Land-use dynamics of Kerala's agroforestry systems

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March 2015

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of Masters of Science

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Abstract

Kerala's homegardens are ancient agroforestry systems celebrated for their ecological sustainability, their subsistence potential, and their high diversity of cultivated species. While homegardens have occupied Kerala's landscapes for thousands of years, some are worried that these systems are under threat from comparatively profitable plantations of rubber and other monoculture-based tree crops. Thus, the aim of this thesis is to examine the land-use dynamics in Kerala's agroforestry systems between 2001 and 2013. In Chapter 2, I analyze high resolution satellite imagery in order to broadly characterize agricultural and non-agricultural land-use changes in three panchayats (counties) of Kerala. The results indicate that: 1) wetlands (mostly paddy rice) are decreasing in all study regions; 2) built surfaces are increasing dramatically in all regions; and 3) agroforestry exists in a dynamic equilibrium with other land covers. In Chapter 3, I use a combination of quantitative surveys and semi-structured interviews to identify land-use changes and their drivers at the homegarden scale for 115 homegardens in 8 panchayats. Results indicate that almost all commercial and food crops, as well as livestock, are decreasing in production on homegardens, and that no crops are increasing. Nearly every farmer interviewed perceived a decline in agriculture in their region, and offered numerous interrelated explanations for why this might be so. Overall, Kerala's landscapes are undergoing a dynamic, multi-scale transition away from both homegarden- and plantation-based agriculture.

Résumé

Les jardins familiaux du Kerala sont de ancients systèmes agroforestiers célébrés pour leur durabilité écologique, leur potentiel de subsistance, et pour leur grande diversité d'espèces cultivées. Bien que les jardins familiaux ont occupé les paysages du Kerala depuis des milliers d'années, certains s'inquiètent que l'existence de ces systèmes soit menacée par des plantations relativement rentables telles que celles de caoutchouc ou d'autres arbres de monoculture. Ainsi, l'objectif de cette thèse est de quantifier, de décrire et d'expliquer la dynamique d'utilisation des terres des systèmes agroforestiers du Kerala de 2001 à 2013. Dans le deuxième chapitre, j'analyse une imagerie satellite de haute résolution pour caractériser les changements des paysages agricole et non agricole dans trois panchayats (comtés) du Kerala. Les résultats indiquent que: 1) les zones humides sont en baisse dans toutes les régions étudiées; 2) les constructions humaines augmentent considérablement dans toutes les régions; et 3) l'agroforesterie existe en équilibre dynamique avec le reste du couvert terrestre. Dans le chapitre 3, j'utilise une combinaison d'enquêtes quantitatives et d'entrevues semi-structurées pour identifier les changements d'utilisation des terres et de leurs origines à l'échelle des jardins familiaux pour 115 jardins familiaux dans 8 panchayats. Les résultats indiquent que la quasi-totalité des cultures commerciales et alimentaires, ainsi que l'élevage, sont en baisse de production dans les jardins familiaux, et qu'aucune autre culture est en augmentation. Presque tous les agriculteurs interrogés ont perçu un déclin au niveau de l'agriculture dans leur région, et tous ont offert de nombreuses explications interdépendantes pour ces faits. Dans l'ensemble, les paysages du Kerala sont en cours d'une transition dynamique à plusieurs niveaux, qui s'éloignent des jardins familieux ainsi que des plantations.

Acknowledgements

I would first like to thank my supervisors Jeanine Rhemtulla and Navin Ramankutty. They have been the best supervisors imaginable, and I am very grateful for their guidance, motivation, kindness, patience, support, and friendship. My thanks also goes to the members of their labs, including Sylvia Wood, Martine Larouche, Sarah Wilson, Theraesa Coyle, Corey Lesk, Emily Clark, Delphine Renard, Dany Plouffe, Jordan Graesser, Verena Seufert, Larissa Jarvis, Jean-Sébastien Landry, Lisa Ribaudo, and Andrea Reid. These intelligent researchers motivated me, gave me inspiration, and listened patiently as I practiced talks and presented preliminary results in lab meetings. I would like to give special thanks to Sylvia Wood and Professor Sarah Turner for their detailed and helpful comments on the first draft of my thesis.

Without a fantastic field team I could never have collected such vast amounts of data. Furthermore, I would have gone crazy spending 5 months in India without having such a fun, silly, motivated, and intelligent group of good friends. So thank you to Corey Lesk, Theraesa Coyle, Nijin BS, Niyas Palakkal, and Haseena Kadiri for being so awesome and for making my fieldwork experience such a pleasure. My special thanks goes to Nijin for being the master of overcoming logistical hurdles – we would have been lost (literally) without you. Thank you also to Mohan (the cook) and Babu (security) at the international hostel of Kerala Agricultural University for being so lovely and helpful at every opportunity.

I must thank Dr. Kunhamu TK, Dr. Sudhakara K, Dr Mohan Kumar, and the rest of the faculty of the College of Forestry at Kerala Agricultural University for warmly welcoming my research team and I to Kerala. I would especially like to thank Dr. Kunhamu for his guidance and for taking so much time to help us come to India. We could never have been successful in our research without all of the work he did to ensure the success of our research program.

I would like to thank Jordan Graesser, Carlomagno Soto, and Julie de Gea for their continual help with all matters related to remote sensing. I had a great deal to learn about imagery analysis during my short time at McGill, and I would have never been able to do it without constantly pestering these three for help. Thank you to Dany Plouffe and Eva Snirer for their help on all things computer related. Thank you to Julie de Gea for translating my abstract into French, Pradeep Nair for helping me acquire a suitable digital elevation model of Kerala, and to Tim Fox for developing the Shape Splitter toolbox for ArcGIS. Thank you as well to Drs. Margaret Kalacska and Pablo Arroyo, and the McGill Geographical Information Center for granting me access to amazing computers and software that I would not otherwise have been able to use. Thank you to NSERC, the IDRC, the QCBS, the Department of Geography, and the Government of Alberta for helping to fund my Masters. Last but not least, thank you to Mom, Dad, Danielle, and Ben for being the best, most loving and supportive family ever, and cheers to my roommate Alex for cooking great food and keeping me sane by forcing me to have fun from time to time.

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Chapter 1 Introduction, literature review, and general objectives

1.1 The importance of agricultural land use

Agricultural land-use strategies have serious implications for global efforts to meet food demand while maintaining environmental sustainability (Foley et al. 2005). Earth's arable land is a finite resource, yet it has been exploited since the agricultural revolution at an accelerating rate in order to meet the nutritional needs of an ever-increasing world population. The resultant conversion of natural ecosystems to human-dominated landscapes has, in turn, been the single largest cause of terrestrial biodiversity loss (Pimm and Raven 2000). Nevertheless, despite these increases in yields and cultivated area, global targets to reduce malnutrition remain elusive (Rosegrant and Cline 2003; Wu et al. 2014), as some 800 million people in the world struggle to have enough to eat (Pinstrup-Andersen 2007). Thus, multiple perspectives have arisen on how landscapes can best be managed to simultaneously maximize both crop yields and species richness (Green et al. 2005; Vandermeer and Perfecto 2007; Phalan et al. 2011).

Food security and loss of biodiversity are not the only contemporary challenges facing agriculture. Others include, but are not limited to, provisioning of ecosystem services, water pollution, water availability, soil degradation, increased resistance of insects and weeds to pesticides, increasingly unpredictable weather and climate, increasing global demand for meat and luxury crops, public resistance to new biotechnologies, pre- and post-harvest wastage, closing yield gaps, and equitable distribution of food (Power 2010; Onstad 2013; Nelson et al. 2013; Boland et al. 2013; Jayasuriya, Mudbhary, and Broca 2013; Foley et al. 2011). Each agricultural land-use system (whether conventional monoculture, agroforestry, urban agriculture, homegarden, etc.) has a particular set of costs and benefits for each of the aforementioned challenges that, while already complex, is further confounded by local environmental conditions, culture, access to markets, infrastructure, resource availability, and so on. Thus, it becomes imperative that a comprehensive understanding is developed of the circumstances under which each agricultural land-use strategy is most appropriate, given local, regional and global environmental, economic and social targets.

1.2 Tropical homegardens

One of the least documented, least understood, and oldest agricultural land uses is the tropical homegarden. Kumar and Nair (2004) define homegardens as "intimate, multi-story combinations of various trees and crops, sometimes in association with domestic animals, around homesteads." In Kerala, India, homegardens have existed for at least 4000 years old, and range in size from less than 0.002 ha to a few hectares, with a mean size of 0.24 ha (Kumar 2006; Kumar 2008). Homegardens are unlike other forms of agriculture (including commercial agroforestry) in that a great variety of species are planted in a complementary manner to optimize the exploitation of light and humidity gradients both vertically and laterally. Canopy cover is roughly 140% in Kerala's homegardens, as shade tolerant and intolerant species are cultivated in tandem (Jose and Shanmugaratnam 1993).

Homegardens exist not only in South India, but across the tropics, and even in some temperate and arid regions. They have been studied in countries such as Brazil (Albuquerque, Andrade, and Caballero 2005), Zimbabwe (Maroyi 2013), Sudan (Gebauer 2005), Cuba (Esquivel and Hammer 1992), Indonesia (Abdoellah et al. 2006), Guatemala and Vietnam (Gladis et al. 2001), and elsewhere (Huai and Hamilton 2009). Around the world, homegardens are united by their high diversity of cultivated species relative to alternative agricultural options, their multi-functionality, and their ecological sustainability (Fernandes and Nair 1986; Gajaseni and Gajaseni 1999; Huai and Hamilton 2009). However, homegardens from different regions can differ depending on environmental and economic factors. In general, homegardens in lesser-developed countries such as Zimbabwe and Sudan play a greater role in terms of providing subsistence (Maroyi 2013; Gebauer 2005). In moderately developed regions such as Kerala and Indonesia, homegardens have a greater commercial emphasis (Abdoellah et al. 2006; Peyre et al. 2006). Finally, homegardens in developed regions such as New Zealand and the Iberian Peninsula are motivated mostly by traditions, lifestyle, or even for political reasons (Gaisford 2010; Reyes-García et al. 2012).

In general, homegardens are thought to embody greater environmental sustainability than conventional forms of agriculture. One of the greatest benefits of homegardens is the high diversity of both introduced and native species (Kumar et al. 1994). In a study of species richness involving 839 homegardens across Kerala, Kumar (2011a) documented 839 cultivated species of herb, shrub, and tree, with an average of 263 species per panchayat (the smallest unit of governance in Kerala). Overall, species richness was found to be greatest in small homegardens, though absolute species abundances were higher in large homegardens. Belowground biodiversity has also been shown to be higher in agroforestry systems than in conventional agriculture (Rahman et al. 2012). Furthermore, intraspecific tree diversity between homegardens has been shown to be high (Resmi, Celine, and Rajamony 2005; Abraham et al. 2006; Nayar 2011). Unfortunately, beta-diversity at a scale inclusive of homegardens and natural systems has not been established.

This high diversity of tree, shrub, and herb species fulfills numerous subsistence and commercial roles in Kerala (examples of uses include: food, beverage, timber, fuel, fibers, green manure, chemicals, latex, spices, oil, waxes, medicinal, charcoal, and others) (Kumar 2011b). A number of structural and functional ecosystem benefits exist in addition to the diversity of products yielded from homegardens. Examples include biogeochemical cycling, low biotic stress, intermediate levels of disturbance, and biomass accumulation comparable to that of natural systems (Kumar and Nair

2004). Indirect as well as social benefits may also exist, such as homegardens' high potential for carbon sequestration (Kumar 2011a), ecosystem services such as pollination, and the preservation of traditional ecological knowledge. However, little research has been done to support or reject any of these hypotheses (Kumar and Nair 2004).

Despite all of the aforementioned benefits of homegardens, there is no formal recognition of homegardens as a universally beneficial land use in Kerala (Guillerme et al. 2011). By extension, there exist few governmental policies or regulation incentives for those engaged in homegardening. In fact, state legislation has been known to act as a disincentive to tree planting on homegardens (Guillerme et al. 2011). Indeed, some suspect that Kerala's homegardens may be threatened by more profitable plantation-based agricultural systems (Kumar and Nair 2004).

1.3 General description of Kerala, India

Kerala is a small state in southwest India (8°18'-12°48' N and 74°52'-77°22' E) with a geographical area of roughly 3.89 million hectares. The state consists of three topographically distinct regions that run parallel to each other in a NW-SE direction: a flat coastal region in the West, rolling midlands in the centre, and the Western Ghats bordering Tamil Nadu to the east. Despite being densely populated, Kerala is considered to be a global biodiversity hotspot (Myers et al. 2000), and consists of approximately 1.1 million hectares of effective forest, of which 22% is protected (Kerala Forest Department 2012). The primary forest types are tropical wet evergreen, semi-evergreen, tropical moist and dry deciduous. The forests are now largely confined to the Western Ghats, where they serve as habitat for some 4000 flowering plant species, of which more than 25% are endemic (Sreedharan 2004). The state also boasts more than 100 species of mammals and nearly 500 known bird species (Prasada, Rao, and Rao 2010). The climate is maritime tropical and is subject to two monsoons annually, resulting in mean annual rainfall of 3.1 m with over 5 m in some regions. Average temperatures are high year round, ranging from 20 to 37 degrees Celsius.

Kerala is a paradox in that it scores high on social indicators of wellness but poorly on economic ones. The state ranks very high among Indian states for Human Development Index (0.79), literacy rate (94%), life expectancy (76.8 years), and sex ratio (1084 women per 1000 men) (India Planning Commission 2008; India Planning Commission 2011; Government of India 2011). Kerala's economy is mostly service-sector-oriented (64% of the Gross State Domestic Product in 2002-2003), and unemployment is high, at 14.8% in 2010 (India Planning Commission 2008; H. Singh and Kumar 2014). Furthermore, overall economic growth and development in Kerala has historically lagged behind most other Indian states, which has led economists to wonder how this “Kerala Model” has made it possible for human development to remain consistently high (Parayil 2000). However, the high levels of educational achievement coupled with low investment and industrial growth have meant that youth emigration rates are high and foreign remittances account for a considerable proportion of GDP. For example, the Kerala Gulf diaspora currently sees some 2.5 million Keralites (mostly men providing unskilled labour) working mostly in United Arab Emirates, Saudi Arabia, Kuwait, and Oman, and sending home between $7-10 billion USD each year, which is nearly double the budget of the entire state (Prakash 1998; Kunniparampil Curien Zachariah, Mathew, and Rajan 2001).

1.4 A brief history of agriculture in Kerala

Gold and pottery left by Roman spice merchants are evidence that Kerala has been part of a globalizing world economy for at least 2000, and perhaps as many as 5000 years (Jeffrey 2001). Beginning in 1498, the subsistence-based, matrilineal, and Malayalam-speaking provinces that eventually joined to form Kerala were successively colonized by the Portuguese, Dutch, and finally the British. The British oversaw a universal transition to a cash economy, such that by the early 1900s the practice of paying taxes in kind was abolished. Despite being an agrarian society, it did not take long for the state's steadily growing population to outstrip domestic food production. By 1930, with a population of 10 million, Kerala was already importing at least 50% of its rice, with most of the shortfall coming from Burma (Jeffrey 2001). In 1943, Japan's invasion of Burma put all exports on hold. While the ensuing food crisis in Kerala paled in comparison to the concurrent Bengal famine, food was extremely scarce and a generation was measurably stunted. Nevertheless, World War II set the stage for a period of unprecedented transition for the people of Kerala. Just after the war, in 1947, India gained independence from the British, and in 1956, Kerala was formed. It would be led by the world's first democratically elected Communist party.

Kerala has experienced a number of dramatic agricultural land-use changes over the last half-century. These changes have been mainly compositional, in that the total amount of land under agriculture and forest have remained relatively stable since the 1970s, while the agricultural systems employed have been in a constant state of transition (Kumar 2005). Area under rice cultivation has dropped dramatically, beginning in the 1970s, due largely to a general lack of labour and the desire to cultivate more valuable crops such as rubber, coconut, and areca (Figure 1-1; Kumar 2005; Raj and Azeez 2009). Concomitant with the decline in rice have been steady increases in both coconut and rubber farming. Rubber, which was initially grown on marginal lands, has become very popular in recent years due to its low maintenance and relatively high market prices (Viswanathan and Shivakoti 2008). According to the 2008 Kerala Development Report (India Planning Commission 2008), the greatest declines since the mid-1970s have been seen in rice, cassava, and cashew nut, while cultivation of coffee, coconut, rubber, pepper, and ginger is on the rise (India Planning Commission 2008).

