindborg, R., 2014. Farmland abandonment: threat or opportunity for biodiversity conservation? A global review. Front. Ecol. Environ. 12, 288–296. https://doi.org/10.1890/120348
Quinn, G., Keough, M., 2002. Experimental design and data analysis biologists | Ecology and conservation. Cambridge University Press.
R Core Team, 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
Radhakrishnan, D., 2016. They join hands to beat labour shortage in tea gardens. The Hindu.
Rahman, S.A., Sunderland, T., Roshetko, J.M., Healey, J.R., 2017. Facilitating smallholder tree farming in fragmented tropical landscapes: Challenges and potentials for sustainable land management. J. Environ. Manage. 198, 110–121. https://doi.org/10.1016/j.jenvman.2017.04.047
Rai, N.D., Bawa, K.S., 2013. Inserting Politics and History in Conservation. Conserv. Biol. 27, 425–428. https://doi.org/10.1111/cobi.12026
Ramachandran, N., 2007. Women and Food Security in South Asia: Current Issues and Emerging Concerns, in: Food Insecurity, Vulnerability and Human Rights Failure,

Studies in Development Economics and Policy. Palgrave Macmillan, London, pp. 219–240. https://doi.org/10.1057/9780230589506_9
Raman, R., 2010. Global Capital and Peripheral Labour: The History and Political Economy of Plantation Workers in India. Routledge Contemporary South Asia, London, New York. https://doi.org/10.2307/23239436
Raman, T.R.S., Mudappa, D., Kapoor, V., 2009. Restoring Rainforest Fragments: Survival of Mixed-Native Species Seedlings under Contrasting Site Conditions in the Western Ghats, India. Restor. Ecol. 17, 137–147. https://doi.org/10.1111/j.1526-100X.2008.00367.x
Ramankutty, N., Rhemtulla, J., 2012. Can intensive farming save nature? Front. Ecol. Environ. 10, 455–455. https://doi.org/10.1890/1540-9295-10.9.455
Ramasamy, S., Balakrishnan, K., Pitchappan, R.M., 1994. Prevalence of sickle cells in Irula, Kurumba, Paniya and Mullukurumba tribes of Nilgiris (Tamil Nadu, India). Indian J. Med. Res. 100, 242–245.
Ramirez, R., 2001. Understanding the approaches for accommodating multiple stakeholders' interests. Int. J. Agric. Resour. Gov. Ecol. 1.
Ranganathan, J., Daniels, R.J.R., Chandran, M.D.S., Ehrlich, P.R., Daily, G.C., 2008. Sustaining biodiversity in ancient tropical countryside. Proc. Natl. Acad. Sci. 105, 17852–17854. https://doi.org/10.1073/pnas.0808874105
Ranganathan, J., Krishnaswamy, J., Anand, M.O., 2010. Landscape-level effects on avifauna within tropical agriculture in the Western Ghats: Insights for management and conservation. Biol. Conserv., Conservation and management in human-dominated landscapes: Case studies from India 143, 2909–2917. https://doi.org/10.1016/j.biocon.2010.04.018
Ranganathan, T., 2014. Farmer's income in India: Evidence from secondary data. Institute of Economic Growth, New Delhi, India.
Rao, N., 2006. Land rights, gender equality and household food security: Exploring the conceptual links in the case of India. Food Policy 31, 180–193. https://doi.org/10.1016/j.foodpol.2005.10.006
Redpath, S.M., Young, J., Evely, A., Adams, W.M., Sutherland, W.J., Whitehouse, A., Amar, A., Lambert, R.A., Linnell, J.D.C., Watt, A., Gutiérrez, R.J., 2013. Understanding and managing conservation conflicts. Trends Ecol. Evol. 28, 100–109. https://doi.org/10.1016/j.tree.2012.08.021
Reed, M.S., 2008. Stakeholder participation for environmental management: A literature review. Biol. Conserv. 141, 2417–2431. https://doi.org/10.1016/j.biocon.2008.07.014
Reed, M.S., Dougill, A.J., Taylor, M.J., 2007. Integrating local and scientific knowledge for adaptation to land degradation: Kalahari rangeland management options. Land Degrad. Dev. 18, 249–268. https://doi.org/10.1002/ldr.777
Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. J. Environ. Manage. 90, 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001
Refsgaard, J.C., van der Sluijs, J.P., Hojberg, A.L., Vanrolleghem, P., 2007. Uncertainty in the environmental modelling process – A framework and guidance [WWW Document]. Environ. Model. Softw. URL http://dspace.library.uu.nl/handle/1874/27087 (accessed 3.17.17).
Rerkasem, K., Lawrence, D., Padoch, C., Schmidt-Vogt, D., Ziegler, A.D., Bruun, T.B., 2009. Consequences of Swidden Transitions for Crop and Fallow Biodiversity in Southeast Asia. Hum. Ecol. 37, 347–360. https://doi.org/10.1007/s10745-009-9250-5

R-help, 2005. AIC in lmer when using PQL [WWW Document]. URL https://stat.ethz.ch/pipermail/r-help/2005-November/083290.html
Richard, A.F., Ratsirarson, J., 2013. Partnership in practice: making conservation work at Bezà Mahafaly, southwest Madagascar. Madag. Conserv. Dev. 8, 12–20. https://doi.org/10.4314/mcd.v8i1.3
Richards, C., Blackstock, K., Carter, C., L. Spash, C., Perspectives, C., 2004. Practical Approaches to Participation. Macauley Land Use Research Institute, Aberdeen.
Ricketts, T.H., 2004. Tropical forest fragments enhance pollinator activity in nearby coffee crops 18, 1262–1271.
Riely, F., Mock, N., Cogill, B., Bailey, L., Kenefick, E., 1999. Food security indicators and framework for use in the monitoring and evaluation of food aid programs. Nutr. Tech. Assist. Proj. FANTA Wash. DC.
Rigg, J., Salamanca, A., Thompson, E.C., 2016. The puzzle of East and Southeast Asia's persistent smallholder. J. Rural Stud. 43, 118–133. https://doi.org/10.1016/j.jrurstud.2015.11.003
Rindfuss, R.R., Entwisle, B., Walsh, S.J., An, L., Badenoch, N., Brown, D.G., Deadman, P., Evans, T.P., Fox, J., Geoghegan, J., Gutmann, M., Kelly, M., Linderman, M., Liu, J., Malanson, G.P., Mena, C.F., Messina, J.P., Moran, E.F., Parker, D.C., Parton, W., Prasartkul, P., Robinson, D.T., Sawangdee, Y., Vanwey, L.K., Verburg, P.H., 2008. Land use change: complexity and comparisons. J. Land Use Sci. 3, 1–10. https://doi.org/10.1080/17474230802047955
Rist, S., Chidambaranathan, M., Escobar, C., Wiesmann, U., Zimmermann, A., 2007. Moving from sustainable management to sustainable governance of natural resources: The role of social learning processes in rural India, Bolivia and Mali. J. Rural Stud. 23, 23–37. https://doi.org/10.1016/j.jrurstud.2006.02.006
Robbins, P., 2015. Coffee, Frogs and Workers: From political ecology to policy for tropical biodiversity.
Robbins, P., Chhatre, A., Karanth, K., 2015. Political Ecology of Commodity Agroforests and Tropical Biodiversity. Conserv. Lett. 8, 77–85. https://doi.org/10.1111/conl.12169
Robinson, D.T., Brown, D.G., Parker, D.C., Schreinemachers, P., Janssen, M.A., Huigen, M., Wittmer, H., Gotts, N., Promburom, P., Irwin, E., Berger, T., Gatzweiler, F., Barnaud, C., 2007. Comparison of empirical methods for building agent-based models in land use science. J. Land Use Sci. 2, 31–55. https://doi.org/10.1080/17474230701201349
Robinson, D.T., Sun, S., Hutchins, M., Riolo, R.L., Brown, D.G., Parker, D.C., Filatova, T., Currie, W.S., Kiger, S., 2013. Effects of land markets and land management on ecosystem function: A framework for modelling exurban land-change. Environ. Model. Softw., Thematic Issue on Spatial Agent-Based Models for Socio-Ecological Systems 45, 129–140. https://doi.org/10.1016/j.envsoft.2012.06.016
Robinson, S., 2014. Simulation. The Practice of Model Development and Use, 2nd ed. Palgrave.
Röckmann, C., Ulrich, C., Dreyer, M., Bell, E., Borodzicz, E., Haapasaari, P., Hauge, K.H., Howell, D., Mäntyniemi, S., Miller, D., Tserpes, G., Pastoors, M., 2012. The added value of participatory modelling in fisheries management – what has been learnt? Mar. Policy 36, 1072–1085. https://doi.org/10.1016/j.marpol.2012.02.027
Rogers, E.M., 2003. Diffusion of Innovations, 5th Edition. Simon and Schuster.
Ruankaew, N., Page, C.L., Dumrongrojwattana, P., Barnaud, C., Gajaseni, N., Paassen, A. van, Trébuil, G., 2010. Companion modelling for integrated renewable resource management: a new collaborative approach to create common values for sustainable development. Int. J. Sustain. Dev. World Ecol. 17, 15–23. https://doi.org/10.1080/13504500903481474

Rudel, T.K., Schneider, L., Uriarte, M., Turner, B.L., DeFries, R., Lawrence, D., Geoghegan, J., Hecht, S., Ickowitz, A., Lambin, E.F., Birkenholtz, T., Baptista, S., Grau, R., 2009. Agricultural intensification and changes in cultivated areas, 1970–2005. Proc. Natl. Acad. Sci. 106, 20675–20680. https://doi.org/10.1073/pnas.0812540106

Rumore, D., Schenk, T., Susskind, L., 2016. Role-play simulations for climate change adaptation education and engagement. Nat. Clim. Change 6, 745. https://doi.org/10.1038/nclimate3084

Ryan, R.L., Erickson, D.L., Young, R.D., 2003. Farmers' Motivations for Adopting Conservation Practices along Riparian Zones in a Mid-western Agricultural Watershed. J. Environ. Plan. Manag. 46, 19–37. https://doi.org/10.1080/713676702

Sabatier, P.A., Focht, W., Lubell, M., Trachtenberg, Z., Vedlitz, A., Matlock, M., 2005. Swimming Upstream: Collaborative Approaches to Watershed Management. MIT Press.

Sahoo, D.C., Muralidharan, P., 2017. Energy budgeting of different land management practices under common vegetable crops in the Nilgiris of South India. Indian J. Soil Conserv. 45, 130–135.

Salles, J.-M., Teillard, F., Tichit, M., Zanella, M., 2017. Land sparing versus land sharing: an economist's perspective. Reg. Environ. Change 17, 1455–1465. https://doi.org/10.1007/s10113-017-1142-4

Salvini, G., Ligtenberg, A., van Paassen, A., Bregt, A.K., Avitabile, V., Herold, M., 2016. REDD+ and climate smart agriculture in landscapes: A case study in Vietnam using companion modelling. J. Environ. Manage. 172, 58–70. https://doi.org/10.1016/j.jenvman.2015.11.060

Sanjith, R., 2004. Tea prices: North–South divergence. Plant. Chron. 24–29.