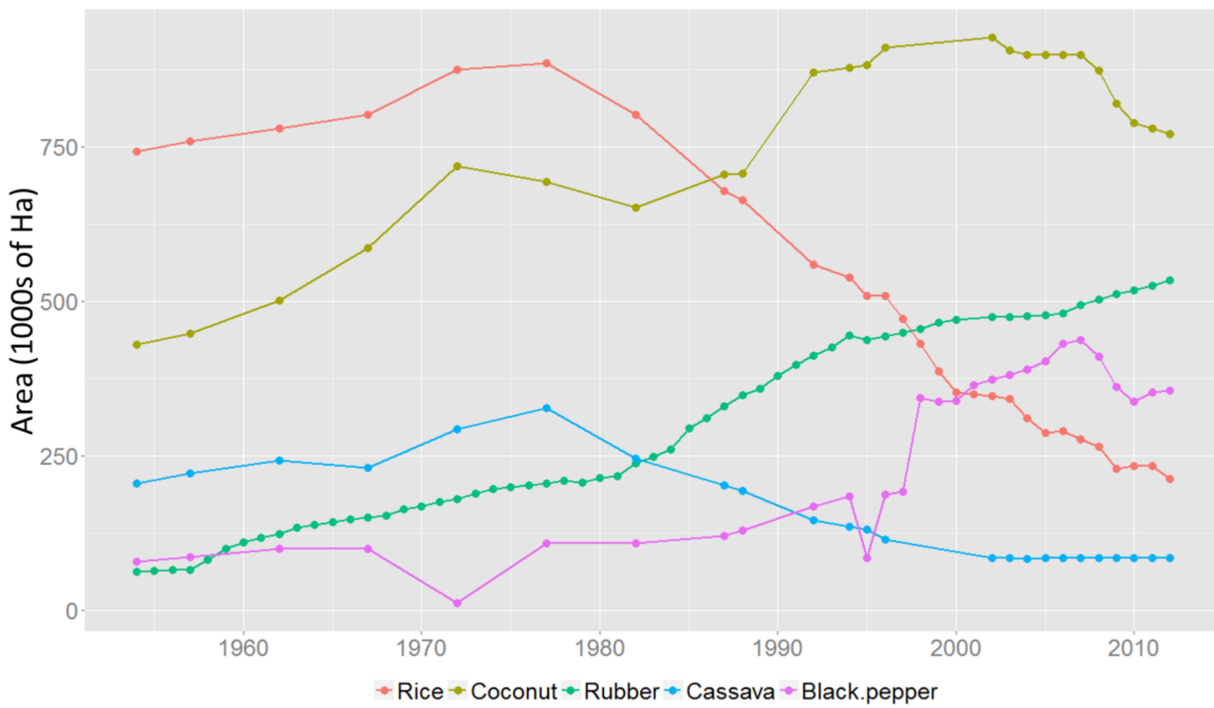

Figure 1-1. Changes in composition of Kerala's major commercial crops, 1954-2012 (sources: State Planning Board, Government of Kerala (1954-1991), Ministry of Agriculture, Government of India (1995—2011).

Little is known about how homegardens have been affected by these trends. It is generally assumed that homegarden extent has decreased in recent years, and that it has likely been replaced with rubber and coconut plantations (Kumar and Nair 2004), though not enough research has been conducted to provide sufficient support to these claims. Guillerme and colleagues (2011) used a qualitative approach to show that certain trees, such as cashew, rosewood, and tamarind are becoming less common, while others, such as rubber and eucalyptus are increasing in occurrence. However, one can only loosely infer that these changes are the result of homegarden loss.

1.5 Thesis objectives and structure

The aim of my thesis is to develop a better understanding of recent land-use trajectories in rural Kerala. My thesis research focuses first on Kerala's overall landscapes in order to characterize recent changes between dominant land-cover types. With the landscape context in place, I then narrow in to the scale of the homegarden in order to develop a comprehensive understanding of how and why the observed changes are occurring from the homegardener's perspective, and if any additional small-scale changes are occurring that could not be detected at the landscape scale. In order to address research aims at differing scales, I combine elements of both physical and human geography. This combined approach provides complementary information that builds greater confidence in results, as well as the opportunity to identify the benefits and challenges of such diverse approaches to land-use change analysis.

My thesis is composed of four chapters: this introduction (chapter 1), two research chapters (chapters 2 and 3), and a conclusion (chapter 4). Chapter two focuses on landscape-scale land-cover change dynamics between 2002 and 2012 using high resolution satellite imagery. Chapter three uses a combination of surveys and semi-structured interviews to identify and elucidate land-use management decisions made by homegardeners from 2003 to 2013. The specific research objectives and associated questions I seek to address for each of these two chapters are presented below.

Objective 1 (Chapter 2): Use remote sensing to measure and describe land-cover change at the landscape scale

- How has land cover changed in Kerala between 2002 and 2012?

- Has agroforestry cover declined from 2002-2012? If so, what land cover has replaced it?

Objective 2 (Chapter 3): Conduct surveys and interviews to gain further insights at the homegarden scale

- What major food and commercial crops are bought, sold, and cultivated by homegardeners?
- How has the production of major crops and livestock changed from 2003 to 2013?
- What are the drivers and implications of land-use change?
- What are homegardeners' intentions for the future?

Chapter 2 Kerala's transitioning agricultural landscapes

2.1 Introduction

Kerala, a densely populated (859 people per km^2) tropical state in South India, has a long and diverse agricultural history (Chandramauli 2011). For most of this history, Kerala was a major rice-producing region (Kumar 2005). Rice remained Kerala's most important crop until the mid-1980s, when its cultivated area dropped from over 800 000 ha to fewer than 250 000 ha in 2009 (Figure 1-1). Over approximately the same period, Kerala witnessed an increase in the cultivated area of coconut, rubber and black pepper, indicating a clear shift towards a heavier reliance on agroforestry, or tree-based crops. However, since the mid-1990s the increase in agroforestry crops has also abated, with only rubber increasing steadily, albeit slowly (Figure 1-1).

Today, most of Kerala's major crops, aside from rice and cassava, are agroforestry-based, meaning either that crops are grown under a canopy or that the crops themselves are trees. The most common agroforestry crops in Kerala include rubber, coffee, coconut, mango, jackfruit, arecanut, and cashew, as well as pepper, cardamom and other spices. While Kerala's agroforestry systems have countless manifestations, they can generally be classified into one of three categories: 1) shade-grown commercial crops such as tea, coffee, and cacao; 2) tree-based commercial crops and silvopastoral systems, such as rubber, coconut, and areca; 3) tropical homegardens (Guillerme et al. 2011). Homegardens are crop-diverse farms around the homestead, and are generally less than a hectare in size (Kumar 2011a). They are thought to encompass roughly 50% of Kerala's agricultural land, and deliver multiple functions, including provision of food, construction materials, spices, medicines, fuel, fodder, and income to homegardeners (Kumar 2011a).

While Kerala's agroforestry types can be split into shade-plantations, tree-based plantations, and homegardens, the lines between these three classes can be profoundly blurred. For example, plantation crops such as rubber and areca are often grown on homegardens, and homegarden crops such as jackfruit and mango are often used as shade cover for plantations crops such as coffee and cardamom. And while some researchers fear that plantation-style agroforestry is gradually replacing homegardens (Kumar and Nair 2004, Peyre et al. 2006; Guillerme et al. 2011), data from the year 2000 onward indicate a clear decline in the cultivated area of most plantation crops (e.g. coconut and pepper, but not rubber, which is increasing slowly) and non-agroforestry crops (e.g. rice and cassava) (Figure 1-1). Therefore, recent land-use data (Figure 1-1) combined with anecdotal reports of homegarden decline (see Kumar and Nair 2004; Guillerme et al. 2011) together suggest that Kerala is undergoing a shift away from agriculture on all fronts, including both agroforestry (plantations and homegardens) and non-agroforestry (paddy and cassava) land uses.

In this chapter I use high resolution satellite imagery in an attempt to provide better insight to the major land-cover changes occurring at the landscape scale in Kerala. I conduct classification and change detection analyses for three topographically, ecologically, and agriculturally distinct rural sites. The questions driving this study arise from the need to determine whether the perceived decline in agroforestry is real, and whether there are competing land uses (e.g. built environments, wetlands) replacing Kerala's agroforestry landscapes.

The two primary questions guiding the research in this chapter are:

1) How has land cover changed in Kerala between 2002 and 2012?

2) Has agroforestry declined during this period? If so, what land cover has replaced it?

2.2 Methods

2.2.1 Study Areas

I selected three study areas to represent Kerala's broad environmental and demographic diversity. Each of these study areas was represented by one panchayat, the smallest unit of rural governance in Kerala (similar to a county). The three panchayats, Avinissery, Kalikavu, and Poothrikka, were selected first by filtering out panchayats lacking historical coverage of remotely sensed data, and then by attempting to maximize representation of Kerala's diverse landscapes (Figure 2-1). Avinissery is a low-lying, densely populated rice producing panchayat with a small average farm size (Figure 2-2a). Kalikavu, up in the mountains, produces large amounts of rubber, in addition to coconut, and has a relatively low population density (Figure 2-2b). Poothrikka, which lies further to the south, is between Avinissery and Kalikavu in terms of population density and elevation, producing both rice and rubber, in addition to pineapple and other homegarden crops (Figure 2-2c).

2.2.2 Data Description and Preprocessing

I acquired two high-resolution multispectral images for each panchayat by attempting to minimize seasonal variation while selecting images from as close as possible to 10 years apart (Table 2-1). The three images from early 2000 are IKONOS-2 (0.8 m panchromatic resolution), and the three images from 2012 are from the GeoEye-1 satellite (0.5 m panchromatic resolution). There were few instances in which two images sufficiently overlapped a panchayat, and fewer still on cloudless or near-cloudless days. The highest quality, most representative images for Avinissery, Kalikavu, and Poothrikka were 11.6, 8.4, and 9.8 years apart, respectively. In terms of seasonality, the differences between images, which are up to 4 months, are not expected to compromise classification results as each image was acquired during the dry season.

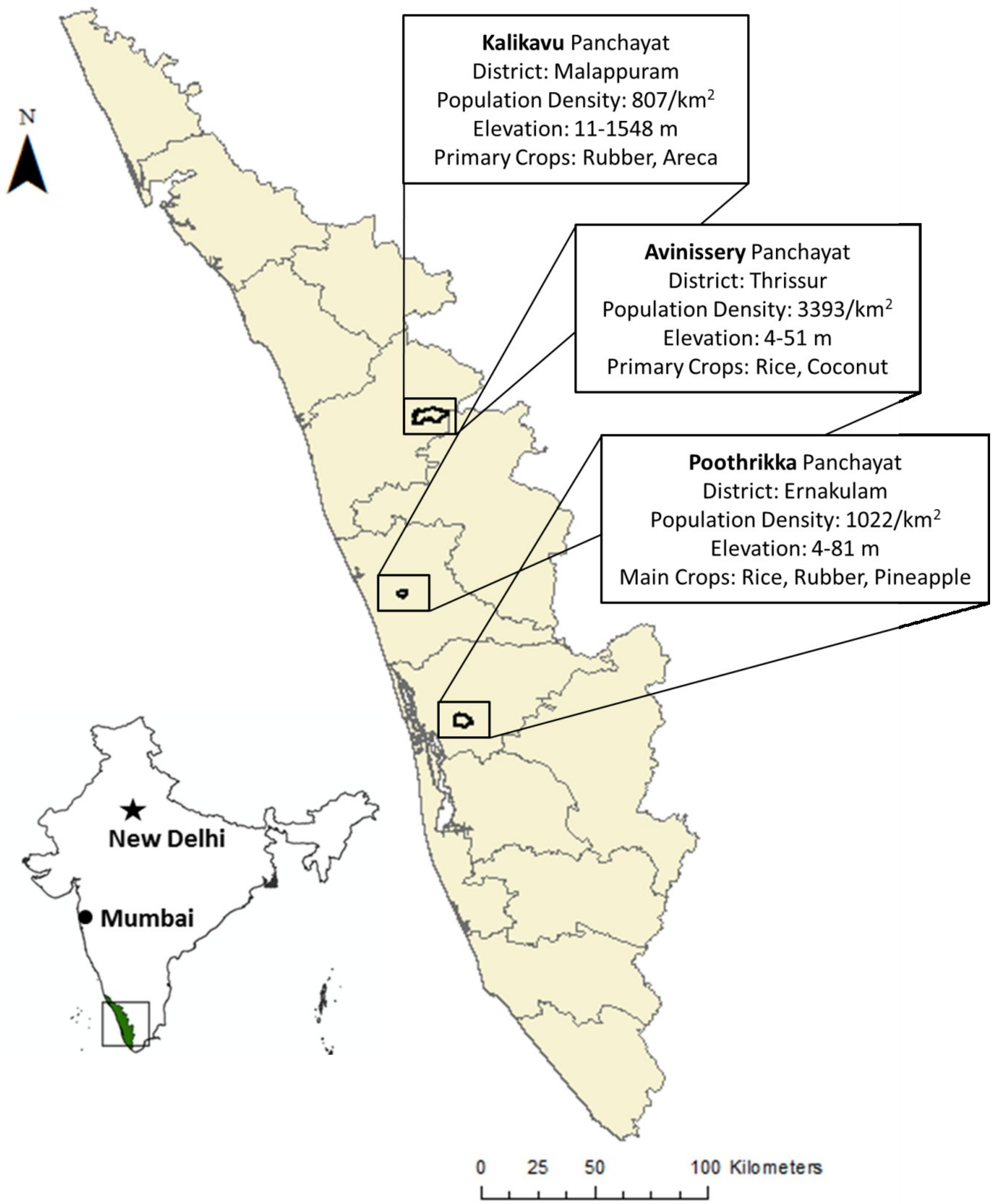

Figure 2-1. Kerala state with district boundaries outlined. Focus is on the three study locations used: Avinissery, Kalikavu, and Poothrikka panchayats.

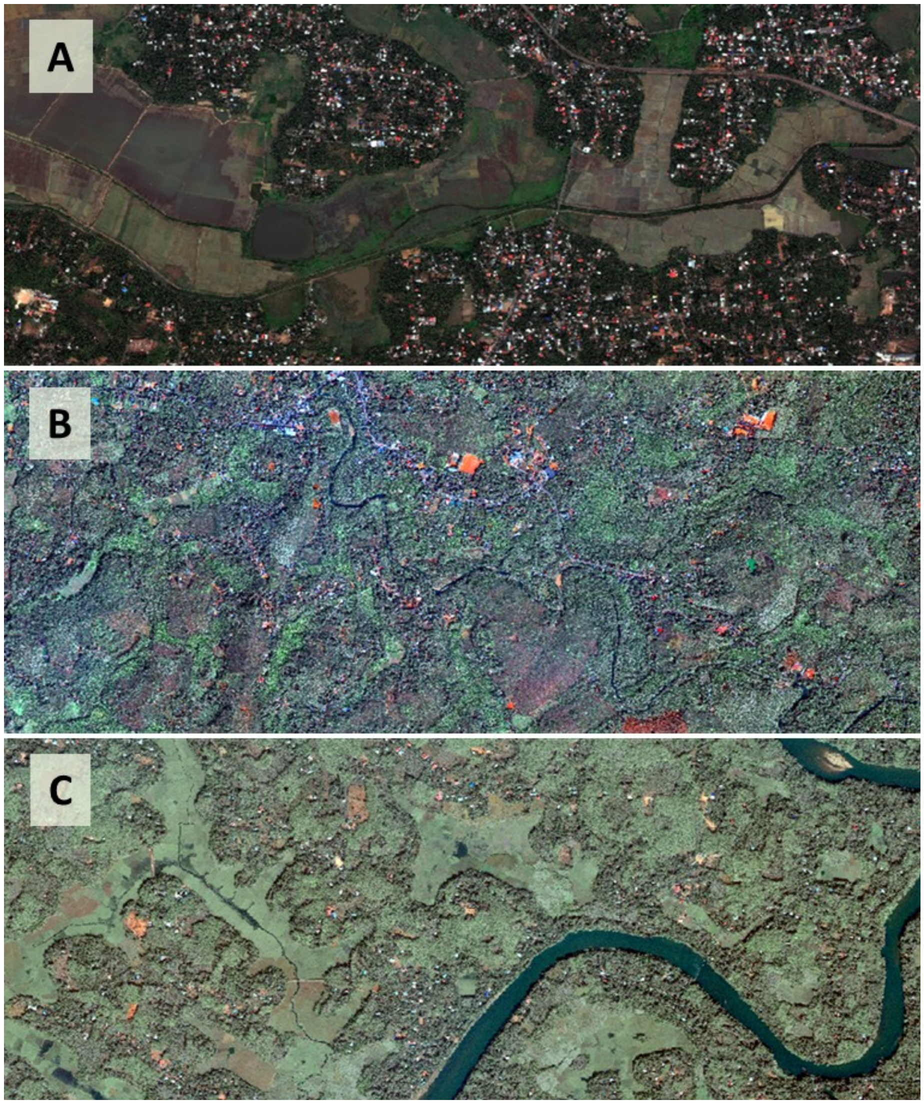

Figure 2-2. Landscape perspective (1:20 000) of Avinissery (A), Kalikavu (B), and Poothrikka (C). Avinissery is the most densely populated, followed by Poothrikka and then Kalikavu, which is at a much higher elevation. Avinissery and Poothrikka have paddy rice wetlands, which are the smooth, contiguous areas separating the speckled, inhabited zones of A and C. Kalikavu does not have wetlands, having only agroforestry-based agriculture. The red and orange patches are exposed soil and rooftops.