Savilaakso, S., Koivisto, J., Veteli, T.O., Roininen, H., 2009. Microclimate and tree community linked to differences in lepidopteran larval communities between forest fragments and continuous forest. Divers. Distrib. 15, 356–365. https://doi.org/10.1111/j.1472-4642.2008.00542.x

Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J.-L., Sheil, D., Meijaard, E., Venter, M., Boedhihartono, A.K., Day, M., Garcia, C., Oosten, C. van, Buck, L.E., 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proc. Natl. Acad. Sci. 110, 8349–8356. https://doi.org/10.1073/pnas.1210595110

Scales, B.R., Marsden, S.J., 2008. Biodiversity in small-scale tropical agroforests: a review of species richness and abundance shifts and the factors influencing them. Environ. Conserv. 35, 160–172. https://doi.org/10.1017/S0376892908004840

Scherr, S.J., McNeely, J.A., 2008. Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes. Philos. Trans. R. Soc. B Biol. Sci. 363, 477–494. https://doi.org/10.1098/rstb.2007.2165

Schleicher, J., Peres, C.A., Amano, T., Llactayo, W., Leader-Williams, N., 2017. Conservation performance of different conservation governance regimes in the Peruvian Amazon. Sci. Rep. 7, 11318. https://doi.org/10.1038/s41598-017-10736-w

Schlüter, M., Baeza, A., Dressler, G., Frank, K., Groeneveld, J., Jager, W., Janssen, M.A., McAllister, R.R.J., Müller, B., Orach, K., Schwarz, N., Wijermans, N., 2017. A framework for mapping and comparing behavioural theories in models of social-ecological systems. Ecol. Econ. 131, 21–35. https://doi.org/10.1016/j.ecolecon.2016.08.008

Schmeer, K., 2000. Stakeholder Analysis Guideline. Health Sector Reform Initiative.

Schreinemachers, P., Berger, T., 2011. An agent-based simulation model of humaneenvironment interactions in agricultural systems. Environ. Model. Softw. 26, 845–859.
Schroth, G., da Fonseca, G.A.B., Harvey, C.A., Gascon, C., Vasconcelos, H.L., Izac, A.N., 2004. Agroforestry and Biodiversity Conservation in Tropical Landscapes. Island Press.
Schroth, G., Faria, D., Araujo, M., Bede, L., Bael, S.A.V., Cassano, C.R., Oliveira, L.C., Delabie, J.H.C., 2011. Conservation in tropical landscape mosaics: the case of the cacao landscape of southern Bahia, Brazil. Biodivers. Conserv. 20, 1635–1654. https://doi.org/10.1007/s10531-011-0052-x
Schroth, G., Ruf, F., 2014. Farmer strategies for tree crop diversification in the humid tropics. A review. Agron. Sustain. Dev. 34, 139–154. https://doi.org/10.1007/s13593-013-0175-4
Sengupta, R., Bennett, D.A., Beaulieu, J., Kraft, S.E., 2000. Evaluating the Impact of Policy-induced Land Use Management Practices on Non-point Source Pollution Using a Spatial Decision Support System. Water Int. 25, 437–445. https://doi.org/10.1080/02508060008686851
Sengupta, R., Lant, C., Kraft, S., Beaulieu, J., Peterson, W., Loftus, T., 2005. Modeling Enrollment in the Conservation Reserve Program by Using Agents within Spatial Decision Support Systems: An Example from Southern Illinois. Environ. Plan. B Plan. Des. 32, 821–834. https://doi.org/10.1068/b31193
Serrat, O., 2017. The Sustainable Livelihoods Approach, in: Knowledge Solutions. Springer, Singapore, pp. 21–26. https://doi.org/10.1007/978-981-10-0983-9_5
Settle, W., n.d. Biodiversity and the Ecosystem Approach in Agriculture, Forestry and Fisheries. FAO Plant Protection Service.
Shanavas, H.., Sumesh, K.A., Haris, M.., 2016. Western Ghats - From Ecology To Economics. Educreation Publishing, India.
Sharma, C.K., Barua, P., 2017. Small Tea Plantation and Its Impact on the Rural Landscape of Contemporary Assam. Int. J. Rural Manag. 13, 140–161. https://doi.org/10.1177/0973005217725454
Shiva, V., 2016. Who Really Feeds the World? The Failures of Agribusiness and the Promise of Agroecology. North Atlantic Books.
Shively, G., 2011. Sampling: Who, how and how many?, in: Measuring Livelihoods and Environmental Dependence: Methods for Research and Fieldwork. Earthscan Publications, Oxford, U.K.
Shively, G., Pagiola, S., 2004. Agricultural intensification, local labor markets, and deforestation in the Philippines. Environ. Dev. Econ. 9, 241–266. https://doi.org/10.1017/S1355770X03001177
Simmons, E., Saundry, P., 2012. Food Security, in: Encyclopedia of Earth. Cleveland C.J. Environmental Information Coalition, National Council for Science and the Environment, Washington, DC.
Simon, H.A., 1956. Rational choice and the structure of the environment. Psychol. Rev. 63, 129–138. http://dx.doi.org/10.1037/h0042769
Singh, A.K., Narayanan, K.G.S., Sharma, P., 2017. Effect of climatic factors on cash crop farming in India: an application of Cobb-Douglas production function model | International Journal of Agricultural Resources, Governance and Ecology. Int. J. Agric. Resour. Gov. Ecol. 13, 175–210. https://doi.org/10.1504/IJARGE.2017.086452
Singh, M., Singh, M., Kumar, M.A., Kumara, H. n., Sharma, A. k., Kaumanns, W., 2002. Distribution, population structure, and conservation of lion-tailed macaques (Macaca

silenus) in the Anaimalai Hills, Western Ghats, India. Am. J. Primatol. 57, 91–102. https://doi.org/10.1002/ajp.10037
Sloan, S., Goosem, M., Laurance, S.G., 2016. Tropical forest regeneration following land abandonment is driven by primary rainforest distribution in an old pastoral region. Landsc. Ecol. 31, 601–618. https://doi.org/10.1007/s10980-015-0267-4
Smithson, J., 2000. Using and analysing focus groups: Limitations and possibilities. Int. J. Soc. Res. Methodol. 3, 103–119. https://doi.org/10.1080/136455700405172
Soares-Filho, B., Rajao, R., Macedo, M., 2014. Cracking Brazil' s forest code. Science 363–364.
Sohl, T.L., Claggett, P.R., 2013. Clarity versus complexity: Land-use modeling as a practical tool for decision-makers. J. Environ. Manage. 129, 235–243. https://doi.org/10.1016/j.jenvman.2013.07.027
Souchère, V., Millair, L., Echeverria, J., Bousquet, F., Le Page, C., Etienne, M., 2010. Co-constructing with stakeholders a role-playing game to initiate collective management of erosive runoff risks at the watershed scale. Environ. Model. Softw., Thematic Issue - Modelling with Stakeholders 25, 1359–1370. https://doi.org/10.1016/j.envsoft.2009.03.002
Speelman, E.N., García-Barrios, L.E., Groot, J.C.J., Tittonell, P., 2014. Gaming for smallholder participation in the design of more sustainable agricultural landscapes. Agric. Syst., Designing sustainable agricultural production systems for a changing world: Methods and applications 126, 62–75. https://doi.org/10.1016/j.agsy.2013.09.002
Srinivasan, M.G., 2015. A Study on Workers Perception about Health, Safety and Welfare Measures in Nilgiris District. Int. J. Sci. Tech. Adv. 1, 51–56.
Steffan-Dewenter, I., Kessler, M., Barkmann, J., Bos, M.M., Buchori, D., Erasmi, S., Faust, H., Gerold, G., Glenk, K., Gradstein, S.R., Guhardja, E., Harteveld, M., Hertel, D., Höhn, P., Kappas, M., Köhler, S., Leuschner, C., Maertens, M., Marggraf, R., Migge-Kleian, S., Mogea, J., Pitopang, R., Schaefer, M., Schwarze, S., Sporn, S.G., Steingrebe, A., Tjitrosoedirdjo, S.S., Tjitrosoemito, S., Twele, A., Weber, R., Woltmann, L., Zeller, M., Tscharntke, T., 2007. Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. Proc. Natl. Acad. Sci. 104, 4973–4978. https://doi.org/10.1073/pnas.0608409104
Sterling, E.J., Betley, E., Sigouin, A., Gomez, A., Toomey, A., Cullman, G., Malone, C., Pekor, A., Arengo, F., Blair, M., Filardi, C., Landrigan, K., Porzecanski, A.L., 2017. Assessing the evidence for stakeholder engagement in biodiversity conservation. Biol. Conserv. 209, 159–171. https://doi.org/10.1016/j.biocon.2017.02.008
Stevens, S., 2014. Indigenous Peoples, National Parks, and Protected Areas: A New Paradigm Linking Conservation, Culture, and Rights. University of Arizona Press.
Stevenson, J.R., Villoria, N., Byerlee, D., Kelley, T., Maredia, M., 2013. Green Revolution research saved an estimated 18 to 27 million hectares from being brought into agricultural production. Proc. Natl. Acad. Sci. 110, 8363–8368. https://doi.org/10.1073/pnas.1208065110
Sun, Z., Lorscheid, I., Millington, J.D., Lauf, S., Magliocca, N.R., Groeneveld, J., Balbi, S., Nolzen, H., Müller, B., Schulze, J., Buchmann, C.M., 2016. Simple or complicated agent-based models? A complicated issue. Environ. Model. Softw. 86, 56–67. https://doi.org/10.1016/j.envsoft.2016.09.006
Sun, Z., Müller, D., 2013. A framework for modeling payments for ecosystem services with agent-based models, Bayesian belief networks and opinion dynamics models. Environ.