I georeferenced the 2012 GeoEye-1 images using ground control points collected between June and November 2013. IKONOS-1 imagery was then co-registered to the GeoEye-1 images, and all images were orthorectified using a 30 m ASTER digital elevation model. For pixel-based classification, images were converted to reflectance using ENVI's FLAASH module. For manual classifications, all images were pan-sharpened in order to improve classification accuracy. All preprocessing techniques were conducted using a combination of ArcGIS (version 10.2.2; ESRI 2014) and ENVI (version 5.1; Exelis 2013)

Table 2-1. Satellites and imagery used.

Panchyat	Satellite*	Bands†	Resolution‡ (m)	Coverage (km^2)	Date	Cloud (%)
Avinissery	IKONOS-2	4+Pan	3.2 (0.8)	27.06	4/2/2001	0
Avinissery	GeoEye-1	4+Pan	2.0 (0.5)	42.84	12/10/2012	5
Kalikavu	IKONOS-2	4+Pan	3.2 (0.8)	34.81	9/22/2003	0
Kalikavu	GeoEye-1	4+Pan	2.0 (0.5)	34.81	1/13/2012	0
Poothrikka	IKONOS-2	4+Pan	3.2 (0.8)	44.88	4/13/2002	0
Poothrikka	GeoEye-1	4+Pan	2.0 (0.5)	44.88	2/1/2012	0

*IKONOS-2: launched 29/09/1999, Global Average Georeferenced Horizontal Accuracy: 15 m
Geoeye-1: launched 06/09/2008, Global Average Georeferenced Horizontal Accuracy: <4 m
† spectral band wavelength range (in nm) for IKONOS-2: Panchromatic - 526 to 929, Blue - 445 to 516, Green - 506 to 595, Red - 632 to 698, NIR - 757 to 853; GeoEye-1: Panchromatic - 450 to 800, Blue - 450 to 510, Green - 510 to 580, Red - 655 to 690, NIR - 780 to 920
‡ presented: multispectral (panchromatic)

2.2.3 Pixel-based vs. Manual Classification

Traditional pixel-based classification methods (i.e. supervised classifications) would normally be sufficient to obtain a satisfactory estimate of land covers in an IKONOS or GeoEye image (e.g., Mumby and Edwards 2002; Goetz et al. 2003; GUTIERREZ and JOHNSON 2012; Fretwell et al. 2012). Thus, I conducted preliminary supervised classifications for Avinissery, but even the best results generated from the IKONOS-2 imagery were not sufficiently accurate for the purposes of this study (Appendix A). This can be attributed to the fact that Kerala's rural landscapes are highly complex, consisting of a mosaic of mixed agroforests, paddy fields at various stages of cultivation, houses and roads often partially or entirely obscured by overhanging trees, and uncultivated wetlands, which often hold standing water. Furthermore, it is difficult to account for shadow in high-resolution imagery, especially in regions with many abrupt changes in micro-topography (Lillesand et al. 2004), such as when coconut trees border a paddy field.

I therefore adopted a manual classification approach for this study. Manual classification (i.e. digitizing land cover polygons by hand), while more labour-intensive, allows for the use of landscape context, texture, and shape in classifying, and makes it easier to classify based on land use as opposed to only land cover (Lillesand et al. 2004; Lu and Weng 2007). For example, if only using spectral information, parts of a wetland may resemble a dirt road, a bare green field, a lake, or a recently planted agroforest depending on the stage in cultivation. However, where wetlands are situated relative to other land uses is very apparent when looking at an image with context (Figure 2-3a). Similarly, pixel-based methods will inevitably lead to an under-estimate of buildings and roads, which are often obscured by trees. Much of this discrepancy can be accounted for using a manual approach, as the shape of the building can be inferred from those parts of it not obscured by foliage (Figure 2-3b). Manual, or a combination of manual and object-based classification has been used in numerous other studies for complex landscapes (e.g. Gibbs et al. 2010; Ramdani and Hino 2013).

However, manual classification is much more time consuming than pixel-based approaches, thus fully classifying each of the 6 images was not feasible (Achard et al. 2012; Shimabukuro et al. 2014). Instead, I adopted a systematic unaligned sampling approach (Bellhouse 1977). I selected 16 sample regions from each panchayat by splitting the overlapping extent of each image pair into 8 equally-sized segments, randomly placing two points in each section, and generating a square buffer of 0.75 ha around each of the 96 points. In order to ensure that the 16 sample regions selected from each image were representative of the broader landscape composition, the maximum likelihood results from the samples were compared to those of the overall image

(Table 2-2). I found the samples to be highly representative of the land cover composition of each image, with differences ranging from 0.2 to 7.9 percent.

Table 2-2. Maximum likelihood classification results (% area) for image samples compared to overall images using GeoEye-1 2012 imagery in each panchayat.

	Avinissery			Kalikavu			Poothrikka		
	Sample	Region	Dif	Sample	Region	Dif	Sample	Region	Dif
agroforest	46.0	53.9	7.9	83.6	87.2	3.6	58.1	56.4	-1.7
bare	3.6	2.1	-1.5	8.9	7.2	-1.7	1.0	2.3	1.3
built	11.5	11.7	0.2	7.3	5.5	-1.8	12.6	9.4	-3.2
water	0.6	0.9	0.3	0.1	0.1	0.0	0.1	1.9	1.8
wetland	38.2	31.4	-6.8	0.0	0.0	0.0	28.2	30.0	1.8
∑ (%)	100	100	0	100	100	0	100	100	0
∑ area (km	0.36	36.40		0.36	22.41		0.36	44.90	

2.2.4 Class Selection

I classified all images into five land-cover classes (built, bare, agroforest, wetlands, and water). The built class consists of all buildings, paved surfaces, and major unpaved roads. The bare class consists of any bare ground, which is usually either exposed red soil or sparsely-vegetated non-agricultural surfaces. The wetland class consists of all cultivated, fallowing, and non-cultivated wetland areas, which are traditionally used for growing rice. The agroforestry class contains all treed agricultural land cover outside of wetland areas, and consists almost entirely of mixed agroforestry, including homegardens and plantation crops: mainly rubber in Kalikavu, and arecanut and coconut in all three panchayats. The agroforestry class was not further subdivided into mixed and monoculture varieties due to the complexity of the landscape; there are as many flavours of mixed agroforestry as there are farmers in Kerala, and most are somewhere in between mixed agroforests and what are typically monoculture-grown cash crops. Furthermore, while non-treed dryland agriculture (e.g. cassava) exists in certain parts of Kerala, it is uncommon in the three panchayats used for this study and does not merit a class of its own.

Agroforestry and wetlands are easily distinguishable from one another due to landscape configuration and the connectivity of Kerala's wetlands (Figure 2-3a). Water bodies, such as ponds, reservoir tanks, and rivers were also easily identified in all images, which were displayed using the NIR band to assist in their delineation. A "forest" class was not included as Kerala's forests occur almost uniquely in protected regions along the Western Ghats. Unprotected areas, such as the three panchayats used in this study, are almost exclusively designated for private and non-conservation-based public land uses.

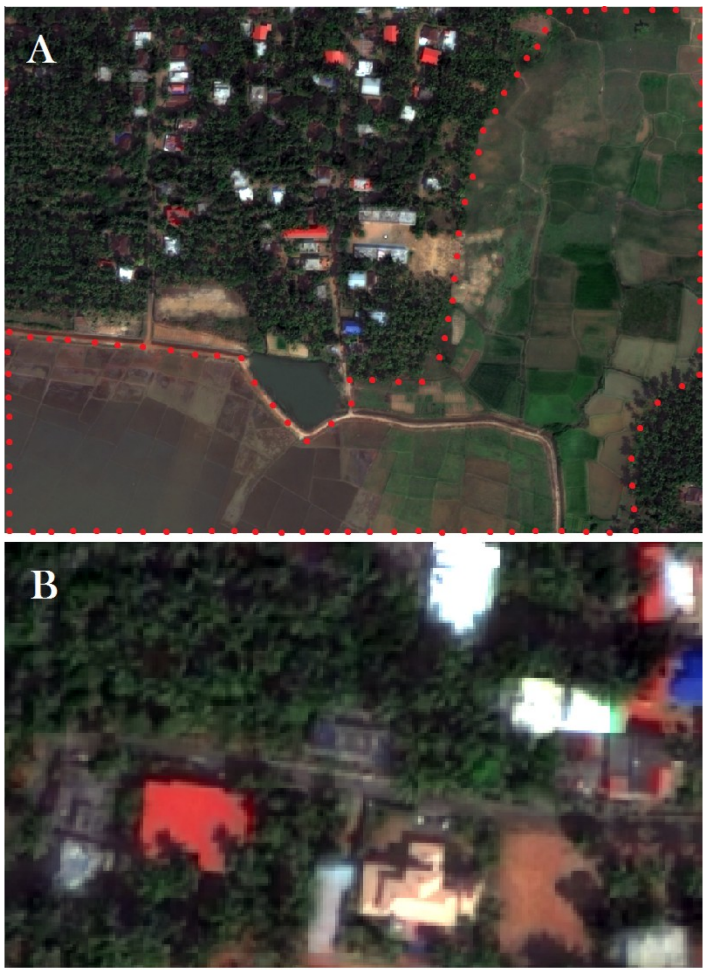

Figure 2-3. A) Description of potential spectral complexity of the wetland class (wetland outlined with dotted red line) and ease with which it can be identified with the use of context and configuration. B) Example of roads and buildings obscured by trees and their shadows. These are easy to classify during manual classification, but hard using a pixel-based approach.

2.2.5 Classification Methodology and Rule Set

I projected each of the 96 sample images using the UTM zone 43N projection, before manually classifying them by digitizing image objects into shapefiles (Figure 2-4). A 25 square meter box was used to determine minimum object size; if any of the feature's axes were longer than 5 m, it was classified as a unique object. Linear features that were too narrow for identification were ignored, meaning that most features were at least 2-3 pixels in width. When feature identity was ambiguous, images were manipulated first by adding the full image so that context could be used, and then by displaying the image using different band combinations. In the very rare case that a feature was still unidentifiable, the sample image was opened in eCogntion (specialized software for remote sensing analysis), and the object was isolated using an appropriate segmentation, and compared against other objects for similarities in texture, shape, spectral properties, and other attributes. A post-digitization cleanup was conducted to ensure that polygons were not overlapping and that no areas were omitted. In some cases it was difficult to distinguish between agroforestry and older roofs in the lower resolution and earlier date IKONOS-2 imagery. In order to remain conservative about the hypothesized finding of rapid rural development in Kerala, I classified those ambiguous features as the built class.

It was not possible to conduct a validation for the manual classification. While ground truthing data were collected, I did not have access to differential GPS, and there were no base stations close enough to our field sites that could be reliably used for augmentation. Furthermore, landscapes in Kerala are in constant transition, with vegetation growing rapidly and sometimes being cleared several times per year. This makes validation for the older IKONOS-2 imagery impossible and validation for the more recent GeoEye-1 imagery questionable at best, since the time between image collection and fieldwork ranged from 9 to 20 months. Fortunately, the features of interest are easily identified using high resolution imagery such as that used for this study. In fact, it is not uncommon for GeoEye-1, IKONOS-2, or even RapidEye imagery to be used to validate lower resolution imagery in both tropical (C. Huang et al. 2009; Potapov et al. 2014) and temperate (Wickham et al. 2013) regions when ground truth data are not available.

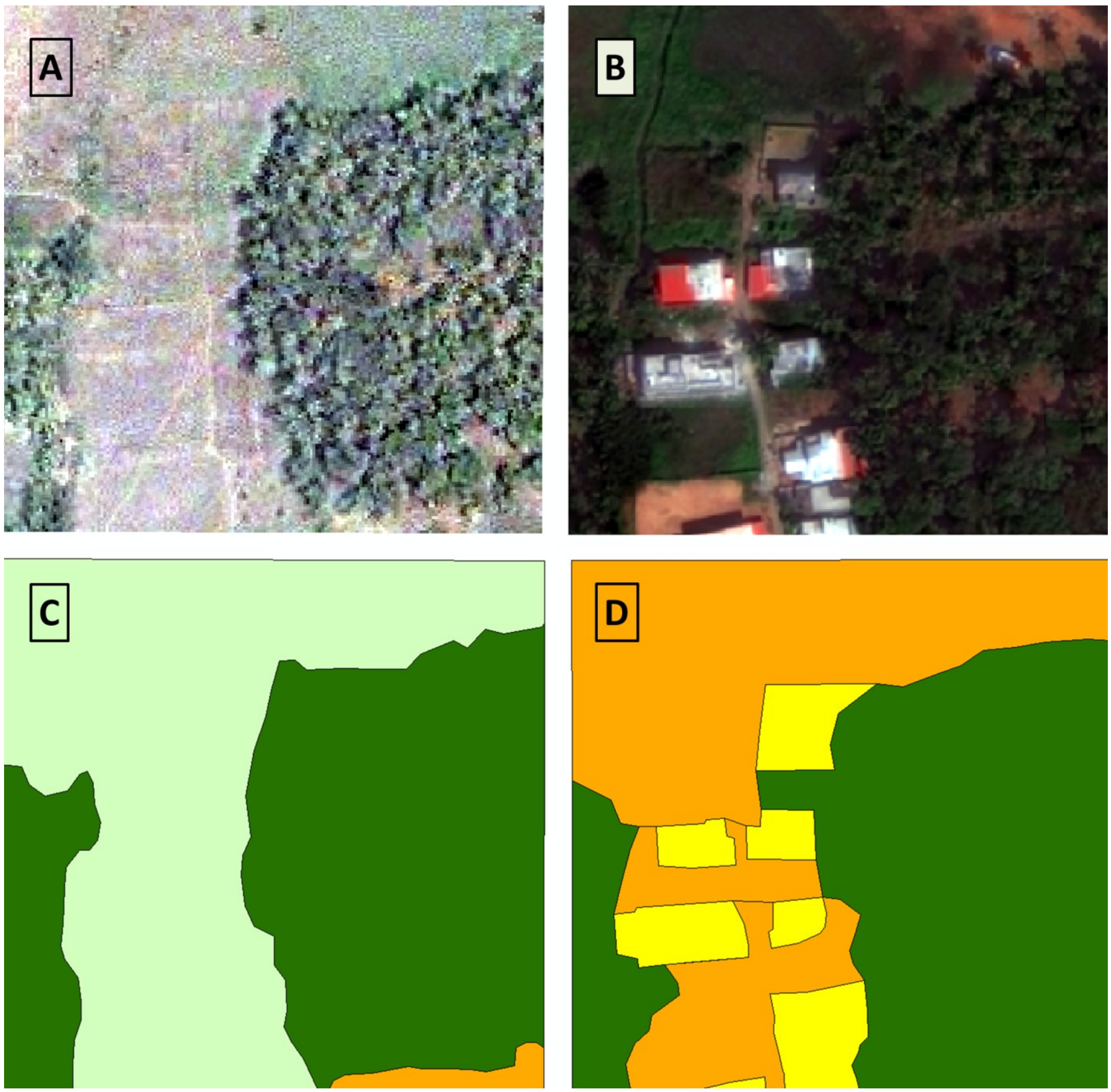

Figure 2-4. Examples of imagery used and manual classification results for one sample region in Avinissery: A) 2001 IKONOS-2 imagery, B) 2012 GeoEye-1 imagery, C) 2001 classification, D) 2012 classification. Classes present are agroforest (dark green), wetland (light green), bare ground (orange), and built (yellow).

2.2.6 Change Detection

A change detection analysis was conducted on classified images by converting them to raster files and assigning unique numerical values to each raster based on class (A. Singh 1989). This allowed me to subtract one image from the other, which resulted in a unique output for each unique class change (or lack thereof). I reported change detection transitions as both transition probability matrices (which express change as a proportion of initial conditions) and absolute change in square meters. In both cases, a first-order Markov model was used to correct for differences in image acquisition dates (Urban and Wallin 2002). Markov models make predictions of land cover composition for unclassified landscapes based on compositional changes that are known to have occurred on the same landscape over a different time period (Usher 1992). As the two images used for Avinissery, Poothrikka, and Kalikavu were collected 11, 10, and 9 years apart, respectively, we used the Markov model to standardize the period of transition to 10 years: from 2002 to 2012.

2.3 Results

There were three main findings across panchayats. First, there were pronounced increases in built surfaces in all areas (Figure 2-5). Approximately 50% of built surfaces mapped in 2012 were not present in 2002, with new contributions coming primarily from agroforest (36%), but also from bare ground (10%) and wetland (4%; Table 2-3). Second, wetland and paddy area declined considerably, with losses averaging 20% across rice-growing regions (Figure 2-5). While most of the wetland losses were accounted for by bare ground and agroforest (roughly 45% each), nearly 10% of lost wetlands were replaced by built surfaces (Table 2-3). Nearly 99% of wetland mapped in 2012 was also wetland in 2002 (Table 2-3), meaning that there have been virtually no conversions into this land-cover class. Finally, agroforests, which declined in two panchayats and increased in one, appeared to be in a complex dynamic equilibrium with the other land covers (Figure 2-6). In general, the agroforest class was a sink for wetlands and a source for built area (Figure 2-6). In other words, it appears that agroforests are being replaced by built surfaces, but are not necessarily declining because they are encroaching upon wetlands.

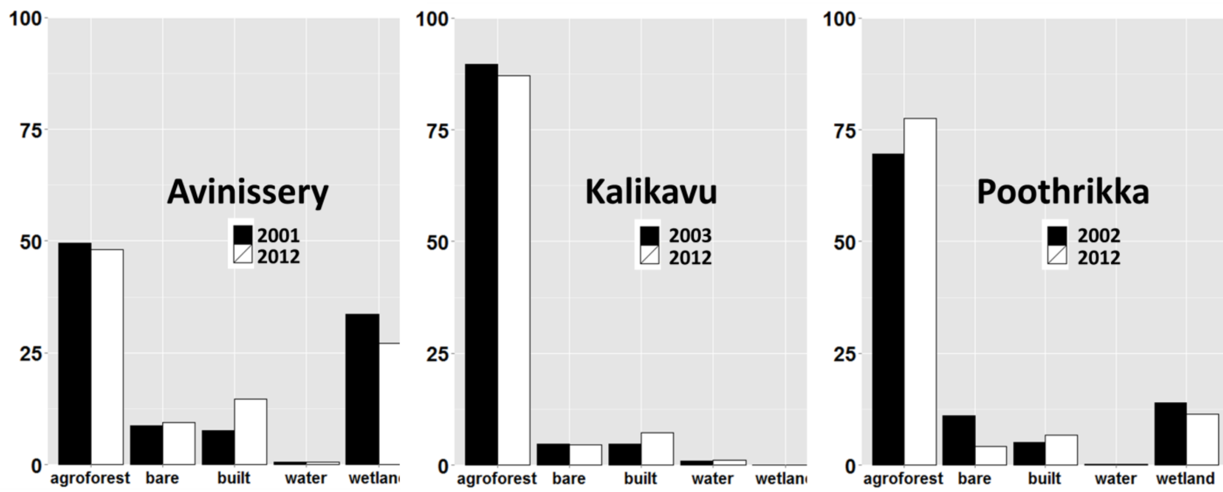

Figure 2-5. Land-cover changes for A) Avinissery (2001-2012), B) Kalikavu (2003-2012), and C) Poothrikka (2002-2012). White represents the historical IKONOS-2 imagery and black represents the

Between 2001 and 2012, Avinissery experienced a 94% increase in built area, a 19% decrease in wetland, and a 3% decrease in agroforestry (Figure 2-5a). Only 36% of Avinissery's built surfaces in 2012 were present in 2001, meaning that 64% had been constructed in the last 11 years (Table 2-3). Newly constructed surfaces originated from agroforestry (65%), bare ground (23%), and wetland (12%). Overall, agroforests in Avinissery were found to be in a dynamic equilibrium with bare ground, wetland, and built surfaces (Figure 2-6a). While agroforest lost most of its area to built surfaces, it was balanced by gains from both wetland and bare ground.

Table 2-3. Change detection analyses for Avinissery, Poothrikka, and Kalikavu. The matrices in the left column (A, C, and E) are transition probability matrices that give the percent chance that a pixel of one land cover class (rows) will change to a pixel of another class (columns) between 2002 and 2012 (e.g. in Avinissery, 5.6% of the pixels on the landscape changed from agroforest in 2002 to built in 2012). It is important to note that the numbers in this column represent the percent of all transitions that occurred on the landscape (i.e. matrices sum to 100%). The matrices in the right column (B, D, and F) are the total area in square meters that transitioned from one land cover to another (e.g. in Avinissery, 22 207 m^2 of land transitioned from agroforest to built). G, H, I, and J give column means and standard deviations.

Avinissery

A

From 2002 \ To 2012	Agroforest	Bare	Built	Water	Wetland
Agroforest	40.6	3.0	5.6	0.0	0.2
Bare	4.2	2.5	1.9	0.1	0.0
Built	1.9	0.2	5.4	0.0	0.0
Water	0.1	0.0	0.0	0.5	0.0
Wetland	1.5	3.7	1.0	0.0	27.5

B

From 2002 \ To 2012	Agroforest	Bare	Built	Water	Wetland
Agroforest	143416	12063	22207	81	917
Bare	16748	6814	7709	323	0
Built	7558	804	18848	1	0
Water	386	0	36	1842	0
Wetland	5977	14535	3979	0	97139

Poothrikka

C

From 2002 \ To 2012	Agroforest	Bare	Built	Water	Wetland
Agroforest	64.6	2.6	2.1	0.0	0.3
Bare	9.5	0.9	0.7	0.0	0.0
Built	1.1	0.2	3.9	0.0	0.0
Water	0.0	0.0	0.0	0.2	0.0
Wetland	2.5	0.2	0.0	0.0	11.2

D

From 2002 \ To 2012	Agroforest	Bare	Built	Water	Wetland
Agroforest	229855	9414	7570	0	1150
Bare	33712	3320	2395	0	0
Built	4068	542	13735	0	0
Water	0	0	0	632	2
Wetland	8872	808	0	0	39785

Kalikavu

E

From 2002 \ To 2012	Agroforest	Bare	Built	Water	Wetland
Agroforest	83.4	3.3	2.7	0.3	NA
Bare	3.0	1.2	0.3	0.0	NA
Built	0.3	0.0	4.5	0.0	NA
Water	0.0	0.0	0.0	0.9	NA
Wetland	NA	NA	NA	NA	NA

F

From 2002 \ To 2012	Agroforest	Bare	Built	Water	Wetland
Agroforest	300686	10527	8817	808	0
Bare	9762	5639	1047	0	0
Built	906	146	16082	0	0
Water	120	0	41	3071	0
Wetland	0	0	0	0	0

Mean Percent

G

From 2002 \ To 2012	Agroforest	Bare	Built	Water	Wetland
Agroforest	62.9	3.0	3.5	0.1	0.3
Bare	5.6	1.5	1.0	0.0	0.0
Built	1.1	0.1	4.6	0.0	0.0
Water	0.0	0.0	0.0	0.5	0.0
Wetland	2.0	2.0	0.5	0.0	19.4

H

From 2002 \ To 2012	Agroforest	Bare	Built	Water	Wetland
Agroforest	224652	10668	12865	296	689
Bare	20074	5258	3717	108	0
Built	4177	497	16222	0	0
Water	169	0	26	1848	1
Wetland	4950	5114	1326	0	45641

St. Dev.

I

From 2002 \ To 2012	Bare	Built	Dryland	Paddy	Water
Agroforest	21.5	0.4	1.9	0.2	0.1
Bare	3.5	0.9	0.8	0.1	0.0
Built	0.8	0.1	0.8	0.0	0.0
Water	0.1	0.0	0.0	0.4	0.0
Wetland	0.7	2.5	0.7	0.0	11.5

J

From 2002 \ To 2012	Bare	Built	Dryland	Paddy	Water
Agroforest	78764	1330	8115	445	608
Bare	12317	1778	3522	186	0
Built	3327	331	2559	1	0
Water	198	0	22	1220	1
Wetland	4524	8169	2297	0	48834

Poothrikka differed from the other two panchayats in that it saw an 11% increase in agroforestry (Figure 2-5c). This was due in part to a massive 62% decrease in bare ground in conjunction with an 18% decrease in wetland. Built area increased substantially (29%), though not as dramatically as in the other two panchayats. As with Avinissery, most of what was converted to the built class was agroforestry (75%), though a quarter of newly constructed surfaces came from bare ground (Figure 2-6b). Poothrikka's patterns of change for wetland and agroforestry were similar to those in Avinissery, with wetlands in 2002 contributing to over 97% of wetland in 2012 (Table 2-3c,d).

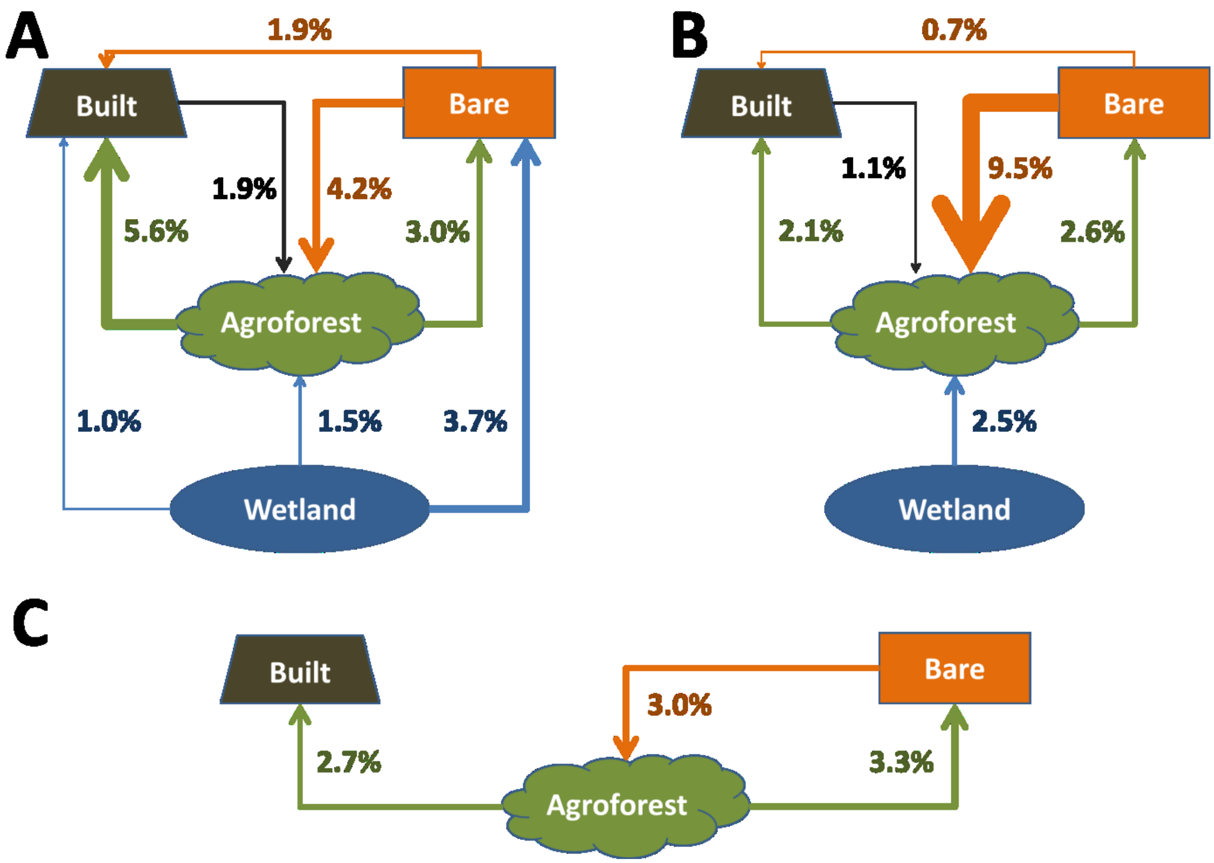

Figure 2-6. Primary land-cover changes (>0.5% of all sampled area) for Avinissery (A), Poothrikka (B), and Kalikavu (C). Arrow colour represents the source of the flow and arrow weight gives magnitude.

Like Avinissery, Kalikavu also experienced a 3% drop in agroforest (Figure 2-5b). This change was the direct result of a 52% increase in built surfaces, as the change detection analysis identified few other relationships (Table 2-3; Figure 2-6c). While agroforests and bare ground were in equilibrium with each other, wetland was not present in Kalikavu, and therefore could not mediate losses of agroforest in the same way as observed in Avinissery and Poothrikka.

2.4 Discussion & Conclusion

Land-change analysis conducted on three panchayats in Kerala using GeoEye-1 and IKONOS-2 imagery revealed increases in built surfaces in all regions, alongside decreases in both agroforests and wetland agriculture. On average, only around 50% of built surfaces mapped in 2012 were present a decade before. The biggest contributor to newly-constructed surfaces was agroforestry (36%), followed by bare ground (10%), and wetland (4%; only present in two panchayats). Very little land was converted to wetland (<2%), and even that could be the result of measurement errors from coconut trees hanging over paddy fields, making the canopy look bigger (e.g. Figure 2-3a). As agroforestry was such a dominant land cover class, it lost only 13% of its original area while contributing 56% and 36% of conversion towards bare and built classes, respectively.

Could rural development be responsible for the recent decline in plantation and wetland crops observed in Kerala's state land-use data (Figure 1-1), as well as the hypothesized disappearance of homegardens (Kumar and Nair 2004; Peyre et al. 2006; Guillerme et al. 2011)? While it is true that built surfaces increased at alarming rates across Kerala, this increase resulted in only a small decrease in agroforestry. The effects of development on agriculture also varied from place to place. For example, Avinissery had both the highest rate of increase in built surfaces (94%, versus 29% in Poothrikka and 52% in Kalikavu) as well as the highest initial proportion of built surfaces relative to other land covers (7.5%, versus 5.2% in Poothrikka and 4.8% in Kalikavu). Kalikavu, on the other hand, with both the smallest rate of increase and the lowest initial level of development, saw very little effect on the extent of agroforestry present between 2003 and 2012. However, this study spanned only a decade, and it is conceivable that more considerable declines in agroforest would be observed if these trends in development were sustained over a longer period. There is good reason to suspect that accelerated development has been occurring since the start of the Gulf diaspora in the 1970s, which paved the way for large amount of capital to flow into Kerala (Prakash 1998). Furthermore, there is no reason to expect a tapering of the rate of development in Kerala, as money continues to flow in from foreign remittances, and as young professionals continue to build on what was once their parents' farmland (Morrison 1997; Peyre et al. 2006; Sharma, Bhaduri, and others 2009; Devi and Kumar 2011).