Model. Softw., Thematic Issue on Spatial Agent-Based Models for Socio-Ecological Systems 45, 15–28. https://doi.org/10.1016/j.envsoft.2012.06.007
TANTEA, 2011. History of Tamilnadu Tea Plantation Corporation [WWW Document]. URL http://tantea.co.in/org.html (accessed 11.22.17).
Tea Board of India, UPASI, 2001. Tea Quality Upgradation in Small Sector: Field Technical Report. United Planters' Association of Southern India-Krishi Vigyan Kendra, Conoor.
Terborgh, J., 1974. Preservation of Natural Diversity: The Problem of Extinction Prone Species. BioScience 24, 715–722. https://doi.org/10.2307/1297090
Thaler, G.M., 2017. The Land Sparing Complex: Environmental Governance, Agricultural Intensification, and State Building in the Brazilian Amazon. Ann. Am. Assoc. Geogr. 0, 1–20. https://doi.org/10.1080/24694452.2017.1309966
Thiagarajan, S., 2014. Tea growing area in Nilgiris fallen by 20% in 10 years. Times India.
Thomas, S., 2005. Keystone Foundation » Human Wildlife Interactions : Conflict, Communication and Collaboration.
Thomas, S., Palmer, M., 2007. The montane grasslands of the Western Ghats, India: Community ecology and conservation. Community Ecol. 8, 67–73. https://doi.org/10.1556/ComEc.8.2007.1.9
Tilman, D., Balzer, C., Hill, J., Befort, B.L., 2011. Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad. Sci. 108, 20260–20264. https://doi.org/10.1073/pnas.1116437108
Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D., Swackhamer, D., 2001. Forecasting Agriculturally Driven Global Environmental Change. Science 292, 281–284. https://doi.org/10.1126/science.1057544
Tittonell, P., Giller, K.E., 2013. When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. Field Crops Res., Crop Yield Gap Analysis – Rationale, Methods and Applications 143, 76–90. https://doi.org/10.1016/j.fcr.2012.10.007
Travers, H., Clements, T., Milner-Gulland, E.J., 2016. Predicting responses to conservation interventions through scenarios: A Cambodian case study. Biol. Conserv. 204, 403–410. https://doi.org/10.1016/j.biocon.2016.10.040
Troiani, N., Tardella, F.M., Malatesta, L., Corazza, M., Ferrari, C., Catorci, A., 2016. Long-term abandonment of croplands in the sub-Mediterranean climate does not lead per se to the recovery of the semi-natural herb communities deemed worthy of conservation in the EU Habitats Directive. Acta Bot. Croat. 75.
Tscharntke, T., Tylianakis, J.M., Rand, T.A., Didham, R.K., Fahrig, L., Batáry, P., Bengtsson, J., Clough, Y., Crist, T.O., Dormann, C.F., Ewers, R.M., Fründ, J., Holt, R.D., Holzschuh, A., Klein, A.M., Kleijn, D., Kremen, C., Landis, D.A., Laurance, W., Lindenmayer, D., Scherber, C., Sodhi, N., Steffan-Dewenter, I., Thies, C., van der Putten, W.H., Westphal, C., 2012. Landscape moderation of biodiversity patterns and processes - eight hypotheses. Biol. Rev. 87, 661–685. https://doi.org/10.1111/j.1469-185X.2011.00216.x
Turner, W.R., Brandon, K., Brooks, T.M., Constanza, R., da Fonseca, G.A.B., Portela, R., 2007. Global Conservation of Biodiversity and Ecosystem Services. BioScience 57, 868–873.
Tweeten, L., 1999. The Economics of Global Food Security. Appl. Econ. Perspect. Policy 21, 473–488. https://doi.org/10.2307/1349892

UN, 2017. World Population Prospects: The 2017 Revision, Key Findings and Advance Tables. (No. Working Paper No. ESA/P/WP/248). United Nations Department of Economic and Social Affairs, Population Division, New York.
UN, 2015. Transforming Our World: The 2030 Agenda for Sustainable Development (No. Resolution A/RES/70/1). United Nations General Assembly.
UNDP, 2016. Human Development Report 2016. Human Development for Everyone. United Nations Development Programme, New York.
UNDP, 2006. Human Development Report 2006 - Beyond scarcity: Power, poverty and the global water crisis (ISBN 0-230-50058-7). United Nations Development Programme, Palgrave Macmillan Houndmills, Basingstoke, Hampshire RG21 6XS and 175 Fifth Avenue, New York, NY 10010.
UPASI, 2015a. Tea Cultivation and practices. United Planters' Association of South India, Regional Centre, Nilgiris. [WWW Document].
UPASI, 2015b. Personal notes from interview with UPASI.
Valbuena, D., Verburg, P.H., Veldkamp, A., Bregt, A.K., Ligtenberg, A., 2010. Effects of farmers' decisions on the landscape structure of a Dutch rural region: An agent-based approach. Landsc. Urban Plan. 97, 98–110. https://doi.org/10.1016/j.landurbplan.2010.05.001
Valin, H., Sands, R.D., van der Mensbrugghe, D., Nelson, G.C., Ahammad, H., Blanc, E., Bodirsky, B., Fujimori, S., Hasegawa, T., Havlik, P., Heyhoe, E., Kyle, P., Mason-D'Croz, D., Paltsev, S., Rolinski, S., Tabeau, A., van Meijl, H., von Lampe, M., Willenbockel, D., 2014. The future of food demand: understanding differences in global economic models. Agric. Econ. 45, 51–67. https://doi.org/10.1111/agec.12089
VAM, 2008. Food consumption analysis. Calculation and use of the food consumption score in food security analysis. Strengthening Emergency Needs Assessment Capacity (SENAC). United Nations World Food Programme, Rome.
VAM, 2003. Comprehensive Food Security and Vulnerability Analysis (CFSVA). United Nations World Food Programme.
van den Belt, M., 2004. Mediated modeling: a system dynamics approach to environmental consensus building. Island press.
van Oel, P.R., Krol, M.S., Hoekstra, A.Y., Taddei, R.R., 2010. Feedback mechanisms between water availability and water use in a semi-arid river basin: A spatially explicit multi-agent simulation approach. Environ. Model. Softw. 25, 433–443. https://doi.org/10.1016/j.envsoft.2009.10.018
van Vliet, N., Mertz, O., Heinimann, A., Langanke, T., Pascual, U., Schmook, B., Adams, C., Schmidt-Vogt, D., Messerli, P., Leisz, S., Castella, J.-C., Jørgensen, L., Birch-Thomsen, T., Hett, C., Bech-Bruun, T., Ickowitz, A., Vu, K.C., Yasuyuki, K., Fox, J., Padoch, C., Dressler, W., Ziegler, A.D., 2012. Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: A global assessment. Glob. Environ. Change, Adding Insult to Injury: Climate Change, Social Stratification, and the Inequities of Intervention 22, 418–429. https://doi.org/10.1016/j.gloenvcha.2011.10.009
Venter, O., Sanderson, E.W., Magrach, A., Allan, J.R., Beher, J., Jones, K.R., Possingham, H.P., Laurance, W.F., Wood, P., Fekete, B.M., Levy, M.A., Watson, J.E.M., 2016. Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. Nat. Commun. 7, ncomms12558. https://doi.org/10.1038/ncomms12558
Venugopal, D., 2006. A guide to John's Sullivan's The Nilgiris. The Blue Mountains of south India. Nilgiri Documentation Centre, The Nilgiris, Tamil Nadu, India.

Venugopal, D., 2004. Development-conservation dilemma in the Nilgiri Mountains of South India. J. Mt. Sci. 1, 74–80. https://doi.org/10.1007/BF02919362
Vhurumuku, E., 2014. Food Security Indicators. Integrating Nutrition and Food Security Programming for Emergency response workshop, WFP East and Central Africa Bureau, Nairobi.
Videira, N., Antunes, P., Santos, R., 2009. Scoping river basin management issues with participatory modelling: The Baixo Guadiana experience. Ecol. Econ., Participation and Evaluation for Sustainable River Basin Governance 68, 965–978. https://doi.org/10.1016/j.ecolecon.2008.11.008
Vira, B., Wildburger, C., Mansourian, S., 2015. Forests and Food: Addressing Hunger and Nutrition Across Sustainable Landscapes - Open Book Publishers. Open Book Publishers, Cambridge, UK. https://doi.org/10.11647/OBP.0085
Viswanathan, N.M., 2012. A Study On The Productivity Of Tea In Tamil Nadu With Special Reference To The Nilgiris District. Bharathiar.
Voinov, A., Bousquet, F., 2010. Modelling with stakeholders. Environ. Model. Softw., Thematic Issue - Modelling with Stakeholders 25, 1268–1281. https://doi.org/10.1016/j.envsoft.2010.03.007
Voinov, A., Kolagani, N., McCall, M.K., Glynn, P.D., Kragt, M.E., Ostermann, F.O., Pierce, S.A., Ramu, P., 2016. Modelling with stakeholders – Next generation. Environ. Model. Softw. 77, 196–220. https://doi.org/10.1016/j.envsoft.2015.11.016
von Wehrden, H., Abson, D.J., Beckmann, M., Cord, A.F., Klotz, S., Seppelt, R., 2014. Realigning the land-sharing/land-sparing debate to match conservation needs: considering diversity scales and land-use history. Landsc. Ecol. 29, 941–948. https://doi.org/10.1007/s10980-014-0038-7
Vongvisouk, T., Broegaard, R.B., Mertz, O., Thongmanivong, S., 2016. Rush for cash crops and forest protection: Neither land sparing nor land sharing. Land Use Policy 55, 182–192. https://doi.org/10.1016/j.landusepol.2016.04.001
Waggoner, P.E., 1996. How Much Land Can Ten Billion People Spare for Nature? Daedalus 125, 73–93. https://doi.org/10.2307/20027371
Walker, D.H., 2002. Decision support, learning and rural resource management. Agric. Syst. 73, 113–127. https://doi.org/10.1016/S0308-521X(01)00103-2
Walter, A., Finger, R., Huber, R., Buchmann, N., 2017. Opinion: Smart farming is key to developing sustainable agriculture. Proc. Natl. Acad. Sci. 114, 6148–6150. https://doi.org/10.1073/pnas.1707462114
Washington-Ottombre, C., Pijanowski, B., Campbell, D., Olson, J., Maitima, J., Musili, A., Kibaki, T., Kaburu, H., Hayombe, P., Owango, E., Irigia, B., Gichere, S., Mwangi, A., 2010. Using a role-playing game to inform the development of land-use models for the study of a complex socio-ecological system. Agric. Syst. 103, 117–126. https://doi.org/10.1016/j.agsy.2009.10.002
WCED, 1987. Report of the World Commission on Environment and Development: Our Common Future.
Webb, P., Coates, J., Frongillo, E.A., Rogers, B.L., Swindale, A., Bilinsky, P., 2006. Measuring Household Food Insecurity: Why It's So Important and Yet So Difficult to Do. J. Nutr. 136, 1404S–1408S.
Weisbuch, G., Boudjema, G., 1999. Dynamical Aspects in the Adoption of Agri-Environmental Measures. Adv. Complex Syst. 02, 11–36. https://doi.org/10.1142/S0219525999000035
Wentworth, J., 2012. POSTnote 418, "Balancing Nature and Agriculture." The Parliamentary Office of Science and Technology, London, UK.