The decline in wetland was the most pronounced land-cover loss in Kerala, which is not surprising as it is considered to be highly threatened due to declining profitability of paddy cultivation (Raj and Azeez 2009). Conversion from wetland to buildings and roads is not common, not only for the obvious reason that developing on wetland increases the risk of flooding, but also because wetland is protected by the Kerala Conservation of Paddy Land and Wetland Act (KCPLWA), 2008. While the act also prohibits conversion of wetland into agroforestry (for example, by planting rubber trees on what the State has classified as wetland), this practice may be much more widespread because 1) trees are more resilient to flooding than houses are; 2) if discovered by the authorities responsible for implementing the act, it is much easier to harvest a few trees that have encroached upon on the wetland boundary than it is to relocate one's home; 3) the construction of buildings in Kerala is logistically complex and requires a great deal of bureaucratic approval, and it would not make sense to attempt to build a house illegally because it would be noticed immediately; and 4) converting wetland to agroforestry could potentially be accomplished discretely if done gradually, a few trees at a time, starting from the periphery of the wetland and working in (Guillerme et al. 2011). As the KCPLWA was enacted roughly midway through our analysis, it is difficult to say whether it has been effective in curtailing the unidirectional conversion of wetlands to agroforests and bare ground. However, if efforts to conserve wetland are successful, they will potentially have indirect negative effects on Kerala's agroforests, which have remained in dynamic equilibrium due to the buffering effects of wetland conversion (Figure 2-6). In other words, putting a stop to the conversion of wetland to other land covers will shift the burden of increasing rural development from wetland to agroforest.

While the increase in built surface area may not have resulted in a net decrease in agroforest, the concurrently increasing rural population may contribute in other ways towards a shift away from agriculture. First, many of the people building large houses in the countryside are moving from either the city or from abroad with considerable sums of money (Prakash 1998; Misra 2013). While they may purchase large tracts of land and keep much of it as unmanaged agroforest, they are not farmers and are likely to only use what is produced for non-commercial purposes. Second, as they are not farmers, when they move into these areas they bring with them not only money, but employment opportunities for those who may have lost interest in the high risk and low returns inherent in small and medium scale agriculture in Kerala. Third, new buildings are often constructed on plots of land acquired through partitioning of a larger farm. Farms and homegardens are often partitioned when land is passed on between generations, or when farmers have problems with money or labour and find that they cannot afford to manage as much land as they once could. With either mechanism, partitioning results in successive levels of fragmentation of the agricultural landscape, which inhibits most farmers from being able to take advantage of economies of scale, and which eventually leads to a landscape composed of a high number of small, unprofitable homesteads. The increase in rural development and the move away from agriculture is further exacerbated by a cultural shift towards the nuclearization of the family unit, along with increases in the cost of labour, which, taken together, make farming even less affordable.

While the imagery used was of sufficient resolution for the analyses conducted, there remain several issues with the study that should be mentioned. First, for reasons mentioned in the methodology, I was not able to validate my manual classifications with an accuracy assessment. While I can be quite certain that the results are highly reliable based on the classes and imagery used, there is still very little indication of what kinds of classification errors occurred, and whether there were any that recurred systematically across regions or panchayats. Furthermore, it is reasonable to assume that a greater number of classification errors would be made in the slightly lower resolution IKONOS-2 imagery as opposed to the GeoEye-1 imagery (Table 2-1). However, it is impossible to predict the magnitude of the difference in errors between the two classification products due to lack of reliable ground truth data for either time period. This research could be built upon by extending the period of analysis and by increasing the number of panchayats. While the three panchayats used are broadly representative of Kerala's diverse environmental and demographic conditions, increasing the sample would help to lessen the impact of anomalous situations (e.g. the abundance of bare ground in Poothrikka in 2002). Future work might also attempt to disaggregate the agroforestry class into several other more detailed classes, in hopes of being able to distinguish between mixed and monoculture agroforestry. Finally, any attempt at estimating agricultural productivity using remote sensing across these landscapes would be very useful. Many of the paddy fields in Kerala have been either abandoned or are being cultivated at reduced rates, meaning that the area of wetland from one time to another is not necessarily the best indication of what is happening with regards to cultivation and productivity. Likewise, agroforestry can be very productive if it is properly managed, but given the nature of Kerala's mixed agroforestry landscapes, this is not something that has yet been measured using satellite imagery.

To conclude, land-change analyses revealed that agroforest and bare ground land-cover classes in Kerala were dynamic between 2002 and 2012. Wetlands, which declined considerably, acted as a source for new agroforests, while built environments increased in all regions, and acted as a sink for older agroforests.

Segue connecting chapters two and three

In chapter two, I assessed overall trends in land use between 2001 and 2012 at the landscape scale in Kerala using satellite imagery. Evidence that Kerala's plantation and wetland crops have declined in production, alongside speculation that homegardens have been disappearing, led to the hypothesis that these changes could be observed at the landscape scale using remote sensing. My main findings were that 1) Agroforestry systems were dynamic, increasing in some regions while decreasing in others; 2) Wetlands, which have traditionally been used for paddy cultivation, were disappearing rapidly; and 3) There was a pronounced increase in built surfaces across all regions studied. While agroforestry systems did not experience an overall net loss of area, I was unable to account for compositional changes occurring within the agroforest class. The remote sensing techniques that I adopted could only reliably indicate whether agroforests were present or absent, but could not reveal the crops being cultivated nor the reasons behind farmer land-use decisions. In the following chapter, I explore agricultural land-use histories from 2003 to 2013 at the farm scale by interviewing local farmers.

Chapter 3 The changing face of homegarden agriculture

3.1 Introduction

The tropical homegardens of Kerala, India are ancient agroforestry systems that offer a broad range of financial, cultural and ecological benefits. Though they have been an important livelihood strategy for thousands of years (Kumar and Nair 2004), and continue to be an important agricultural land use in the state, there have been accounts that farmers are moving away from homegardening. In particular, Kumar and Nair (2004) suggest that homegardens are threatened by a widespread preference for plantation crops such as rubber and coconut. This "modernization of the homegarden" has been documented not only in Kerala, where there has been an increase in the proportion of cash crops in homegardens (Peyre et al. 2006), but also elsewhere in the tropics (Abdoellah et al. 2006). In Kerala, these purported changes in homegarden management and purpose come at a time of rapid social change, especially in the countryside, where a new class of educated, wealthy, and economically diversified farmers has emerged (Morrison 1997).

In some tropical countries, the shift towards plantation-style agriculture has come largely at the expense of natural forest. In Kalimantan, Indonesia, oil palm plantations expanded by 278% between 2000 and 2010 (Carlson et al. 2013). While some 20% of the areas converted to oil palm came at the expense of agroforestry systems, which include homegardens, the majority came from rainforests (Carlson et al. 2013). In comparison to Indonesia, the availability of new land in Kerala is limited, and few opportunities exist for expansion. Not only is the population density of Kerala much higher than Indonesia (860 vs 26 people/km^2), but Kerala's remaining forests are nearly all protected by state legislation. Furthermore, Kerala's Conservation of Paddy

Land and Wetland Act of 2008 prohibits landowners from converting their wetland to any other land use. Therefore, as Kerala's farmers are unable to expand agricultural operations into forests or wetlands, their attempts to modernize agriculture in shifting towards plantation-style crops may likely be putting pressure on lands historically used for homegardens.

By process of elimination, it seems that homegardens are almost uniquely capable of facilitating the hypothesized transition towards plantation-style agriculture. Nevertheless, land in Kerala is very valuable, rural holdings are relatively small, and homegardens have great cultural significance for Keralans. Given that the drivers of land-use change in Kerala are both complex and poorly understood, two hypotheses exist for how plantations might be replacing homegardens. On one hand, farmers may be converting their land by abruptly clearing their land of homegarden and replacing it entirely with plantation crops such as rubber (*Hevea* brasiliensis) or areca (*Areca catechu*). Alternatively, farmers may be choosing, perhaps even subconsciously, to gradually replace their gardens with plantation crops by preferentially planting more economically viable species to replace those that have grown old and died. If this were to prove true, homegardens would be more likely to 'fade away' from the landscape, undergoing an "invisible transition", than to abruptly disappear (Guillerme et al. 2011).

Determining whether homegardens are threatened by plantation-style agriculture, and identifying whether the mechanism of change is invisible or abrupt, requires a combination of qualitative and quantitative data collected at the scale of the homegarden. In chapter 2, I used high resolution imagery to determine that agroforestry in Kerala (which includes homegardens and plantations) was a dynamic land cover between 2002 and 2012. The results from chapter 2 suggested that agroforestry, while expanding into wetlands and bare ground, were simultaneously being cleared for household construction at approximately the same rate. This suggests that the composition of agroforests could be changing, because it is conceivable that newly planted agroforests resemble plantations, while the older agroforests cleared for construction were closer to traditional homegardens. However, attempting to discriminate between these two extremes using remote sensing is problematic, as homegardens exist along a relatively smooth gradient, with those that are more diverse and traditional on one end, and those that more closely resemble plantations on the other.

Landscape-scale land-use changes are fundamentally a cumulative result of millions of individual (and often unrelated) land-use management choices made by homegardeners on small parcels of land. A combination of environmental, cultural, market-related, and social factors are responsible for guiding these land-use management choices, which in turn lead to the manifestation of numerous distinct varieties of agroforestry system (Nair 1985). For example, homegarden land-use decisions in Cuba have been driven by a number of unpredictable and geographically specific circumstances, including the dissolution of the former Soviet Union and continually changing government agricultural and social policies (Buchmann 2009). Given that the drivers of land-use change in Kerala are equally complex, and that remote sensing is not ideal for elucidating land-use changes within the agroforestry class, land-use histories provided by homegardeners are the best way to understand recent homegarden land-use trajectories.

The research I present in this chapter was conducted to explore recent trends in homegarden land use across Kerala from the perspective of homegardeners. I used a combination of quantitative surveys and semi-structured interviews to answer the following questions: i) What major food and commercial crops are bought, sold and cultivated by homegardeners?; ii) How has the production of common homegarden crops and livestock changed from 2003 to 2013?; iii) What are the drivers and implications of homegarden land-use change?; iv) What are homegardeners' intentions for the future? I expect to find support for the hypothesis that homegardeners are undergoing an "invisible transition", whereby traditional homegarden crops are gradually being replaced with plantation crops (Peyre et al. 2006; Guillerme et al. 2011). This will manifest as an increase in the cultivation of plantation crops such as coffee, rubber, and coconut, alongside a decrease in the cultivation of traditional crops such as mango and jackfruit. However, I suspect that homegardeners will still retain traditional species for non-economic reasons, albeit to a lesser extent. I expect that the drivers of this transition will manifest as a diverse and complex web of environmental, economic, social, cultural, and policy-related reasons.

3.2 Methods

3.2.1 Study Site, Participants, and Research Team

With the assistance of a field crew of 3 research assistants and 2 translators, I conducted 115 interviews and surveys between July and October 2013. It was important that the sample encompassed a broad geographic range because i) homegardens are a major land use across most of Kerala, and ii) the 14 districts of Kerala are highly diverse with regards to ecology, physical environment, religion, and history. I therefore selected 8 contiguous districts of central Kerala to maximize topographic, ecological, and demographic representation: Alappuzha, Idukki, Ernakulam, Thrissur, Palakkad, Malappuram, Kozhikode, and Wayanad (Figure 3-1). In each district I selected one panchayat (the smallest rural administrative unit, typically consisting of several villages) based on the availability of high quality archival remote sensing data. In districts with suitable satellite imagery available for more than one panchayat, the selection was made so as to ensure that the overall sample had representation from broad ranges of population density and elevation. The panchayats visited (districts in parentheses) were Avinissery (Thrissur), Kalikavu (Malappuram), Thamarassery (Kozhikkode), Kadampazhipuram (Palakkad), Vengappally (Wayanad), Poothrikka (Ernakulam), Kattappana (Idukki), and Thiruvanvandoor (Aleppy). Permission to engage homegardeners in our research was sought from the local government of each panchayat prior to our arrival. As taxation centres, panchayat level governments possess detailed registries of each household within their jurisdiction. These registries were used to generate random samples of 15 homegardens for each panchayat, except in Vengapally where only 10 were visited due to logistical constraints.

Households were visited in the order they were selected and incorporated into the study if i) the property was considered to be a homegarden, and ii) the head of the household consented to participate (Appendix B). Properties were considered homegardens if they possessed at least 3 different cultivated species of trees in combination with multiple understory herb and shrub species. Overall, only one household failed to qualify as a homegarden, and two others chose not to participate in the study. Under these circumstances, we sought the next homegarden on our randomized list in order to meet sample size requirements.

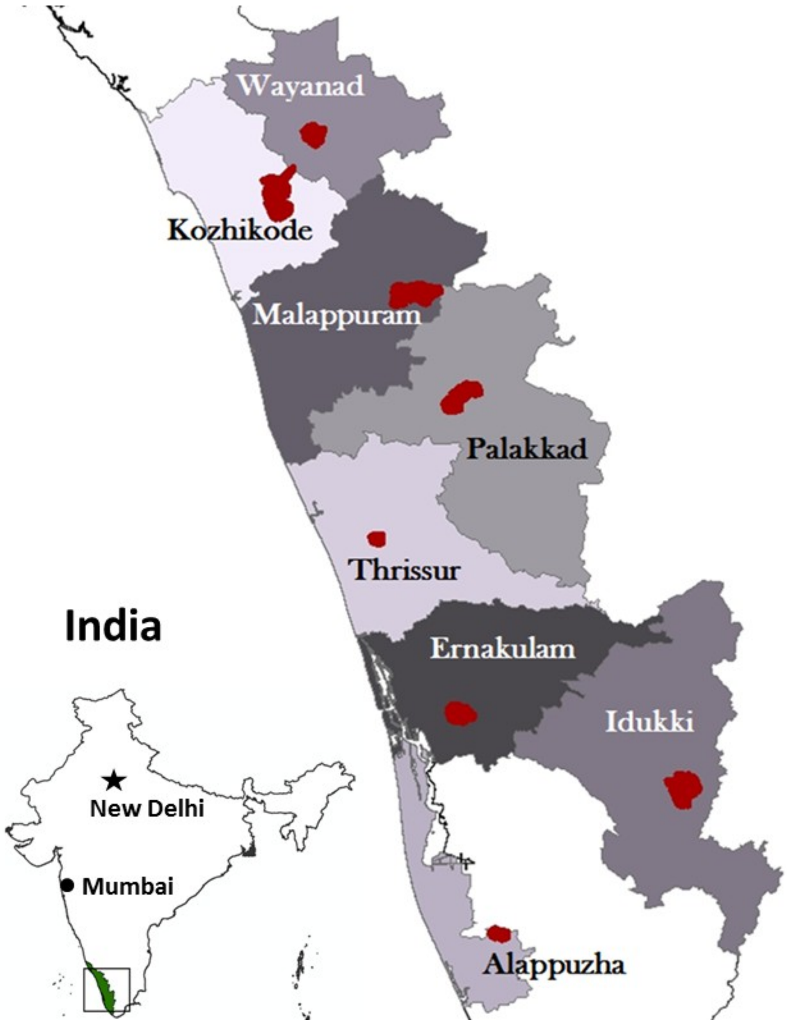

Figure 3-1. Study area in Kerala, India. We visited 8 panchayats (red) in 8 districts (gray) across the state. The panchayats associated with each district are: Avinissery (Thrissur), Kadampazhipuram (Palakkad), Kalikavu (Malappuram), Kattappana (Idukki), Poothrikka (Ernakulam), Thamarassery (Kozhikkode), Thiruvanvandoor (Aleppy), and Vengappally (Wayanad).

3.2.2 Surveys

I conducted surveys at each of the 115 homegardens (Appendix C). As this study was part of a broader research program, the survey was concise and designed to be completed within approximately 20 minutes. For each household, we collected basic demographic data (e.g. main source of income, size of family), the spatial extent and land-use history of the homegarden, information on future land-use intentions, and cultivation histories of 18 common traditional and plantation-based homegarden crops (including spices, staple foods, plantation crops, food crops, fuelwood, and timber) bought, sold, and grown by the household (Appendix C). Rice was included among these crops, even though it is grown exclusively in Kerala's wetlands and never on homegarden land. However, I do not suspect that a cohort of paddy farmers were excluded from our study based on our homegarden-centered sampling design, as paddy farmers live in rural areas, and therefore will almost always live on or own a homegarden.