West, P., Igoe, J., Brockington, D., 2006. Parks and Peoples: The Social Impact of Protected Areas. Annu. Rev. Anthropol. 35, 251–277. https://doi.org/10.1146/annurev.anthro.35.081705.123308
West, P.C., Gerber, J.S., Engstrom, P.M., Mueller, N.D., Brauman, K.A., Carlson, K.M., Cassidy, E.S., Johnston, M., MacDonald, G.K., Ray, D.K., Siebert, S., 2014. Leverage points for improving global food security and the environment. Science 345, 325–328. https://doi.org/10.1126/science.1246067
WFP, 2012. Food Security in the Northern and Eastern Provinces of Sri Lanka. World Food Programme.
Wiesmann, D., Bassett, L., Benson, T., Hoddinott, J., 2009. Validation of the world food programme's food consumption score and alternative indicators of household food security | IFPRI. International Food Policy Research Institute, Washington, DC.
Wiles, R., Crow, G., Pain, H., 2011. Innovation in qualitative research methods: a narrative review. Qual. Res. 11, 587–604. https://doi.org/10.1177/1468794111413227
Wilkie, D.S., Bennett, E.L., Peres, C.A., Cunningham, A.A., 2011. The empty forest revisited. Ann. N. Y. Acad. Sci. 1223, 120–128. https://doi.org/10.1111/j.1749-6632.2010.05908.x
Wilkinson, S., 1998. Focus group methodology: a review. Int. J. Soc. Res. Methodol. 1, 181–203. https://doi.org/10.1080/13645579.1998.10846874
Williams, D.R., Alvarado, F., Green, R.E., Manica, A., Phalan, B., Balmford, A., 2017. Land-use strategies to balance livestock production, biodiversity conservation and carbon storage in Yucatán, Mexico. Glob. Change Biol. https://doi.org/10.1111/gcb.13791
Wilson, G.A., 2004. The Australian Landcare movement: towards 'post-productivist' rural governance? J. Rural Stud. 20, 461–484. https://doi.org/10.1016/j.jrurstud.2004.03.002
Wilson, G.A., Hart, K., 2000. Financial Imperative or Conservation Concern? EU Farmers' Motivations for Participation in Voluntary Agri-Environmental Schemes. Environ. Plan. A 32, 2161–2185. https://doi.org/10.1068/a3311
Wittman, H., Chappell, M.J., Abson, D.J., Kerr, R.B., Blesh, J., Hanspach, J., Perfecto, I., Fischer, J., 2017. A social–ecological perspective on harmonizing food security and biodiversity conservation. Reg. Environ. Change 17, 1291–1301. https://doi.org/10.1007/s10113-016-1045-9
World Bank, 2017. Poverty & Equity Data Portal [WWW Document]. URL http://databank.worldbank.org/data/Views/Reports/ReportWidgetCustom.aspx?Report_Name=pov_cou_4_2017&Id=c5b0ae6a&wd=430&ht=390&tb=y&dd=n&pr=n&export=y&xlbl=y&ylbl=y&legend=y&isportal=y&inf=n&exptypes=Excel&country=IND (accessed 11.19.17).
World Bank, 2014. World Development Report 2015: Mind, Society, and Behavior. The World Bank. https://doi.org/10.1596/978-1-4648-0342-0
World Bank, 2008. Agriculture for Development. World development report.
Wunderle, J.M.J., 1999. Avian distribution in Dominican Shade coffee plantations: area and habitat relationships. J Field Ornithol 70, 58–70.
Young Badaga Association, 2015. Badagas of the Blue Mountains. Their unique history, origin, culture, customs, rituals, language and lifestyle. [WWW Document]. URL https://badaga.co/about-badagas/
Young, J.C., Jordan, A., R. Searle, K., Butler, A., S. Chapman, D., Simmons, P., Watt, A.D., 2013. Does stakeholder involvement really benefit biodiversity conservation? Biol. Conserv. 158, 359–370. https://doi.org/10.1016/j.biocon.2012.08.018
Young, J.C., Waylen, K.A., Sarkki, S., Albon, S., Bainbridge, I., Balian, E., Davidson, J., Edwards, D., Fairley, R., Margerison, C., McCracken, D., Owen, R., Quine, C.P.,

Stewart-Roper, C., Thompson, D., Tinch, R., Hove, S.V. den, Watt, A., 2014. Improving the science-policy dialogue to meet the challenges of biodiversity conservation: having conversations rather than talking at one-another. Biodivers. Conserv. 23, 387–404. https://doi.org/10.1007/s10531-013-0607-0
Yu, Q., Wu, W., Yang, P., Tang, H., Zhou, Q., Chen, Z., 2013. Progress of agent-based agricultural land change modeling: A review. Shengtai Xuebao Acta Ecol. Sin. 33, 1690–1700. https://doi.org/10.5846/stxb201112131904
Zabala, A., 2015. Motivations and incentives for pro-environmental behaviour: the case of silvopasture adoption in the tropical forest frontier (Thesis). University of Cambridge.
Zabala, A., Pascual, U., García-Barrios, L., 2017. Payments for Pioneers? Revisiting the Role of External Rewards for Sustainable Innovation under Heterogeneous Motivations. Ecol. Econ. 135, 234–245. https://doi.org/10.1016/j.ecolecon.2017.01.011
Zomer, R., Coe, R., Place, F., Trabucco, A., van Noordwijk, M., Xu, J.C., 2014. Trees on farms: an update and reanalysis of agroforestry's global extent and socio-ecological characteristics. Bogor Indones. World Agrofor. Cent. ICRAF Southeast Asia Reg. Program Working Paper 179. https://doi.org/10.5716/ WP14064.PDF
Zorrilla, P., Carmona García, G., de la Hera, A., Varela Ortega, C., Martinez Santos, P., Bromley, J., Henriksen, H.J., 2010. Evaluation of Bayesian Networks in Participatory Water Resources Management, Upper Guadiana Basin, Spain.

Appendix 3.1

Household Survey

Kotagiri 2015

The Household (HH) instrument has been developed to collect baseline information about general demographics, agricultural practices, food availability, access, use and stability, land use change, perceived biodiversity change and incentives schemes available/benefiting individual households.

The data collected will be used to develop a study aimed at answering research questions such as:
Q1: What are the current local agricultural practices?
Q2: How did the landscape change over time?
Q3: What are the benefits/subsidies HH obtain from agriculture?
Q4: What are the changes that might occur in the future in the agricultural field and what is the associated impact on the socio-economic status of the HH and the surrounding landscape?

Enumerator: The following paragraph contains the detailed research questions. For further reference regarding research please refer to the following questions:

> ***Q1:*** *What is the current land use and socio-economic context and how will the landscape likely change in the future?*
> ***Q2:*** *What types of agricultural and environmental schemes have been implemented in the landscape and what other plausible policy interventions (including land sharing and land sparing) and external drivers of change might occur in the future ('scenarios' hereafter)?*
> ***Q3:*** *How would the scenarios impact on landscape configuration, habitat for biodiversity and pollination services?*
> ***Q4:*** *How would the scenarios impact on HH food security and food accessibility?*
> ***Q5:*** *How do food security, household socio-economic profile and ecosystem services compare under the different scenarios? Who wins and who loses?*
> ***Q6:*** *How do stakeholders respond to policy tools such as agent-based modelling?*

The household survey consists of 8 sections:

Section A.	Introduction and respondent's consent
Section B.	Data Handlers
Section C.	Household Respondent and Type
Section D.	Household Profile
Section E.	Land Assets and Income
Section F.	Agricultural activities
Section G.	Decision-making and scenario testing
Section H.	Food security, consumption and composition

Enumerator: Acknowledging that men and women have different roles and different viewpoints in a household and in the community, we would like you to ensure that both women and men will be interviewed.

Section A. Introduction and consent by main respondent

Hello. My name is [interviewer name] ____. I am working with a researcher from University of Cambridge in collaboration with Keystone Foundation. We are conducting a survey about the agricultural practices within the area and how different agricultural policies for land management affect household livelihoods, the ways in which natural resources are managed, especially trees and forests and the overall conditions of the environment. The aim of this research is to understand how land-use change has impacted on people's way of living in Niligiris area and what type of incentives are successful to implement a change in the land management that can benefit both livelihoods and the environment. We would like to ask you some questions about your household, your livelihood and your farming practices and your use of natural resources. It should not take longer than 1 hour of your time. Approximately 500 people in different villages in Niligiris area will take part in this study, including approximately _______ people from this village.

We would like to share the results of the study, so that more people understand how food is grown and used in this region and the issues that you face regarding food production and land management. Your name will not appear in any data that is made publicly available. The information you provide will be used purely for research purposes; your answers will not affect any benefits or subsidies you may receive now or in the future.

Do you consent to be part of this study? You may withdraw from the study at any time and if there are questions that you would prefer not to answer then we respect your right not to answer them.

Has consent been given? **1=YES** **2=NO**

If NO, please give reason *1= Nobody home, 2 = Respondent refuses to participate, 3 = Respondent postponed the interview, 4 = Household head (or other knowledgeable member) is not present at the house, 5 = Other ________________________*

Section B. Household survey general information

Country ID: India	**Site ID:**	**Household Address and telephone:**
District Name: Niligiris		**GPS reference for household (Lat/Long in decimal degrees):** *Latitude: ° S Longitude: ° E*
Village Panchayat Name:		
Hamlet name:		**Language ID** *(Circle the languages used during the interview)* *1. English 2. Tamil 3. Badaga*
Local currency: INR		**Date of interview (dd-mm-yyyy):**
Enumerator's Name:		
Date of 1st visit (dd-mm-yyyy):		**Time Start/End:**
Computer data entry by (Name and Date): ***Additional information to be filled by researcher:*** *Main land use: ______________________* *Land use intensity (circle one):* *Low Medium High*		

Section C. Household Respondent and Type

Enumerator: The ideal respondent is the household head or spouse. Most of these questions can be completed without having to to question the respondent directly. Be sensitive about the way you gather this information. Please identify the gender of the respondent prior to starting the question in the section.

Gender of respondent	Female [____]	Male [____]

Name Head of Household:	Full Name:
	Father's Name:
Name of respondent	Full Name:
	Father's Name:
Relationship of the respondent to the household head, if not the head	[___________________________]

Household type |_____|
01=Male headed
02=Male headed, divorced, single or widowed,
03=Female headed,
04=Female headed, divorced, single, widowed
05=Other, specify [………………………………………………………………..]

Has your family always lived in this village? 1=Yes 2= No
If No, complete the following questions:

When was the household established here? *(Year)* ____________________

Where was the previous household? 1. In Nilgiris District ; **2**. In Tamil Nadu; 3. In another state; **4**. Other country________

What was the main reason for moving? *(Circle one reason only)*
*1. Work Related 2. School / Studies 3. Marriage 4. Other Family Reasons 5. Better Services / Housing 6. Land / Plot 7.Other, Specify*_______

Have any of the family members moved away from this area? 1=Yes 2= No

If Yes, complete the following questions:
How many? ____

What were the reasons? *(Circle as many as applicable)*
*1. Work Related 2. School / Studies 3. Marriage 4. Other Family Reasons 5. Better Services / Housing 6. Land / Plot 7.Other, Specify*________

Are you or any family member part of any group/association? *(Circle as many as applicable)*

1=Farmers' Association 2= Village Group 3= Educational group 4=Other, specify
____

Section D. Household Profile

Please list all the members in the household. We consider member of a household all people that regularly eat in your household, even if they are not related to you. Please list here any workers that live with you.

Name (*)	Sex *1 = M* *2 = F*	Religion	Ethnicity	Relationship to respondent	Education	Main occupation	% of time working on their farm per month	% of time working on others farms per month

Section E. Land Assets and Income

Do you own or lease land? 1= Yes 2=No

If No, **jump to E2**

If Yes: **Out of the following categories what type of land, do you own:**

1. Pasture land **(Table A)**

2. Agricultural land, for example: for vegetables; beans etc **(Table B)**

3. Plantation (tea, coffee, fruit trees) **(Table C)**

4. Native vegetation (such as natural forest with jungle wood, shola forest, natural pastures) **(Table D);**

5. Secondary vegetation (Fallow/Abandoned land) **(Table E)**

Now, please fill in the Tables for the categories of land the respondent owns.