In addition to these crops, I collected data on the number of cows and chickens in each homegarden. For my analysis I used the total number of cows and chickens present on the homestead rather than the number of animals per unit area because it better represents the resources that would be available to the family unit as well as providing an indication of whether livestock were being reared for subsistence or commercial purposes. However, I did control for changes in area of both livestock and crops by excluding the 23 homegardens from the analysis that changed in size between 2003 and 2013. I used paired sign tests to determine whether changes in the number of livestock between the two periods were significant. When reporting the multi-generational duration of homegarden ownership (i.e. number of years the homegarden land was owned by the family), many homegardeners indicated that the homegarden had been with the family for many hundred, if not thousands of years. For purposes of averaging, these estimates were given a conservative value of 200 years (Russell 2002).

A field assistant from Kerala Agricultural University in Thrissur fluent in English and educated in forestry was hired to translate between English and Malayalam, though roughly 10% of participants were proficient enough in English to be interviewed directly. It was not uncommon for several people to be actively engaged in both the survey and the interview, as not only were other family members curious, but local politicians were oftentimes interested in accompanying our research team. However, interviewing multiple members of the family at once proved to be a beneficial occurrence as it not only made participants more comfortable, but also gave them the opportunity to discuss the questions with their families before coming to a consensus, which is particularly important when attempting to remember agricultural management and land-use histories from a decade before. While it could be argued that the occasional presence of local officials led to respondents feeling pressured into giving dishonest answers, the questions were not contentious and it is more likely that their presence legitimized the survey.

3.2.3 Semi-structured Interviews

We conducted semi-structured interviews immediately following the completion of the surveys. Our first leading question was: "Has agriculture on your land and/or this panchayat decreased over the past 10 years?", and further examples of common questions can be found in Appendix B. As the scope of our interest was limited to understanding the basic drivers of recent land-use change, the interviews tended to be relatively brief. The answers, which were recorded on paper, were initially analyzed for information relevant to my research questions. In certain instances two people (e.g. wife and husband) would offer differing, and occasionally opposing, views or perspectives in response to one of my questions. When this happened I recorded both answers and weighted them equally. I developed a total of 99 codes from 115 files, which were then arranged into 14 themes. RQDA qualitative data analysis software was used to analyze the interview data (R. Huang 2014).

3.3 Survey Results

3.3.1 Characteristics of Homegardens and Homegardeners

The average homestead area reported over all panchayats was 0.34 ± 0.16 ha, ranging from 0.19 ha in Thamarassery, a region near the coast with high population density, to 0.67 ha in Vengapally, which is situated in the Western Ghats at an altitude of over 700 m and has a low population density (Table 3-1). These accounts of homegarden size are consistent with those of Kumar (2006), who found them to be roughly 0.24 ha across all of Kerala. In addition to their homegardens, 64 percent of farmers reported owning additional land nearby, which was either a plantation or wetland, and which averaged 0.87 ha. The mean duration of ownership was 95 ± 45 years in the multi-generational possession of the family and 27 ± 5.6 years under the name of the current land manager. However, the family history estimates varied greatly, both among and within panchayats. Furthermore, it was often the case that homegardens had been with the family for a period of time greater than accounted for by written records or memory. A total of 80% of respondents relied on agriculture as either their primary (52%) or secondary (28%) source of income, with the remainder relying exclusively on business, service sector employment, remittances, or pensions (Table 3-1).

Table 3-1. Descriptive statistics by Panchayat.

			Other Land Owned		Ownership (years)		Agricultural Income		Family Size	
Panchayat	*n*	*Homegarden Area (ha)*	*Percent Reporting †*	*Mean Area (ha)*	*With Family ‡*	*Current Owner*	*Primary Source (%)*	*Secondary Source (%)*	*2003*	*2013*
Avinissery	15	0.26	53	0.85	143	28	40	33	5.4	4.5
Kadampazhipuram	15	0.42	53	0.97	85	34	53	7	5.3	4.7
Kalikavu	15	0.23	60	0.81	43	26	60	27	7.6	6.7
Kattappana	15	0.37	53	1.85	39	21	80	13	5.4	5.4
Thiruvanvandoor	15	0.24	93	0.80	161	29	27	53	4.6	4.3
Poothrikka	15	0.33	40	0.19	101	35	40	27	6.1	4.9
Thamarassery	15	0.19	67	0.39	47	26	33	47	5.2	3.7
Vengapally	10	0.67	90	1.06	58	19	80	20	5.0	4.5
Total	**115**	-	-	-	-	-	-	-	-	-
Mean	-	**0.34**	**63.63**	**0.87**	**94.75**	**27.25**	**51.63**	**28.38**	**5.58**	**4.84**
St. Deviation	-	**0.16**	**18.82**	**0.49**	**46.98**	**5.60**	**20.37**	**15.77**	**0.92**	**0.90**

† "Percent Reporting" refers to the percentage ofrespondents in a panchayat who report owning additional land outside of the homegarden area.
‡ Ownership time was calculated by assigning an age of 200 years to homegardens owned by the family for "time immemorial" (Russell 2002).

The most commonly planted subsistence tree crops were coconut (*Cocos nucifera*), banana/plantain (*Musa paradisiaca/Musa sapientum*), jackfruit (*Artocarpus heterophysllus*), and mango (*Mangifera indica*) (Figure 3-2). Coconut, the most common, and arguably the most culturally and economically important tree in Kerala, was found in 97% of homegardens. Banana, mango and jackfruit were grown by 94%, 88%, and 87% of homegardeners, respectively. In the few cases where these four trees were not grown, the most common reason was that the local topographical, soil, or climate conditions were not suitable. Despite on-farm production, more than 50% of households relied on local markets to supplement their production of both banana and mango. It was rare to find homegardens that were fully sufficient in the production of these food crops. On a side note, rice, the main staple in the Kerala diet, was cultivated by less than 25 % of respondents (but never on homegarden land).

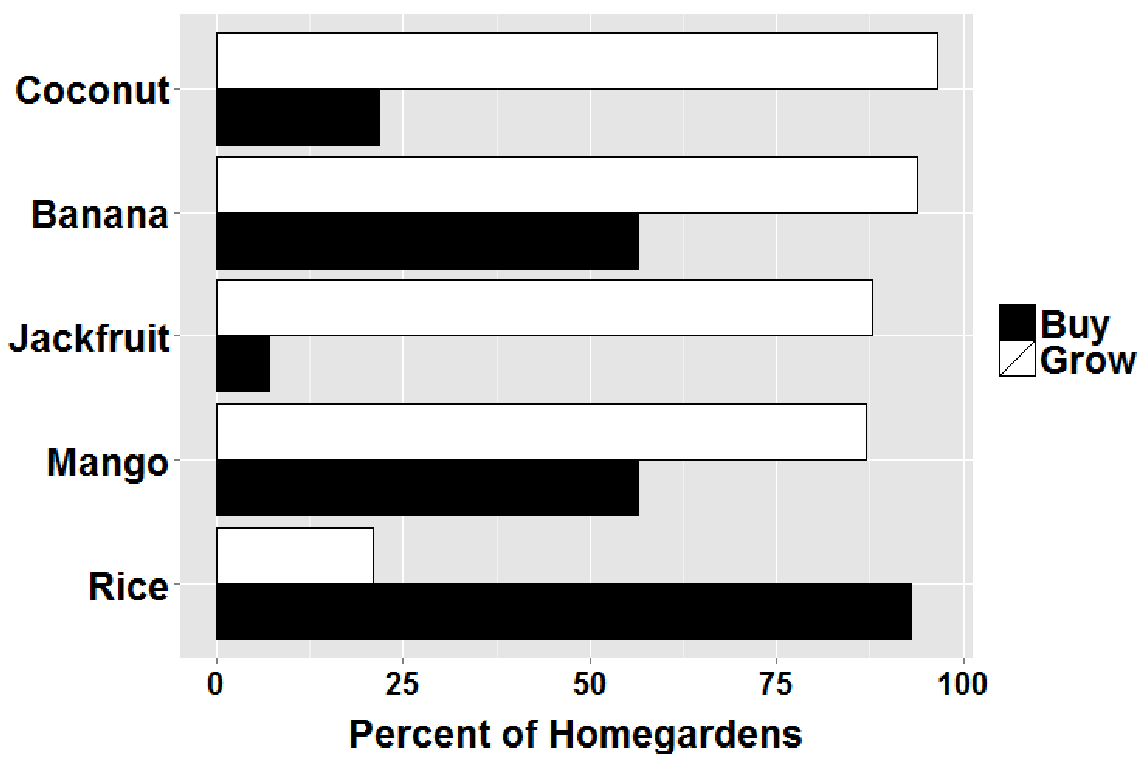

Figure 3-2. Major food crops grown and bought by homegardeners.

Commercial crops, including areca (*Areca catechu*), pepper (*Piper nigrum*), coffee (*Coffea canephora* or *Coffea arabica*), rubber (*Hevea brasiliensis*), and green cardamom (*Elettaria cardamomum*) were also commonly grown in homegardens (Figure 3-3). Coffee, rubber, and cardamom were geographically concentrated; in general, Wayanad contained most of the coffee (100% of homegardens), Idukki was dominated by cardamom (93% of homegardens), and nearly 50% of rubber was found in Palakkad and Malappuram. While commercial crops could be found in nearly every homegarden, not all farmers were actively engaged in selling what they produced. This was especially the case for pepper, coffee, and cardamom, which were being sold by roughly 50% of those engaged in their cultivation, with the remaining 50% using these crops for home consumption or not bothering to harvest.

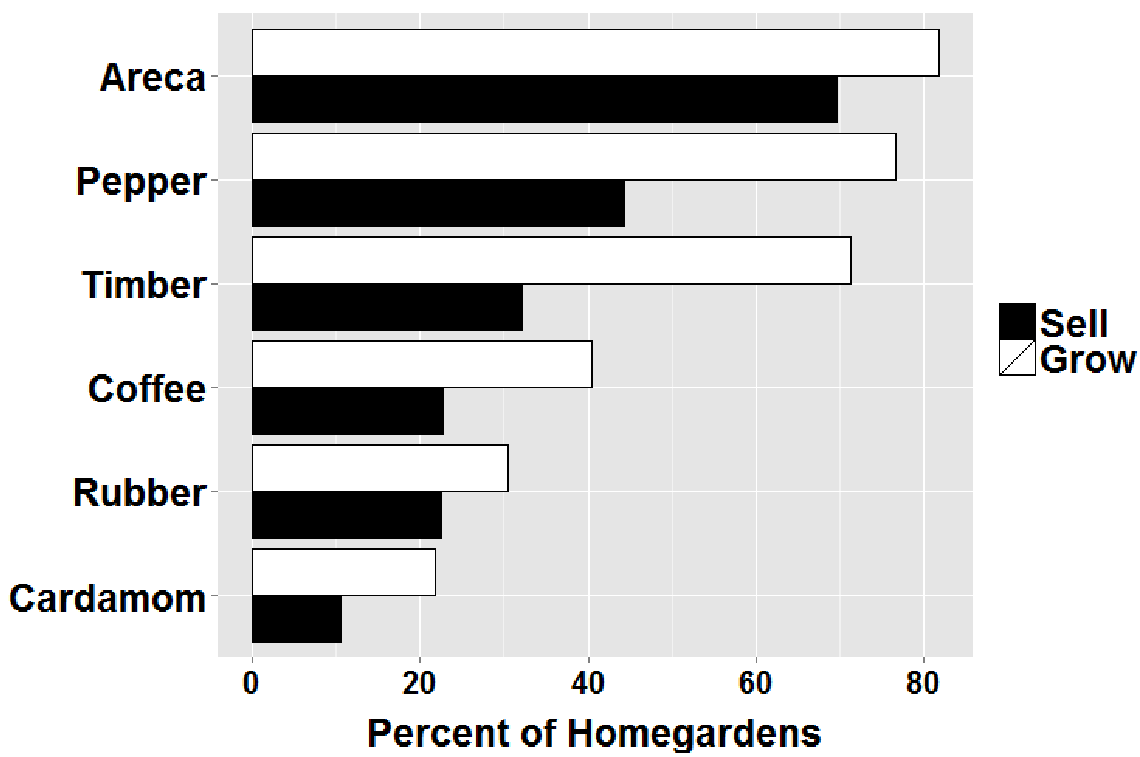

Figure 3-3. Major commercial crops cultivated and sold by homegardeners.

3.3.2 Trends in Crop and Livestock Production

The majority of homegardeners maintained or decreased production of the 15 common homegarden and plantation crops used in this study (Figure 3-4). Rice, the most important staple food in Kerala, showed the greatest overall decline, with 83% of rice-growing homegardeners (n=52) producing less in 2013 than they had 10 years prior. In some cases, this was the result of farmers having fewer crop rotations (e.g. going from 3 to 1 crops per year), but for the most part the trend was attributable to the complete abandonment of paddy farming. The number of homegardeners growing rice fell from 52 in 2003 to 22 in 2013, even though 46 farmers continued to own wetland in 2013. Pepper and cashew showed similar trends, with 80% (n=85) and 73% (n=49) of homegardeners reporting declines in production, respectively. The remaining crops varied considerably in terms of the proportion of homegardeners increasing or decreasing their cultivation (Figure 3-4), but the overall trend was one of decline. Furthermore, plantation crops and traditional homegarden crops were just as likely to be found among both the most and the least changed. For example, rubber and coffee, both plantation crops, were two of the least likely crops to have decreased. However, curry and jackfruit, which are found in most homegardens – and are rarely produced commercially, were similarly unaffected.

Livestock numbers between 2003 and 2013 also showed decreasing trends. The average number of chickens per homestead fell from 12.5 to 2.6 (381%) over the 10 year period, ranging from a decline of 185% in Poothrikka to 1556% in Kattappana (Figure 3-5a). The average number of cows per homestead fell from 1.7 to 0.8 (112%), with all but one panchayat showing declines (Figure 3-5b). These trends coincide with increases in the number of families relying on local markets for dairy products (from 35% to 68%) and eggs (from 20% to 61%).

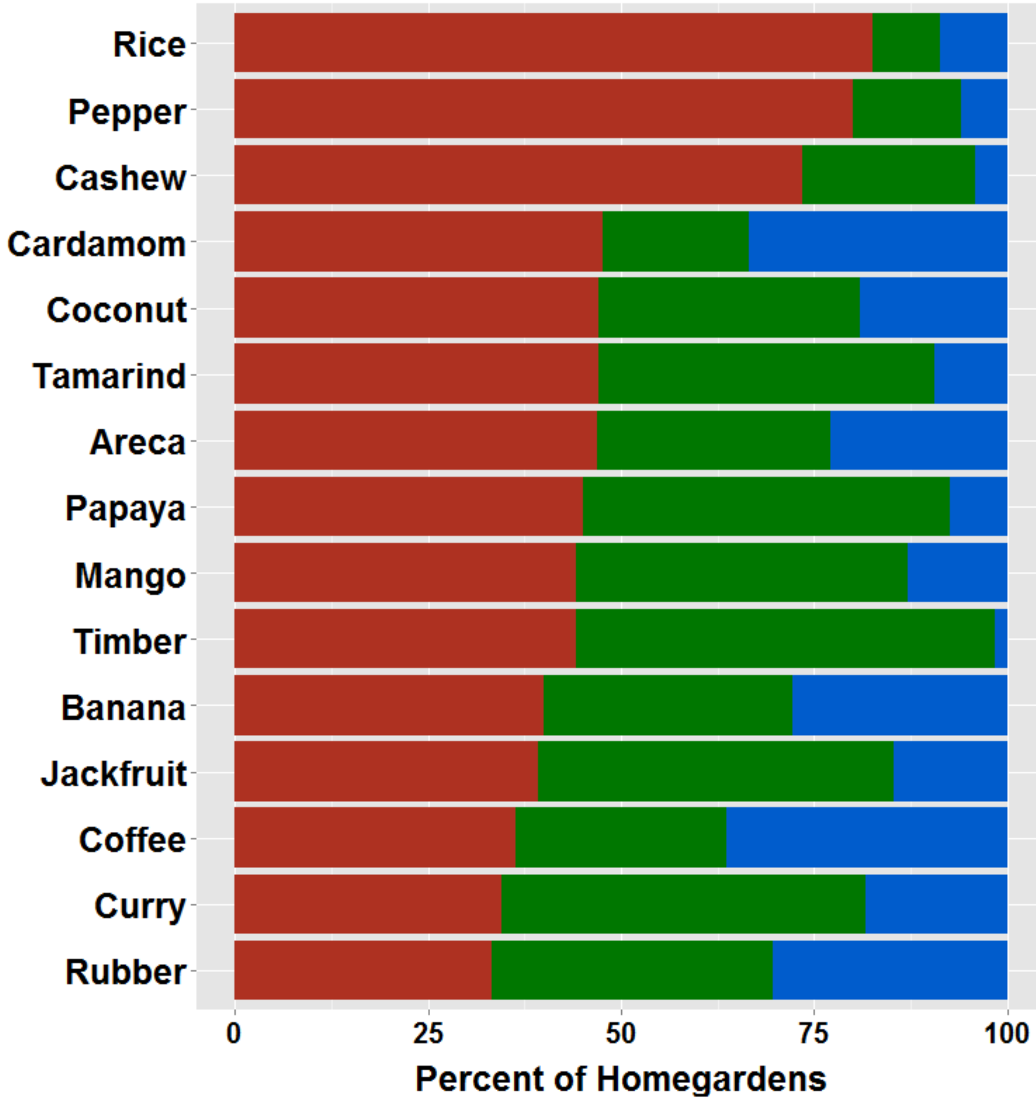

Figure 3-4. Percent of homegardeners growing more (blue), less (red) or the same (green) amount of common plantation and traditional homegarden crops in 2013 as compared with 2003. We controlled for changes in area and removed respondents who did not grow a given crop in 2003 (when reporting declines) and 2013 (when reporting increases).