Table A: **Pasture Land**	**Total Area (acres)**	**Stock density** *(Number of animals)*
	1. < 1 acre; **2.** 1 – 3 acres; **3.** 3-5 acres; **4.** > 5 acres	**Cows:**
		Poultry:
		Goats:

Table B: **Agricultural land**	**Total Area**	**How many different types of crops do you grow on the land per year?**	**Total quantity of pesticides/fertilizers used** Quantity (bags or litters per acre per year)
	1. < 1 acre; **2.** 1 – 3 acres; **3.** 3-5 acres; **4.** > 5 acres		**Chemical:**
			Organic

!!!! *If tea and coffee are intercropped than please fill in the crop that represents the main land use and mention the other crop as being intercropped*

Table C: **Plantation (tea, coffee, fruit trees)**	**Plantation type** *tea/coffee /fruit trees*	**Total Area** **1.** < 1 acre; **2.** 1 – 3 acres; **3.** 3-5 acres; **4.** > 5 acres	**Number of plants per acre**	**Total quantity of pesticides/fertilizers used** Quantity (bags or litters per acre per year)	**Tree species intercropped** **Type** *Tick the box were applicable*	**Tree species intercropped** No of trees per acre	**Previous land use before tea/coffee**
				Chemical:	Jungle wood		
				Organic:	Silver oak or other exotic species		
				Chemical:	Jungle wood		
				Organic:	Silver oak or other exotic species		
				Chemical:	Jungle wood		
				Organic:	Silver oak or other exotic species		

Table D: Native vegetation	Total Area 1. < 1 acre; 2. 1 – 3 acres; 3. 3-5 acres; 4. > 5 acres	Use of native vegetation (Please select one category ONLY) Used for paths, non timber forest products collection or/and occasional hunting	Selective logging, moderate grazing, and/or hunting of protected species	Clear-felling, intense grazing
Native vegetation* (Forest)				
Native Vegetation (Non-forest)				

**Refers to vegetation that is not known or inferred to have ever been completely destroyed. Synonyms include "ancient woodland", "natural grassland", "shola forest"*

Table E: Secondary vegetation (Fallow/Abandoned land)	Total Area	Age of vegetation/ When the land was abandoned (Please select one category ONLY) Young vegetation (less than 10 years)	Intermediate vegetation (between 10-30 years)	Mature vegetation (over 30 years)
	1. < 1 acre; 2. 1 – 3 acres; 3. 3-5 acres; 4. > 5 acres			

E2.

What is the village communal land *(other than cultural purposes)* **used for?** **1.** Agricultural purposes; 2. Pasture land; 3. Forested area; 4. Other, specify______________

What is the ownership of the largest percentage of the land?

1= Title deed (patta); 2= Rented-in/ other short term arrangement, 3= Revenue Encroachment; 4= Forest land; 5= Other ____________________

Have you acquired land in the last 10 years? 1=YES 2=NO

If No, move to the next box

If Yes, continue with the questions in this box:

What was the SIZE and the PRICE of the land acquired? ____________________

How did you acquire the land?

1=bought;2=bought by parents; 3=inherited; 4=other, specify________________

Why did you acquire land? (*Allow respondent to provide the answer and circle the one that best matches)*

1=higher crop yields; 2=growing family; 3=at the time of marriage; 4= money investment; 5=price of land; 6= other, please specify______________________

Have you disposed of land in the last 10 years?

If No, move to E3

If Yes, continue with the questions in this box:

What were the SIZE and the PRICE of the land disposed? ____________________

Why did you dispose of land?

1=financial needs; 2=low productivity; 3=price of land; 4=other, specify__________

E3. Income

Please specify what are the main sources of income in the HH and the distribution of income:

Category	1=Yes ; 2=No	Percentage of the total annual income *(Alternatively use stones bag)*
Sale of agriculture and livestock products		
Sale of forest products *(e.g. charcoal, firewood, timber, honey, medicinal plants, wild foods)*		
Wages or salaries *(e.g. daily labour; temporary contracts; business)*		
Governmental and livelihood allowances *(including pension, child care)*		
Environmental allowances		
Other *(please specify):*		
Other *(please specify):*		
Other *(please specify):*		

Enumerator: The next question is more sensitive. There are two options for asking this question. You will only need to fill one of the options. If the respondent doesn't want to answer Option 1, please move to Option 2.

Option 1:

What is your current HH income per year?

1. Below 10 000;
2. 10 000-30 000;
3. 30 000-50 000
4. 50 000 -1 Lakh 5.
5. 1 Lakh and above

Option 2:

What would be your YEARLY dream budget that will allow you to meet all the expenses and expectations of the household?

____

What percentage of the dream budget does your HH currently own?

____

Section F. Agriculture activities

I would like to ask you about the main crops that your household has been planting and harvesting in the last 12 months.

What are the MAIN FOOD crops you have been planting in the last 12 months?

Crops / **Annual**	Crops grown 0=No; 1=Yes	Crops are grown for the following PREDOMINANT reason 0=Cash crops; 1=HH Consumption; 2=both	**What are the top 5 crops grown in the household by area?** *(Includes perennial)*	**Season length (cultivation-harvesting)**	**Land size for each crop cultivation** *(specify which crops are grown on the same land at different time of year)*	**Total yield per crop** (Kg)	**% That goes for HH consumption**	**% For fodder**	**% For selling**	**Income from selling in the last season**
Ragi			1							
Beans			2							
Maize			3							
Millet			4							
Sorghun			5							
Wheat										
Barley			**Cost of production with**	**Tea**	**Vegetables**					
Peas			Seeds							
Vegetables			Labour							
Other			Irrigation							
			Opening up the land							

What is the total cost of production with all agricultural activities in a year?

____

Perennial		
Coffee		
Tea		
Fruit trees		
Shade trees		
Pepper		
Other		

Are any of the young members of the family interested to practice agriculture?

1= Yes 2=No

Do they stay in the area or do they go for employment outside the district?

1= Stay in the area; 2=go for employment outside the district

Who will continue to practice agriculture on the family lands?

1. Members of our family; 2. No one; | 3. Other, specify___________

What do you think it will happen to your agricultural land in 30 years time? *(Please note key answer in few words)*

Section G. Decision Making and Scenario Testing

Have you ever converted permanently from one type of land use to another? *(e.g. forest to agriculture) 1=Yes 2=NO*

If YES please mention from what land use type to what land use type and when.

Initial land use: _____________ to Land use:_____________________Year of conversion: __________ Slash and Burn: YES NO

Initial land use:_____________ to Land use:_____________________Year of conversion: __________ Slash and Burn: YES NO

What were the reasons for land conversion?

Allow the respondent to answer before providing examples such as *labour shortage; unprofitable land use; natural disaster; cash crops; logging restrictions; changes in right acts on trees; incentives from different organisations/institutions.*

____

Have you ever switched from one crop to another? *1=Yes 2=NO*

If YES please mention from what land use type to what land use type and when.

Initial land use:_____________ to Land use:_____________________Year of conversion: __________ Slash and Burn: YES NO

Initial land use:_____________ to Land use:_____________________Year of conversion: __________ Slash and Burn: YES NO

What were the reasons for land conversion?

Allow the respondent to answer before providing examples such as *labour shortage; unprofitable land use; natural disaster; cash crops; changes in right acts; seeds offered for free; incentives from institutions/organisations.*

____

Scenario 1: Labour shortages

! For the next questions do not mention options. Allow respondent to provide the answer and circle the ones that best match.

Imagine you have a labour shortage, how do you overcome this problem?

1. Members of the HH have to work extra to compensate the labour shortage
2. The total cultivated area reduces accordingly
3. Our neighbours help us and we help them in return
4. We have to convert the land to a different land use
5. Other,specify____

If the labour shortages persist what will you do in the future *(land use, agricultural practices)?*

1. Members of the HH have to work extra to compensate the labour shortage
2. The total cultivated area reduces accordingly
3. Our neighbours help us and we help them in return
4. We have to convert the land to a different land use
5. We give up practicing agriculture
6. We rely on money from our children or relatives
7. We move to the city ; 8 Other, specify____

Scenario 2: Land sharing & land sparing

! For the next questions do not mention options. Allow respondent to provide the answer and circle the ones that best match.

What are the main factors your HH considers when you take decisions about how to use the land for agriculture? *(Please **BRIEFLY** list the factors in order of importance, starting with the most important)*

Do you think the way in which you practice agriculture impacts on the environment & biodiversity? 1= YES; 0=NO

If YES, **in what way?**

When you practice agriculture to what extent do you take decisions based on the potential impact on the environment and biodiversity?

1. I don't base my decision on the potential impacts on the environment & biodiversity;
2. I am aware that certain practices might have an impact on the environment so I try to minimise the negative impacts;
3. Without a good condition of the environment and biodiversity agriculture has to suffer so all the decisions that I take are in the best interest of the environment;
4. Other, specify___________________________________

Are you aware of any policy interventions, benefits, subsidies or governmental/non-governmental funds made available to farming communities that benefit both agriculture and the environment & biodiversity? 1=Yes 2=No

If Yes, specify

How would you best describe the type of agriculture you are practicing on your farm?

a. The crops are intercropped with patches of native tree species or exotic tress and there are wild animals and birds coming into my fields
b. The agricultural land is separated from my forested land
c. I don't have any forest. The only forest in the area belongs to the forest department.
d. Other. Please specify ____

Do you experience any crop losses due to animal disturbance? 1=Yes 2=No

If Yes, **what animals and what crops do they raid?**

Did you ever have to give up growing crops due to animal disturbance? (*e.g. fruit trees*) **1=Yes 2=No**

If yes, **what crops?**

Do you think implementing a scheme that incentivise agricultural practices benefiting biodiversity is a good idea?

1=Yes 2=No; Why?____

Under what conditions do you think you will take part in such a scheme? (*Circle as many applicable)*

a. I am not interested to take part in any such schemes
b. I am happy to take part in such schemes because it is in the interest of our community and the future generations
c. I am interested to take part only if my neighbors join
d. I am interested to take part, but it depends which institution/authority is implementing the scheme
e. I am interested to take part only if I receive financial support
f. I am interested to take part only if I receive technical support
g. Other, please specify____

Scenario 3: Low tea prices

What is the average price per kg of green tea leaves that you obtained in the past one year? ________________________

Do you think it is a fair price? 1= Yes 2=No

If no, **what do you think it would be a fair price?** ____________________

If the tea price continues to be low for at least the next 5 years, will you continue growing tea? 1= Yes 2=No

If Yes, **why?**

____

If no, **what will you do as an income alternative?**

____

____

Do you make income from selling timber obtained from trees intercropped with tea? 1= Yes 2=NO

Will you be willing to intercrop more jungle wood with tea? 1= Yes 2=NO

If Yes, **under what conditions?** ____

If NO, **why not?** ____

Will you be willing to intercrop more fruit trees with tea? 1= Yes 2=NO

If Yes, **under what conditions?** ____

If NO, **why not?** ____

Section H. Food Security, Consumption, and Composition

Enumerator: Please ensure that the person preparing food for the household is present when asking this Section. Please be sensible when asking these questions.

Have there been any days in the last month when your household experienced a shortage of food to eat? 1=Yes 2=No
If No, please jump to Table H1

How many days in the last month did your household not have enough to eat? ____________________________________

Is there a particular time of year when food is more difficult to obtain? 1=Yes 2=No
If YES, please complete with the period of time (specific months) ______________________________________

What were the reasons for food shortages? *Circle all applicable*

1. No income available at home
2. Did not receive pension/grant/food aid
3. Did not receive expected money from other household members
4. Poor harvest
5. Shocks and natural disasters
6. Too many family members to feed
7. Unexpected large expenditure
8. Other (*please specify*) ______________________________________

What coping strategies were employed? *Circle all applicable*

1. Loan from neighbours/family members/friends /institutions/groups
2. Reliance on a small number of products
3. Smaller portions of food
4. Children were sent at relatives
5. Other (*please specify*) __________________

Table H1

Types of foods	**Does your HH produce any of the following?** *1 = Yes, 2 = No*	**Does your HH buy any of the following?** *1 = Yes, 2 = No*	**In the last 7 days how many times have the HH consumed the following?**	**What are the three main products consumed in the HH?**	**Please tick the products category you would like to spend more money on**
A. Cereals, Grains and Cereal Products					
B. Roots, Tubers, and Plantains (e.g. Cassava Tuber/Flour; Potato)					
C. Nuts, Berries and Pulses (e.g. Bean; Lentils; Pea; Groundnut; arecanut; Wild nuts and berries)					
D. Vegetables					
E. Meat, Fish and Animal Products (Egg; Fish ; Poultry; Other Meat, Excluding Milk products)					
F. Fruits					
G. Milk/Milk Products (Milk; Yogurt; Cheese)					
H. Fats/Oil (Cooking Oil; Butter; Margarine; Other Fat/Oil)					
I. Sugar/Sugar Products/Honey (e.g. Sugar; Honey; Jam; Chocolate)					
J. Spices/Condiments (e.g. Tea; Coffee/Cocoa/Salt; Spices; Yeast)					

What is the minimum monthly budget needed to meet the food needs of the HH ?

____

Where do you usually buy food? *Circle all applicable*

1. Local market
2. Salesmen that come in the village
3. Town market
4. Other (*please specify: e.g. Public Distribution System*)
   ____

How far do you have to travel to buy food?

1. Less than 2 km
2. Between 2 and 10 km
3. Over 10 km

How do you usually travel to the places you buy food from?
Circle all applicable

1. Public transport (bus, train, shuttle)
2. Bicycle
3. Scooter/motor bicycle/auto
4. Car
5. Walk
6. Other (*please specify*) ___________________________

Which HH member takes decisions on? *(If multiple, list them all)*

1. Crops to grow ___________________________
2. Fuel wood/energy/timber ___________________________
3. Land and labour allocation ___________________________
4. Crop marketing ___________________________
5. Food purchasing ___________________________
6. Forest product collection/use___________________________

Please rank in order of importance how does the household decide which crops to grow? Mark only the ones which are mentioned.

1=the least important......7 =the most important

1. Seed availability _________________
2. Previous yields _________________
3. Profitability on the market _________________
4. Ease of management _________________
5. HH food needs _________________
6. Public institutions' advice _________________
7. **Neighbour's advice** _________________

Please rank in order of priority how is the household budget allocated for the following activities? *1=smallest priority......8=highest priority*

1. Education ___________
2. Health ___________
3. Food ___________
4. Utility bills & taxes ___________
5. Production costs (including labour)___________
6. Transport ___________
7. House maintenance ___________
8. Clothing items ___________

How did you find the way in which the interview was conducted?

a. Excellent
b. Very good
c. Good
d. Average
e. Unsatisfactory

Signature of respondent___________________________________

Appendix 3.2

Ethical assessment and local collaborator

For submitted and approved by the Department of Geography, University of Cambridge

Section III: Research Checklist

Please answer each question by ticking the appropriate box:

	YES	NO
1. Does the study require the informed consent of its subjects?	✓	
2. Does the study involve participants who are particularly vulnerable or unable to give informed consent? (e.g. children, people with learning disabilities, your own students)		✓
3. Will the study require the co-operation of a gatekeeper for initial access to the groups or individuals to be recruited? (e.g. students at school, members of self-help group, residents of nursing home)		✓
4. Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g. covert observation of people in non-public places)		✓
5. Will the study involve discussion of sensitive topics (e.g. sexual activity, drug use)?		✓
6. Will the study involve any invasive, intrusive or potentially harmful procedures?		✓
7. Will blood or tissue samples be obtained from participants?		✓
8. Is pain or more than mild discomfort likely to result from the study?		✓
9. Could the study induce psychological stress or anxiety or cause harm or negative consequences beyond the risks encountered in normal life?		✓
10. Will the study involve prolonged or repetitive testing?		✓
11. Will financial inducements (other than reasonable expenses and compensation for time) be offered to participants?		✓
12. Will the study involve recruitment of patients or staff through the NHS?		✓
13. Will the study be associated with significant damage to the environment?		✓
14. Will the study involve potential harm to animal welfare?		✓

<u>Ethical issues</u>

Data will be collected over a 13-month period with the support of a research assistant and three enumerators. For each activity enumerators will receive trainings prior to data collection, including household survey data collection or developing and running role-playing games and group activities. Assistants will be selected with the support of the local project partner, following interviews carried with the applicants. Selected applicants may be previously trained field survey assistants or students interested in social and natural sciences. All team members will be required to have a good knowledge of the necessary local languages.

The study will follow the three core principles that form the universally accepted basis for research articulated in The Belmont Report (Ryan et al., 1979): 1. *Respect for persons* -

ensures that people will not be used simply as a mean to achieve research objectives; 2. *Beneficence-* requires a commitment to maximizing the benefits that accrue to the researched community, minimizing the risks associated with research, (including social risks); 3. *Justice-* the people who are expected to benefit from the knowledge should be the ones who are asked to participate. Considering these principles, it is believed that through the engagement of the stakeholders at every step in the process, the research will facilitate collective learning and open discussions between parties, stakeholders, which may have not been brought together before. The outcomes of the research will be discussed with the stakeholders allowing more informed decisions about land use practices and the type of policy interventions that can benefit both agricultural production and biodiversity.

Additionally, the study will ensure that the values and interests of the community are respected and that people understand what it means to participate in the study so they can decide in a conscious, deliberate way whether they want to participate (see informed consent for household survey). First, the leaders of the communities will be approached and informed and then a forum will be facilitated where interested people can learn about the research and ask questions.

Positionality

Positionality and power relations at multiple scales are important elements of ethical research. Richa et al (2002) highlights the "impasse" in the feminist geography where fewer scholars are pursuing research in the Global South due to fear of misrepresentation and inauthenticity. However, the study also provides guidance on how these limitations can be overcome by keeping in mind the critiques and undertaking research that is more institutionally sensitive, materially grounded and politically engaged (Richa et al., 2002).

Sultana (2007) highlights that while some scholars have criticized that politically engaged research is not necessarily the result of acknowledging positionality, reflexivity, and identity, and may not bring dramatic change, not considering these issues may be of even more concern. Additionally, the study provides guiding principles by drawing from fieldwork experiences in South Asia.

The study aims to build upon these experiences and recommendations, and recognize that working with multiple positionalities of researchers and research participants is required in enabling ethical relations, which should be encouraged and embraced.

Keystone Foundation

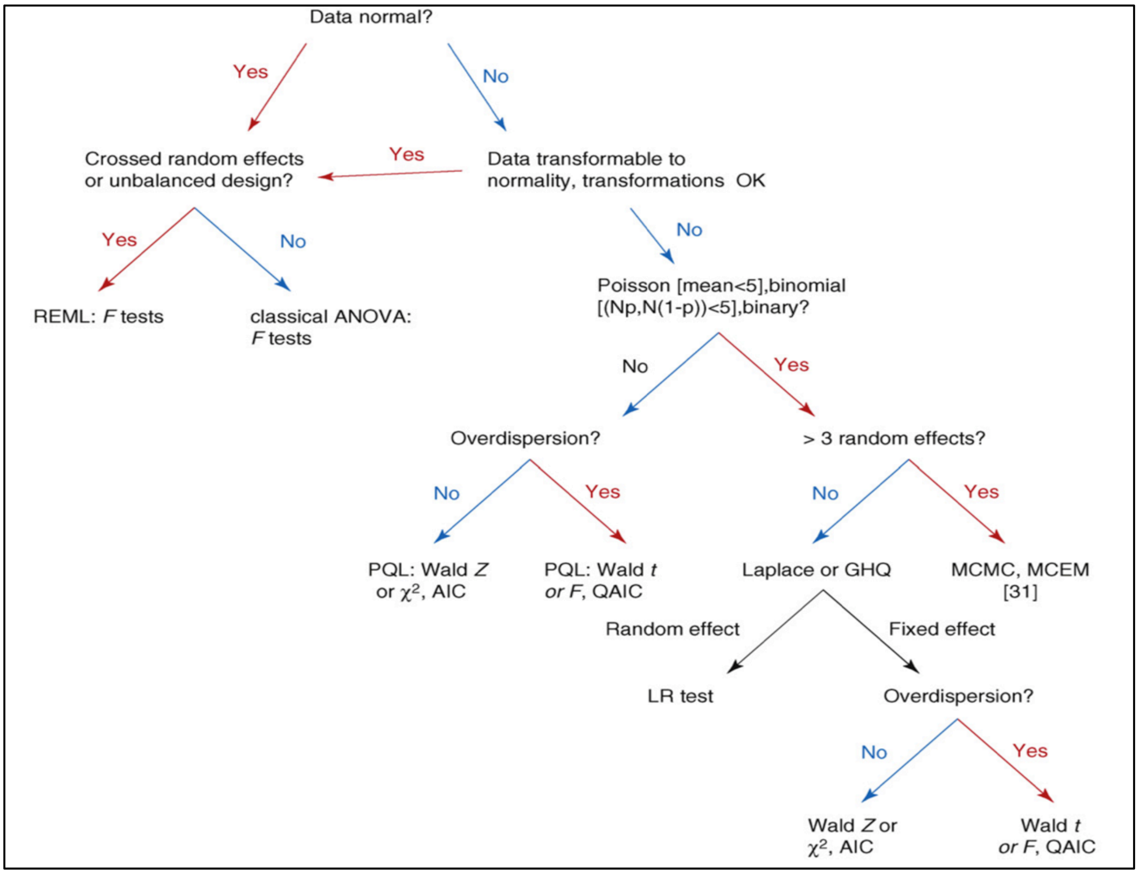
The research was undertaken with the support of a local organisation, Keystone Foundation (KF). The organisation, based in the town of Kotagiri, has been working in the Nilgiri Biosphere Reserve since 1993. The organization's main objective is to work with indigenous and local communities on eco-development initiatives. The support received by the NGO included local contacts, proof reading of the household survey, support with finding a research assistant, local accommodation and transportation as well as accessing their library and office facilities.

In order to minimize any biases that could occur from association with Keystone Foundation, when carrying out the survey the work was presented as that of an independent researcher undertaking a study to fill meet the requirements of a university qualification. If asked, it was explained that the research did not have an official affiliation with Keystone Foundation and that the respondents' answers would not be seen by organisations working in the Nilgiris area. Given that KF work focuses on Scheduled Tribes communities and that the sampled population is predominantly from the Scheduled Caste and Badaga groups, I believe there to be a negligible bias arising from the support from KF.