When asked if they had intentions to increase or decrease cultivation of any crops, most farmers indicated that they had no intention to increase (48%) or decrease (83%) cultivation of any crop species. Of those who responded, most did so by listing crops that they planned to increase in cultivation, and very few indicated that they planned to reduce any of the crops they were already growing (Figure 3-6). This runs contrary to the finding that not a single crop considered by our study had increased in production over the 10 year period. However, most homegardeners only listed one or two crop species that they intended to increase. Thus, the results in Figure 3-6 could be a sign that homegardens are on the way to becoming less diverse and increasingly specialized.

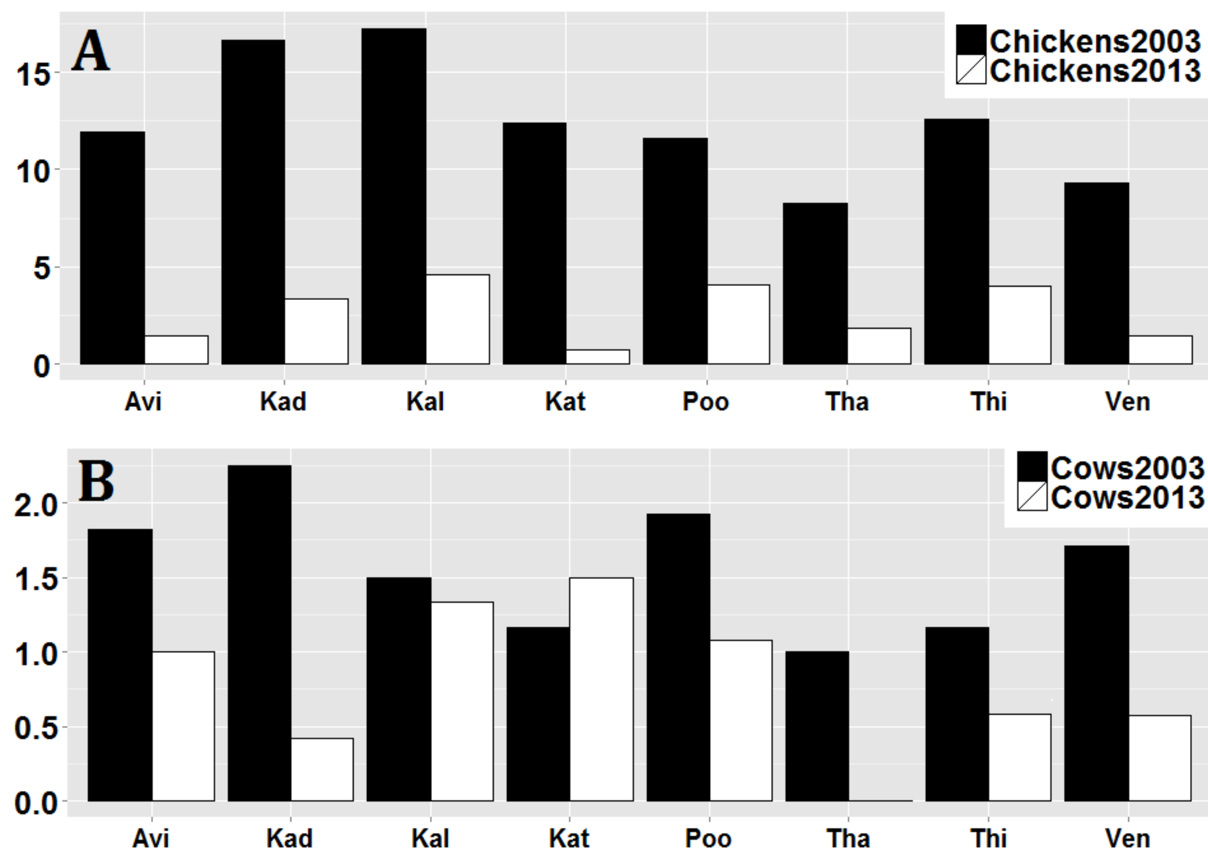

Figure 3-5. Average number of chickens (A) and cows (B) per homegarden for each panchayat in 2003 (black) and 2013 (white). Paired sign tests indicate that overall trends are significant for both chickens ($s = 4$; $p < 0.0001$) and cows ($s = 8$; $p < 0.0001$). Panchayat names are abbreviated to the first three letters.

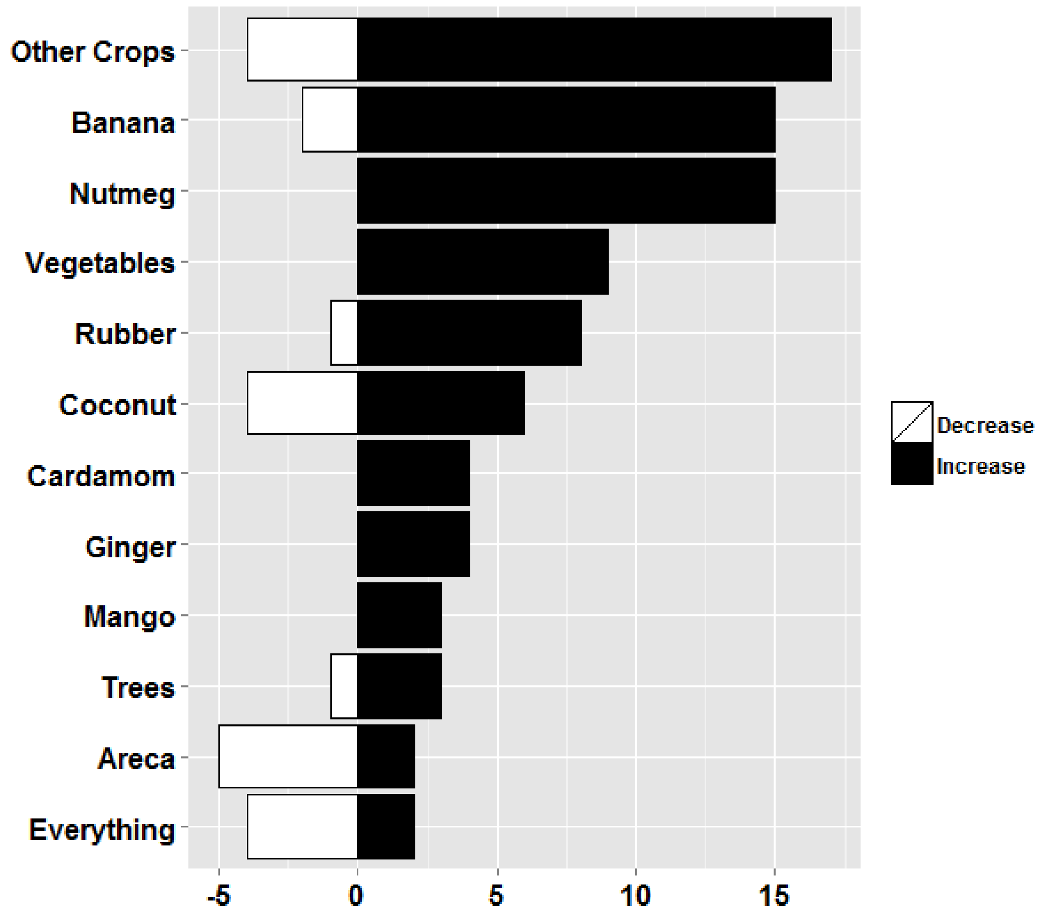

Figure 3-6. Overall number of farmers intending to increase and decrease future production of stated crops. "Everything" and a large "Other Crops" category exist because farmers were not given prompts, but were permitted to answer freely (48% of farmers did not intend to increase any crops and 83% did not intend to decrease any crops).

3.4 Discussion of Survey Results

Taken together, the results suggest that both plantation and homegarden-based agriculture is decreasing in homegardens across Kerala. This runs counter to the hypothesis that a large number of homeowners are converting their entire homegarden to conventional, plantation-style agriculture. If this were the case, we would find increases in the production of crops such as rubber, coconut, and coffee at the expense of traditional crops such as mango, jackfruit, and curry. Furthermore, it would be counterintuitive to witness such dramatic declines in the rearing of livestock, as agroforestry plantations such as rubber and coconut can double as pastureland (Reynolds and others 1995; Chong et al. 1997). Instead, our data suggest that homegardeners are growing less of everything: traditional crops, food crops, plantation crops, livestock, and rice. Furthermore, these results agree with Kerala's census data, which have already shown that most varieties of plantation agriculture are also on the decline (Figure 1-1).

Although I have shown that it is unlikely that plantations are replacing homegardens, the data are not able to explain the general decline in agriculture. If both homegardens and plantation-based agricultural systems are on the decline, what is the competing land use? For homegardens, one possibility is that a different kind of "invisible transition" is occurring: by relying more heavily on non-agricultural sources of income, rural homeowners are investing less effort in the management of their gardens. This would presumably result in a gradual reduction in the cultivation density of all crops, as they inevitably grow old and die or are consumed by disease. Over time, homegardens would become unmanaged tropical yards, as cultivated tree, shrub, and herb species are replaced and outcompeted by various weeds, competitive crops, and naturally establishing species. Homegardeners may be likely to maintain the most culturally important (and least labour intensive) garden crops, such as coconut, banana, mango, jackfruit and curry. However, a shift away from a subsistence-oriented lifestyle would be expected as individuals adopt day jobs as alternate sources of income. As such, there would be insufficient time or incentive to optimize homegarden diversity and productivity.

Alternatively, it could be that landowners are reducing the surface area of homegarden by developing their properties. While I controlled for changes in homegarden area by excluding homegardens that changed size, I did not collect detailed information on land-cover changes within property boundaries, aside from finding that 31% of homeowners had built a new house between 2003 and 2013, which was carved out of homegarden area. As land is traditionally kept within the family, and is passed on to children via partitioning, ownership dynamics can often be quite complex. For example, if a partitioning is inevitable, it is not uncommon for adult children to clear land and build houses on what will eventually become their property. However, unless the partitioning had been made official, this study considered the entire land area a single homegarden. The hypothesis that homegarden agriculture is decreasing as a result of loss of farmed surface area in homegardens is likely given the unprecedentedly high rural population density in Kerala: the population density of Kerala in 2011 was 859 people per km^2 (Chandramauli 2011), compared to 435 people per km^2 in 1961 (Devi and Kumar 2011). Furthermore there has been a trend towards nuclearization of the family unit, meaning that not only is population density higher, but household sizes are also smaller (Figure 3-1). In addition to building construction, there has been a recent move towards landscaping, which can result in covering extensive surfaces with ornamental species, concrete, grass, or clay bricks.

These homegarden land use-changes have important implications for Kerala's ecosystems, culture, economy, and food security. As an increasing number of people become highly educated, leave agriculture, and seek jobs in business or service, homegardens may become increasingly simplified (Peyre et al. 2006). This may risk impacting both natural and cultivated species diversity (Kumar and Nair 2004; Bhagwat et al. 2008)(Kumar and Nair 2004), though the link between tropical homegardens and biodiversity is extremely understudied (Webb and Kabir 2009). Keralans will become ever more dependent on imported food, and thus increasingly reliant on not only the state economy, which is not very strong, but also the stability of the oil-producing Gulf States where some 2.5 million Keralans work to send home remittances (K. C. Zachariah and Rajan 2008).

3.5 Discussion of Interview Outcomes

3.5.1 Land-use Change: Further Insights

Perspectives on the status of agriculture

The semi-structured interviews supported many of the findings that arose from the surveys. The majority of homegardeners indicated that agriculture was decreasing on their own land, at the panchayat level, and across Kerala. Only two farmers suspected that agriculture might be increasing regionally, though they were quick to qualify their responses by suggesting that it was only among older cohorts whose children had grown and who were therefore able to invest more time in their land. They dubbed this a "return to agriculture" by the older, less educated members of society whose skillsets were limited to farming and who were therefore unable to find work outside the agricultural sector. Nevertheless, the narratives of over 95% of homegardeners converged, pointing towards a large-scale shift away from agriculture among both homegardens and conventional agricultural systems. Thus, I find strong agreement between the results derived from the qualitative and quantitative methods used in this study.

Examples of Land-use changes

Landholder interviews were able to offer further insight into the transitions experienced by Kerala's agricultural landscapes between 2003 and 2013. Paddy lands, which are separate from homegardens, but which saw the greatest declines in cultivation, were in many cases simply abandoned. Conservation legislation enacted by the State in 2008 has made it difficult for crops other than rice to be cultivated on wetlands (Raj and Azeez 2009). Furthermore, most forms of construction and land development on wetland are prohibited. This body of legislation, combined with the fact that paddy cultivation has in recent years become unprofitable (for reasons discussed in the following section), has negatively impacted land value. However, not all paddy fields have been abandoned. In some cases, farmers are growing one crop per year, as opposed to the 2-3 rotations formerly typical of paddy farming in Kerala. In other fields, entrepreneurial farmers are taking advantage of mechanization and economies of scale by renting wetland at a low price from those not farming their own land. In other cases still, wetland owners have been converting paddy land to banana, areca, coconut, cassava, or even to impervious urban land covers (Raj and Azeez 2009). These land-use changes, which occurred legally until 2008, have since continued illegally at a lesser rate (Dipson et al. 2014).

Land-use changes towards, away from, and within homegardens have taken much more diverse forms. The local manifestations of deagrarianization are often very subtle, occurring gradually over numerous years. This is because homegardeners who have little interest in turning to conventional agriculture, and who are even less inclined to sell their land, find themselves unable to keep up with the large amounts of work required to properly manage a homegarden. Thus, weeds are not removed, fertilizers are not applied, pests are not dealt with, and old trees eventually die without being replaced. In this way an “invisible transition” occurs, and homegarden landscapes may not appear on the surface to be changing, but may in fact be transitioning from highly productive agro-ecosystems to unmanaged tropical “yards” with little cultural or economic value.

Nevertheless, 52% of homegardeners still claim to rely on agriculture as their primary source of income. These farmers, who are facing similar pressures as those leaving agriculture altogether, are being forced to focus their energy on the most cost-effective and least economically risky activities available to them. For example, a farmer with a subsistence-based vegetable garden and an integrated rubber patch chose to abandon his vegetable garden as his children had left home and he could not access labour markets. While this did not result in a land-use change at the regional scale (because he still manages a “homegarden”), nor an important land-cover change (as vegetable gardens are often grown beneath the canopy), it did affect the cultivated species richness and composition of the homegarden, as well as the family’s capacity to provide for itself.

I encountered numerous other manifestations of land-use change involving homegardens and the micro-plantations often present on homegardens. In many cases, patches of homegarden were cleared in order to build a new house or a road. Many of these newly constructed houses were non-agricultural holdings. These houses had a tendency to be large and the homegardens were often relatively simple, with an abundance of ornamental species and paved or tiled surfaces. In the panchayats where rubber grew well, several farmers had, as initially hypothesized, converted much of their homegarden to rubber. However, even the most plantation-like homegardens retained numerous homegarden species. Furthermore, the conversion from plantation to homegarden appeared to be equally, if not more, likely. These plantation-to-homegarden conversions occurred with a broad range of crops, including not only areca and coconut, but also more profitable crops such as rubber and coffee (Figure 3-7). This ultimately occurs because real estate in Kerala is more profitable than agriculture, but also because homegardens are culturally important, and even non-agricultural households maintain small homegardens.