Appendix 3.3

Decision tree for GLMM fitting and inference

When faced with nonnormal data it is common to transform data to achieve normality and homogeneity of variance, using nonparametric tests or relying on the robustness of classical ANOVA to nonnormality for balanced designs (Quinn and Keough, 2002). Too often random effects are omitted, thus committing pseudoreplication, or are treated as fixed factors (Crawley, 2002). Such shortcuts can fail because: i) certain data (e.g. variables with many zeros) cannot be transformed to normal, or ii) statistical assumptions are violated, or iii) they limit the scope of inference (one cannot extrapolate estimates of fixed effects to new groups). Generalized linear mixed models (GLMMs) have the advantage that they combine the properties of two statistical frameworks: linear mixed models, which incorporate random effects, and generalized linear models, which can handle nonnormal data by using link functions and exponential family. GLMMs are considered to be the best tools for analyzing nonnormal data that involves random effects (Bolker et al., 2009).
This study used a decision tree in selecting the appropriate GLMM and the necessary tests for selecting the best model and evaluating differences in goodness of fit among models:



Decision tree for GLMM fitting and inference. Conditions on the Poisson and binomial distributions along the right branch refer to penalized quasilikelihood (PQL) rules of thumb: to use PQL, Poisson distributions should have mean > 5 and binomial distributions should have the minimum of the number of successes and failures > 5. MCEM = Monte Carlo expectation-maximization. *Source:Bolker et al., 2009*

Appendix 3.4

Role-playing game documents

A. RPG Players' Sheet

Player No.								
Year	**Land Use**	**Land size**		**Crop**	**Cost of production**	**Price (per kg)**	**Income**	**Profit**
	Vegetables		**Season 1**					
			Season 2					
			Season 3					
	Tea							
	Total Profit							
	Land Use	**Land size**		**Crop**	**Cost of production**	**Price (per kg)**	**Income**	**Profit**
	Vegetables		**Season 1**					
			Season 2					
			Season 3					
	Tea							
	Total Profit							

B. Income and Expense Sheet

Player No____

Income/Expenses	**Year1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Other sources of income	+	+	+	+	+
Agriculture income/loss					
Costs of living	-	-	-	-	-
Converting	-	-	-	-	-
Selling or buying land					
Schemes	+	+	+	+	+
Bonuses from education	+	+	+	+	+
Total profit/loss					

C. Decision making form

Player No __________

Year	What strategy did you adopt?	Did you change your strategy from previous year?	Why?
Example	*Grow beans, cabbage and potatoes; Take a loan from the bank*	*No, I didn't change*	*I got good return from my crops so I decided to grow the same*
Example	*Grow tea and cabbage; I made my food income smaller*	*Yes, I changed from potatoes to cabbage*	*Because I didn't have a good yield in potatoes; I decided to priorities other expenses than food;*
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

D. Final Evaluation Form

Date ___________________ ***Player No ________***

Final Evaluation Form

What have you thought of the game?

a. *Was it difficult?*
   - *Too simple*
   - *A bit simple*
   - *Just right*
   - *A bit complex*
   - *Too complex*

b. *Was it relevant to land use decisions in your village?*
   - *Nothing like managing our land*
   - *A bit far from reality*
   - *Some aspects are relevant to my household decisions*
   - *Quite close to the way I manage my land*
   - *I felt I was managing my own land*

c. *Was it fun?*
   - *Too long*
   - *A bit too long*
   - *OK*
   - *Fun*
   - *I would like to play again*

Appendix 5.1

Frequency of food consumption

Frequency of food consumption per food group before and after 1990 and information on whether the food was produced (partially or completely) on the farm or harvested from the local forest

Types of foods	Time period			
	Before 1990		After 1990	
	Produced Or Harvested	Frequency of consumption	Produced Or Harvested	Frequency of consumption
A. Cereals, Grains (Raghi, Millets, Corn)	x	Every day		Rarely
Rice		Occasionally		Every day
B. Roots, Tubers, and Plantains	x	Most of the days	x	Frequently
C. Pulses	x	Most of the days	x	Frequently
D. Nuts, wild fruits and berries	x	Occasionally		Rarely
E. Vegetables	x	Most of the days	x	Most of the days
F. Meat, Fish and Animal Products	x	Frequently		Rarely
G. Fruits	x	Rarely		Rarely
H. Milk/Milk Products	x	Most of the days		Frequently
I. Fats/Oil	x	Rarely		Most of the days
J. Sugars		Rarely		Every day
Honey	x	Occasionally		Rarely
K. Spices/Condiments		Every day		Every day
Tea/Coffee	x		x	Every day

Appendix 6.1

Players' profile example

Player 1

You are a farmer in Nilgiris and you are the household head of a family of:

- 5 members (2 grandparents; 2 parents; 1 child in school education)

You own:

- 1 acre of tea

Apart from the income from tea you have an income from other sources of:

- 100,000 Rupees/year

Your aim is to cover the costs of the household every year and increase your livelihood:

- Food: 72,000 Rupees/Year
- Education: 50,000 Rupees/Year for the first 6 years and 100,000 Rupees/year for the next 4 years
- House maintenance: 15,000 Rupees/Year

Every round you have several options to choose from:

1. Buy land from your neighbours or from the bank
2. Sell land to your neighbours or to an outsider
3. Continue to grow the same crop or change to a different crop
4. Take part in an environmental scheme
5. Abandon the land and move to the city (sell the land)
6. Take a loan from the bank
7. Decide to spend less on food, education and house maintenance
8. Decide to stop the education of one of your children and ask their help in the agricultural field (that will reduce your agricultural production costs)

Information about different costs:

A. Converting from tea to vegetables requires a start up investment of 120,000 Rupees/acre
B. Converting from vegetables of tea requires a start up investment of 150,000 Rupees/acre and for three years no income will be produced
C. Price of buying/selling land from the bank is:
    - 1 cent of tea land: 40,000 Rupees
    - 1 cent of vegetable land: 40,000 Rupees

    If you want to buy land from your neighbour you have to negotiate directly.
D. If you are interested in taking part in an environmental scheme for some extra cash check with the environmental agency!

Appendix 6.2

Examples of crop yields, costs per unit of production and market prices used in the RPG

Cabbage								
Year	**Yield (acre)**	**Yield per acre (kg)**	**Price (INR/kg)**	**how many cabbages in an acre**	**Cost of production (acre)**	**Income (acre)**	**Profit**	**Cost-benefit ratio**
1	28340	33340	6	25646.2	102584.9	200040.5	97456	2.0
2	27935	32935	13	25334.8	101339.1	428157.9	326819	4.2
3	32308	37308	2	28698.2	114792.9	74615.4	-40178	0.7
4	31984	36984	4	28449.1	113796.3	147935.2	34139	1.3
5	31583	36583	6	28140.8	112563.1	201206.5	88643	1.8

Market-prices

Years with Season 3	**Cabbage** (INR/kg)	**Carrot** (INR/kg)	**Potato** (INR/kg)	**Beans** (INR/kg)	**Tea** (Rupees/kg)
Y	6-8	15-17	14-16	25-27	5.6-7.6
Y	13-15	19-21	20-22	23-25	6.6-8.6
N	2-4	16-18	16-18	24-26	6.5-7.5
N	4-6	24-26	29-31	25-27	8.6-10.6
N	6-8	35-37	22-24	20-22	10.6-12.6
N	4-6	15-17	17-19	29-31	8.9-10.9
Y	3-5	15-17	18-20	28-30	9.2-11.2
Y	5-7	21-23	24-26	35-37	12.2-14.2
N	5-7	15-17	14-16	21-23	12.5-14.5
N	10-12	25-27	28-30	22-24	10.6-12.6

Appendix 7.1

PLUSES Overview, Design concepts and Details

This Appendix provides complimentary data to the ODD+D processes detailed in Chapter 7. Thus, it only includes information of the processes that have not been explained in Chapter 7.

Structural elements	
Overview	1. Purpose *(detailed in Chapter 7)*
	2. Entities, state variables, and scales *(detailed in Chapter 7)*
	3. Process overview and scheduling *(detailed in Chapter 7)*
Design concepts	4. Design concepts
	• Theoretical and empirical background *(detailed in Chapter 7)*
	• Individual decision-making *(detailed in Chapter 7)*
	• *Basic principles (addressed in Theoretical and empirical background)*
	• Emergence
	• Adaptation
	• Objectives
	• *Learning (Not Applicable)*
	• Individual prediction
	• *Sensing (addressed in Individual decision-making)*
	• Interaction *(detailed in Chapter 7)*
	• Stochasticity
	• Heterogeneity
	• Collectives
	• *Observation (Not Applicable)*
Details	5. Implementation details
	6. Initialization *(detailed in Chapter 7)*
	7. Input data
	8. Sub-models

Design concepts

Emergence

There are two main outputs of the models that emerge from land use decisions and policy implementation.

Firstly, land use patterns emerge in response to land conversion prompted by more profitable land uses, enrolment in different schemes and land acquisition by the policy implementation agency.

Secondly, the diffusion of scheme uptake emerges from the relative profitability of the scheme compared to the return on investment from other land uses and the social network contagion (which means the more agents join the schemes the more likely it is that other will join too; see *Section 7.4.4.2*).

Adaptation

Agents can adjust their household budgets in response to their financial history of profit or loss.

Land use conversions and land transactions alter agents' landholdings. The total number of trees on the farm alters, in response to changes in agents' livelihood strategies prompted by changes in annual balance status. Decisions about land use strategies adjust also as a result of introducing new agro-environmental policies in the landscape.

Objectives

Households may differ in certain attitudes relevant to the schemes, and in which spending budgets are prioritised. However, agents' objectives are not explicitly represented in the model. The decision processes imply that agents are motivated by profits (and negatively motivated by losses) and the return on investment on land. Additionally agents aim to improve their livelihoods by increasing their spending and not allowing a too greater gap between the socioeconomic identities implied by their respective levels of spending with farming, food and other household costs. Decisions about land conversions or transactions are motivated by long-term benefits or urgent financial obligations, whereas financial decisions influenced by livelihood strategies are optimized using short-term interests.

Agents are also obliged to clear debt when it has been rolled over three years in succession. These influences are common to all households. Agents that cannot repay the debt and cannot meet a minimum cost of living for multiple years are forced to abandon their livelihoods and migrate out of the landscape.

Individual prediction

Agents are myopic, and base expectations of return on investment on the immediately preceding year's results. Where they have no personal experience, having not farmed any land that year, they consult their social neighbours for a local average estimate.

Stochasticity

There are a number of processes that are random or partly random.

Firstly, at initialization cloning households from the household survey creates the landscape population. The houses are randomly sampled and they have a uniform chance to be selected.

Secondly, agents belonging to a village receive randomly allocated fields within their own village boundaries (see *Section 7.4.5)*. The fields are allocated by growing from the centre of the village towards the edges.

In the process of buying and selling the land the order in which households are prioritised is subject to a random permutation function.

There is also stochasticity in the total number of patches enrolled under Scheme A and B. On top of enrolling 15-25% of viable patches, farmers could also enroll an additional 15% plus a random float to account for the variation observed in the role-playing game. The maximum amount of land that can be enrolled by each farm under Schemes A, B and C is 30%, 30% and 100% respectively.

Because the schemes are hypothetical and given that no scheme abandonment was registered in the RPG it was difficult to characterize the conditions under which farmers would leave the schemes. As a result, stochasticity is used to simulate scheme drop out events among enrollers (see Table 7.4).

The *noise* used in the production function is also a measure of stochasticity. Sampled from a normal distribution the value attributed to this residual accounts for variation in productivity of land, variation in price market, climatic conditions and soil fertility.

Stochasticity is also used to simulate farmers that want to grow vegetable crops for three seasons in a year. Depending on climatic conditions season three can bring a harvest or not. To account for this, the success of season three has a random probability.

Heterogeneity

The agents are not divided into typologies of behaviours, but they represent a heterogeneous population because they have different social identity (different farming, financial and enrolment preferences). For example each household prioritises spending on food, farming and other costs differently.

Agents also differ in their state variables e.g. the location in space, financial budget, land use type and landholding size.

Collectives

Farmers are part of six clusters delimitated by village borders. Within the village boundaries neighbouring farms form social networks. There is only one exception. Given the

geographical proximity of two of the villages (Kercombai and Milidhen) the social network transcends the administrative borders.
The formation of the social network is triggered by the proximity of farms and not by certain behavioural characteristics.

Implementation details

PLUSES is a Java operated model developed in NetLogo v. 5.3.1.
After the thesis publication the model code will be made available on an open model library known as openabm.org.

Input

ABM input data are organized by modules in a set of three Excel workbooks and one document containing five GIS files:

Input file	Explanation	Function
1. Scenario Manager	Defines the scenarios to be investigated	Scenario setup
2. Households	Basic characteristics of the agent population (e.g. family size, landholdings, income sources) and information on decision-making processes related to scheme enrolment, land use and financial strategies (e.g. allow trees on land or not, priorities food security over farming investments)	Defines the initial characteristics of the agents
3. Land cover	Information on the land use and land cover classes	Defines the LULC classes represented in the model
4. Villages	Information about the size of agent population (number of households and number of people) by village	Defines the initial settings of the modelled population
5. GIS	All spatial information including maps of land use and land cover, roads, distance to roads, villages, digital elevation model and village boundaries.	Defines the initial conditions of the environment

Sub-models

The sub-models can be divided in three main groups: 1) Policy enrolment and scheme drop out, 2) Balance status and 3) History of profit and loss.

1. Policy enrolment and drop out

Policy enrolment

Scheme enrolment follows a stepwise process that was presented in *Section 7.4.4.2*.

Once a farmer has decided to join a scheme, the size of land enrolled results from farmers' land use strategy and is additionally influenced by a scheme bonus (optional in the model) that neighbouring agents receive when they enroll together contiguous land over a certain adjustable threshold. Scheme enrolment concludes with: i) a subroutine that calculates the size of the land to be enrolled by each farm and the type of land use prioritized for enrolment and ii) an update on land conversion (from tea or agricultural land to wildflower meadows, tree plantations or intercropping), the number of trees cultivated under each scheme and the amount of compensation received from the policy implementer.

Scheme drop out

Every year there is a 10% chance that a farm will drop out of schemes. Farmers that enroll in Scheme B and C and decide to drop out pay a fee equivalent with 5% of the cumulated income received from the schemes over the duration of enrolment. This is to compensate the policy implementation agency for the loss of forested landscapes. Because Scheme A, wildflower meadows was set up as a flexible scheme to attract enrollers even for shorter periods of time there is no fee for dropping out.

2. Decision-making processes determined by balance status

Agents' annual balance (Equation 7.2) influences livelihood strategy choices.

$$\boldsymbol{Balance_{yi}} = \boldsymbol{Balance_{yi-1}} + \boldsymbol{Income_{yi}} - \boldsymbol{Cost_{yi}} \quad \text{Where } \boldsymbol{yi} = \text{current year}$$

Equation 7.2 Balance function

All agents follow this linear process. A positive balance means agents can perform any of the following actions in this order: conversion to a more profitable land use, land acquisition or save money for the next years if finances are not sufficient enough to perform any of the previous two actions. A negative balance requires one or several of the following actions to address financial shortages: access a bank loan, sell available timber, sell some of their land, sell all their land or, both sell all their land and leave the area. All of these possible actions (sub-models) are detailed in the next two sections.

Positive Balance

A. Conversion to a more profitable land use

This sub-model refers only to the conversion of land used for tea cultivation to agriculture or vegetable land and vice versa. Land use conversions resulting from scheme enrolment are detailed in *Section 7.4.4.2* and in earlier in this Appendix in *Section 1. Policy enrolment*.

Farm agents using information from their social network compare the information about the profitability of the two land uses every year. Agents decide to convert to a new land use when there is a more profitable alternative.

Decisions about land use conversion can include soft constraints (limited information) as well as hard constraints (budget availability). Soft constraints can create a fissure between the actual farm decisions and the economic optimum decisions when the agents' social network holds limited information about the profitability of different land uses. Hard constraints are straightforward and look at the agents' financial capacity to meet the costs of conversion. The costs of conversion from agriculture to tea (100,000 - 150,000 INR per acre depending on slope with 3 subsequent years of no harvest) are higher than those of converting from tea to vegetable cultivation (100,000 - 120,000 INR per acre depending on slope). However, the annual farming costs of vegetable land can be up to 6 times higher than those of tea plantations.

B. Land acquisition

Land acquisition is seen as a long-term investment of both landless households and those that already own land. Land can only be bought when it becomes available for sale on the local market, within an agent's own village.

The price of land (Equation 7.3) is established in NetLogo based on the land use type (agriculture, tea or forest), distance to roads and slope, with an inverse relationship between price and both slope steepness and distance to roads. The price can vary between 70,000 INR per patch of agricultural land to 400,000 INR per patch of forestland.

$$Price\ Land = f\ (Size\ of\ land, Land\ use\ type, Distance\ to\ road, Slope)$$

Equation 7.3 Price of land as a function of land use type, distance to road and slope

Negative Balance

A. Access bank loan

Agents faced with financial difficulties, which cannot cover their living expenses and farming costs, can apply for a bank loan that carries an interest rate. The interest rate and the number of years the agent is entitled to rollover the debt are adjustable in the model. All agents that apply for a loan receive one.

For this research the number of years and the interest rate have been maintained at the baseline value (see Table 7.4).

B. Sell timber

Timber sales occur on farms that either had trees at the beginning of the simulation or on those that cultivated trees as a result of scheme enrolment.

Land that has been converted to forestland or agroforestry through scheme enrolment caries a restriction on the number of trees that can be sold. No more than 10% of the total trees planted under Scheme B and C can be transacted. Agents can sell different tree species, native or exotic. The price of timber is established based on trees' age (Equation 7.4).

$$Price_{timber} = a + (age_{current} - age_{commercial\ value}) * b$$

Where a is a constant reflecting the standard price on the market and b is the value by which price increases with the age of the trees. The costs and fees for felling of trees and transportation charges paid to the Forest Department (INR 1,500) have been deducted from the price. Model settings: a=1500 INR; b=500 INR.

Equation 7.4 Price of timber as a function of tree age and commercial value

The older the tree the higher the value it receives on the market. Trees can only be sold once they reach a minimum age (10 years) dictated by commercial value. An upper age threshold (16 years) also exists after which tree prices stay the same. Once sold, agents will replant on the farm the same number of trees of the same type or of a preferred type if reported (preference reported in the household survey).

C. Sell land

The sale of land, like its acquisition, can only occur in the local market and it carries the same price formula (Equation 7.3). Transactions follow a prioritisation criterion derived from the value of land or restrictions and fines associated with scheme enrolment. More specifically agents will prioritise selling tea land over agricultural land, because tea land is less profitable. The farmers will also prioritise selling tea or agricultural land over any scheme land to avoid any fines from dropping out of the scheme.

D. Abandon land or leave the landscape

Agents will only reach this phase after they exhausted all other options for covering household costs and debts. Abandonment occurs when households can no longer satisfy a minimum living cost that can ensure their survival in the landscape.

3. Decisions based on profit or loss history

The history of profit or loss determines households' expectations of future income and the criteria based on which they adjust their spending. If households make a profit or loss for 2 consecutive years they will increase or decrease respectively their spending on food, farming and other household cost following a prioritisation procedure. Some households will prioritise increasing food spending prior to investing in farming, while others do the opposite (based on information from the in-depth household-survey data). Each of the three categories of spending, food, farming and household costs, have three groups of spending (low, medium, high). Households that are in the lowest group for food and household costs are considered food insecure and below poverty line. The thresholds between the groups are based on the first and third quartile derived from the household survey data. Increasing or decreasing budget will allow households to move between the three groups of spending (low, medium, high) for each of the three categories of spending (food, farming and other household costs). The households are not allowed to move from a "low" group to a "high" one in a single year or vice versa (unless they need to clear debt).

Appendix 7.2

PLUSES Validation and Verification

Data validity

Data Validity was established in three stages:

1) Household data validation was done using secondary data from the literature;

Data on household size distribution, landholding size and production on the farm were compared and found to follow similar distribution to data obtained during fieldwork from the Department of Statistics and Economics, documents later on released in the Nilgiris District Statistical Handbook (Department of Economics and Statistics, 2017).

Data on farm income and spending were validated by Horticulture Department (vegetables) and United Planters Association of South India (tea and vegetables), whereas data on food spending where similar to findings of Indian Institute of Pubic Administration (CPRC, 2009).

Because it was difficult to obtain and validate data on household income, debts and savings the model was constructed to include several options that can test the sensibility of the model to variation in these indicators. The lack of data on the financial balance of the household is considered a limitation of the model given its local importance. About 55% of the rural population of Kothagiri have access to and utilise banking services (District census handbook Nilgiris, 2011).

There was no secondary data available to validate the age of the trees on the farm and the Forest Department provided no records either.

2) Decision-making processes validation

The processes that informed scheme enrolment and the management on the farm were based on in-depth household survey data validated through the RPG workshops. The RPG provided additional information on farm management and enrolment and those data were discussed and validated with stakeholders.

Financial decision processes resulting from the RPG were discussed and validated during RPG debriefing sessions.

The Operation Validity

Operations and results of the final software and their validation with the real system:

1. Land conversion

There is a notable conversion of tea land to agricultural land in the model. While the household survey does not support these findings, Nilgiris Small Tea Growers Association and Tea Board (South India) confirmed that the tea-growing land area in Nilgiris is following a downward trend. The area under harvest has been reported to have decreased by up to 20% between 2004-2014 (Thiagarajan, 2014).

2. Outmigration/Land abandonment

About 6% of the households in the modelled landscape migrate out of the landscape and abandon their lands due to financial insecurity. Focus group data support these findings with the six Badaga villages under study reporting land abandonment up to 20%). While there is no reported official data on out migration, census data of the area shows that between 2001 and 2011 the population of Nilgiris district decreased with 3.51% (District census handbook Nilgiris, 2011)

3. Land Market

Results show that the land market is very dynamic with the total number of transactions exceeding the expectations derived from household survey data. The frequency of land transactions is not surprising considering that the low profitability of tea crops pushes farmers to land conversion, abandonment and sale.

4. Economic decisions

The model is fitted with validation charts that allow users to observe the fit of budget decisions (the cost of tea, the cost of agriculture, the cost of farm) to the initial data distribution. Under all scenarios tested the fit of the model produces results where $R^2 > 0.6$.

The Computerized Model Verification

The verification process was conducted in four main stages that included:

1. Debugging the model by verifying the code line;
2. Performing different subroutines and sub-models independently (data training) and in different combinations and observing if the programmed model accurately reflects the conceptual model. Additionally, the model was split in six agent-based models of the independent villages to observe the fitness of the model.
3. Setting up a tracking household tool that provides information about the decision processes that households take under given conditions. This tool has provided invaluable support in tracking errors and problems in the programming code.