Figure 3-7. New house under construction in Palakkad that replaced part of a rubber plantation. The trees in the background are mature rubber.

As Kerala's forests are adamantly protected by state legislation and reliable enforcement (Kumar 2005), I encountered not one case of conversion from natural forest to another land cover. Indeed, forest reserves are mostly relegated to the mountains, and most of our study sites were dozens of kilometers from the nearest patch.

3.5.2 Drivers of Land-use Change

Declining profitability

"The cost of labour is increasing, and the market price for cardamom is decreasing. This year, the cost of fertilizer and pesticide is double what it was last year. Cardamom is like a child that requires too much care, but no other crop is profitable. [...] We are planning to build lots of houses on this land for renting instead of agriculture. We want to build a new house every year, as they are a stable source of income." – Female homeowner in Kattappana, Idukki

Of the numerous reasons for declining agriculture cited by farmers, the most common theme was the notion that commercial farming had become unprofitable and risky. A farmer from Vengapally put it simply: *"Twenty-five years ago we had 80 cows, but now we have none. I am not interested in agriculture anymore because there is no profit. We have to invest 5-6 lakhs to get a return of 10 lakhs, which is too risky."* The concern that agriculture had become a financial risk arose repeatedly in each of the panchayats. Most farmers agreed that market prices for food crops have not been able to keep up with the annual cost of investment, which has been rising at a consistently greater rate. Furthermore, this narrowing gap between investment and return has been compounded by the fact that yields, for environmental reasons such as drought, flooding, and pest attack, have become increasingly unreliable.

In terms of investment, homegardeners worry that they can no longer afford the inputs required to remain competitive with globalized food markets. The most frequently stated problem was that labour has become prohibitively expensive. This in itself is a complicated issue, but the most immediate reason is that real wages for both skilled and unskilled agricultural labourers have risen dramatically in Kerala over the past twenty years (Figure 3-8). Of course, immigrants from less prosperous Indian states have come to Kerala looking for work. However, many of them take jobs in construction or with the government, which tend to pay better. Furthermore, many farmers complain that these labourers, many of whom originate from North India, do not possess the knowledge or the experience required to work in agriculture. In addition to labour, agents of intensification such as pesticides, fertilizers, and mechanization have become both increasingly necessary and prohibitively expensive for smallholding farmers.

In addition to limited financial incentive to engage in agriculture, Kerala's growing economy has opened up numerous enticing jobs in the service sector. Furthermore, Kerala's youth are now highly educated, and many are emigrating for work in the Gulf States, typically as either unskilled workers or as professionals, especially with medical training. This is not surprising, as both farmers and recreational homegardeners express an adamant desire to have access to a stable source of income, which is becoming ever less possible with agriculture.

Climate and environment

"Over the last ten years our soil fertility has decreased because we no longer use cow dung. There have been more problems with pests as well, and in this region, everybody was growing sugarcane until disease destroyed all the crops. This year we have had heavy rain. We normally expect the monsoon in June, but now it is irregular and flooding is a big problem. It is too hot in the past years, and sometimes there are water shortages." – Farmer from Thiruvanvandoor

Most homegardeners identified environmental factors as drivers of land-use change, which work to increase risk by compromising yields. Most commonly discussed were abnormal weather events and climate patterns, which differed markedly by panchayat. A major concern was that rains had become irregular both between and within years. Historically, Kerala's two monsoons have been reliable both in terms of the volume of rain and the time that it could be expected. The seasonal wet-dry cycle is critically important for farmers because it provides a reference for planting and harvesting times. However, in recent years farmers claim that the monsoon has come at either the wrong time or not at all. When it does come, the amount of rain varies greatly, and frustration was expressed with the occurrence of both water scarcity and flooding, depending on the panchayat. Homegardeners also claim that summers have, over the past five years or so, been hotter than usual, sometimes so much so that they reported crop failures.

After weather and climate, the most common environmental impediment was a reported increase in the prevalence and diversity of crop diseases and pests. With viral, bacterial, or fungal pathogens infecting nearly every crop type, specific pesticides are necessary, and these are often prohibitively expensive or logistically inaccessible. In terms of pests, homegardeners mentioned having had problems with bats, boars, peacocks, snails, foxes, birds, and various insects. Some homegardeners mentioned that certain species had only recently become problematic, and even suspected that these new pests and diseases were introduced from outside of Kerala.

Less common yet recurring environmental drivers of land-use change included loss of soil fertility, inadequate pollination, and local nonpoint source industrial pollution. A popular notion was that homegardeners had become reliant on chemical fertilizers and that soils had transitioned from a healthy and sustainable state to one that was unhealthy and depleted of nutrients. Some farmers went further to identify the changing face of homegarden agriculture as the immediate cause, blaming the loss of cows and use of chemical fertilizers instead of green manure, animal manure, and compost. In general, this shift was spoken of disapprovingly, and many farmers lamented the fact that it would be nearly impossible to return to a sustainable model.

Society, demographics, and globalization

Many homegardeners identified a social transition as an important driver of Kerala's move away from agriculture. Some of the older farmers claimed to be getting tired, and said they were unable to keep up with the work necessary to maintain their homegarden. Many explained that their children were not interested in continuing with agriculture, as most of them had received a post-secondary education and were committed to finding white-collar jobs. A stigmatization of agriculture among the younger generation was often described, so much so that, with employment opportunities being few and far between, young graduates were often accused of being too proud, and choosing unemployment over the abundance of available manual work. This tendency for modern youth to be turned off by agriculture is not unique to Kerala, but has been seen in both the rest of India (Sharma, Bhaduri, and others 2009), as well as in other tropical regions with homegardens (White 2012; Susilowati 2014). Laziness, not only of the younger generation, but also of skilled and unskilled agricultural labourers in general, was a recurring theme in the interviews.

"Agriculture [here] is pathetic. It is failing mostly because the new generation is not interested. Before, if the father was a farmer, sons would be farmers as well. Now young people are leaving and agriculture is suffering." – Homegardener in Wayanad

With a constant surplus of graduates over job opportunities, many young people look abroad for work. Currently, it is estimated that some 2.5 million of Kerala's 33 million inhabitants are working on the Arabian Peninsula (K. C. Zachariah and Rajan 2008), with most concentrated in the United Arab Emirates or Saudi Arabia. Homegardeners often argued that the emigration of these workers was one of the biggest reasons for Kerala's labour shortage. Furthermore, members of Kerala's Gulf diaspora often return home after their time away, bringing with them considerable savings and often building large concrete houses on non-agricultural or pseudo-agricultural smallholdings in the countryside. These homesteads are often established on previously agroforested land that belonged to their parents, whose generation likely consisted of farmers.

In addition to education and changing career aspirations, demographic shifts and changes in family structure have made homegardening more difficult. According to our survey, the average family size has fallen from 5.6 to 4.8 individuals between 2003 and 2013, indicating a shift towards a more nuclear family with fewer children (Table 3-1). This not only means that there are fewer helping hands to contribute to agricultural work, but also that a greater proportion of young adults can be put through university, assuming that educational resources for a given family are limited. Of course, having fewer children will presumably alleviate pressure from the issue of farm size, whereby partitioning of land among children of the next generation eventually renders plots too small to be agriculturally profitable. However, some say that it is already too late for this, and that the average homegarden is already too small to be able to make a reasonable living. Furthermore, partitioning will continue to occur for at least the next few decades, as the trend of having only 1-2 children is relatively new, and there still remain a cohort of 15-40 year olds from large families who are waiting to inherit land of their own.

Government and policy

"[The government] does not give support to farmers or agriculture, but they should. The government needs to regulate prices of crops as they are very unstable. Kerala's reliance on imports is the government's fault. […] They may be providing discounted pesticides, but these are in Mahali and it is too far for me to travel. – Homegardener in Wayanad.

Many farmers blamed government policy, or lack thereof, for the increasingly difficult farming conditions in Kerala. Most commonly cited was the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), a national scheme that seeks to improve living conditions and reduce unemployment by guaranteeing 100 days of work per year to those willing to perform unskilled wage labour (usually infrastructure development). In Kerala, the scheme was implemented first in 2006 for Palakkad and Wayanad districts, and later in 2008 for the remaining 12 districts. While arguably a great step towards the elimination of rural poverty in Kerala, farmers claim that the scheme has compromised their livelihoods by drawing labourers away from agriculture. They argue that this resulted in an increase in cost of agricultural labour, which is, at least compared to government work, physically demanding and difficult (Figure 3-8).

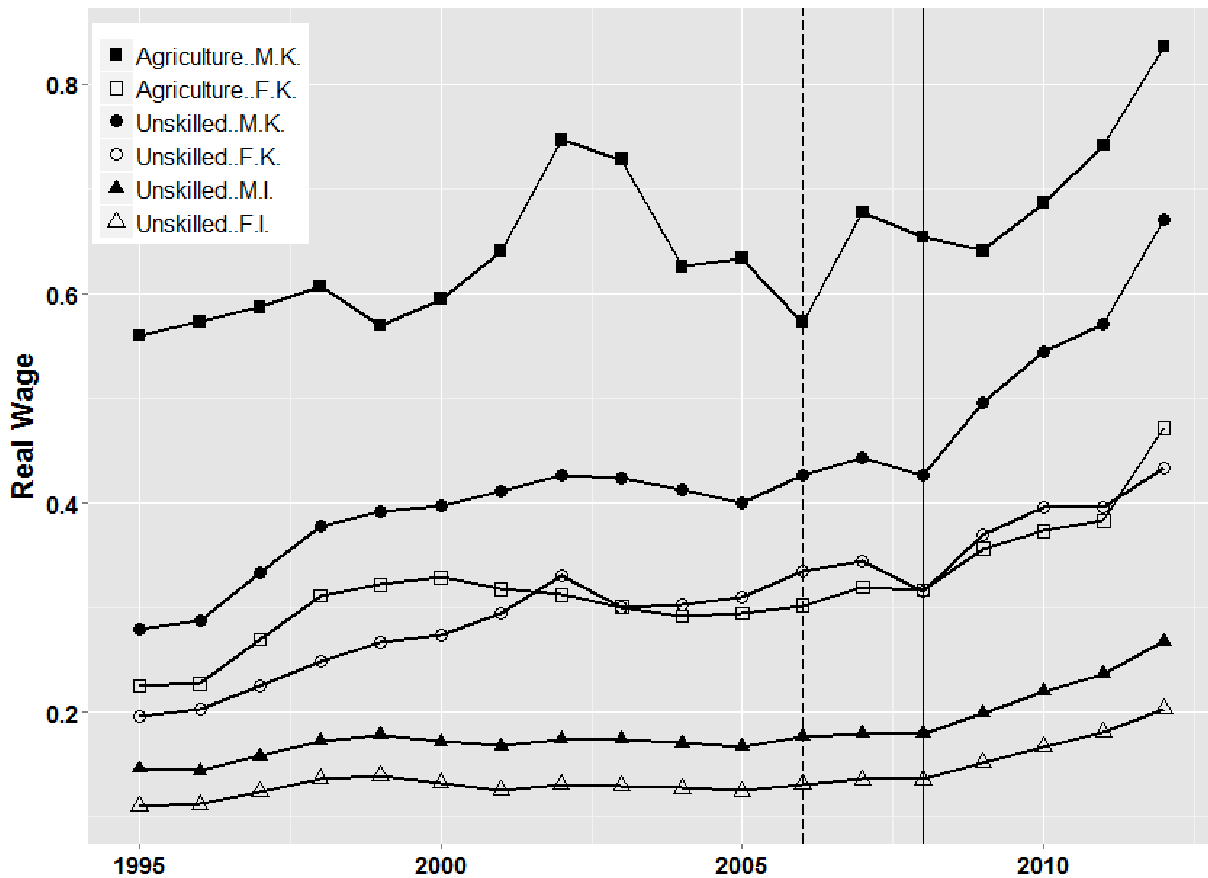

Figure 3-8. Real wages of male (M) and female (F) agricultural and unskilled labourers in Kerala (K) and India (I) from 1995-2012. Vertical lines show the two implementation phases (2006 and 2008) of the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA).

In Kerala, farmers have noticed a rapid increase in the cost of living, and the state's consumer price index has nearly doubled from 2003 to 2013 (Government of India 2015). Unfortunately, they claim that market food prices have not kept up with production costs, and blame the government not only for failing to make up the difference with subsidies, but for not ensuring that there is adequate state infrastructure for the integration of agricultural products into the market. Furthermore, some see policies such as the Kerala Conservation of Paddy and Wetland Act as failed attempts to encourage farmers to cultivate more rice, despite the fact that doing so is no longer a financial sensible option.

3.5.3 Coping Strategies

Homegardeners across Kerala have come to adopt a number of strategies for coping with what they have described as increasingly unwelcoming agricultural conditions. Homegardeners have implemented numerous adaptive management strategies, which manifest most commonly as choosing various crops over others given a particular set of mostly environmental and economic circumstances (e.g. switching from sugarcane to banana as a result of regional pest attacks and the subsequent closure of a local sugarcane processing plant). Furthermore, a number of farm-specific adaptive management strategies were described, such as incorporating intercropping to increase and diversify yields (Rajasekharan and Veeraputhran 2002), or attempting to substitute organic for chemical fertilizers in order to reduce reliance on the latter. Additional adaptive management strategies included renting unused land to those willing to farm, supplementing agricultural income with additional sources of income (e.g. remittances from abroad, owning a shop, part-time construction work), and adopting mechanization, especially for tilling paddy fields and harvesting coconuts.

Coping strategies also exist between community members and between communities and their local governments. Many households reported sharing food (e.g. mangos, milk, eggs, bananas, curry leaves, etc.) between families or neighbours in cases where an excess was produced. Farmers also identified a need to cooperate in order to be able to manage paddy fields, which need to be protected from birds. Many also said that paddy farming would not be profitable without the ability to either share a tractor between multiple families, or have access to a rental during specific times of the year. Local landholder associations were also mentioned as a way in which more money can be funneled from the government to agriculture by way of subsidies for fertilizers, seeds, and labour. There seemed to be consistent differences between panchayats in terms of how much support was being offered by the government. In Thiruvanvandoor in particular, farmers were very enthusiastic about the support systems set in place, such as providing chickens to every household, giving subsidies for seeds, helping farmers to plant trees (e.g. teak, mahogany) and plantains on their property, and providing insurance schemes to protect against crop loss. However, this enthusiasm was limited to Thiruvanvandoor, and farmers in other panchayats spoke of their local institutions with less appreciation.

"Even a loan for farming carries more interest than for a car. I want to stay with agriculture, but I am thinking about what to do for income instead, and I have no ideas." – Farmer in Wayanad

While many of the coping strategies adopted by homegardeners have had positive effects on their ability to preserve their agricultural livelihoods, others have been less beneficial. A number of farmers expressed a strong desire to leave agriculture, but felt as though they were trapped due to a combination of factors such as their age, experiences, skillsets, and financial circumstances. In some situations, farmers were reported to have taken out considerable loans in order to continue farming, which could then result in being forced to sell land in order to pay back debts. Other farmers admitted to having neighbours who had illegally converted part of their wetland from paddy to banana, areca, coconut, or even rubber, which cannot be grown successfully in the presence of high soil moisture.

3.5.4 Perceived Implications

Implications for the environment

According to farmers, Kerala's shift away from homegardening, and agriculture in general, will have mixed implications. With regards to the environment, these implications were seen almost exclusively as negative. Many interviewees spoke bleakly of the inevitable decline in the number of trees on the landscape, and reported missing trees that had already been removed due to old age or to make way for more profitable crops. Some farmers also mentioned the importance of having a diversity of crops in the homegarden, and worried that as agriculture continues to decline, so will crop diversity. Diversity of wild species was not mentioned in terms of being an important issue on the homegardens, and most of the wild fauna and flora mentioned in the interviews were seen as agricultural pests. However, farmers were very concerned with the mining of clay from paddy fields for the production of bricks, which has been made illegal but has continued at a lesser rate (Suraj and Neelakantan 2014). While financially enticing, mining clay from paddy fields is said to render them nearly useless, as they lose their ability to hold water and nutrients (Santhosh et al. 2013). By doing so, farmers also risk harming those "downstream", in the case that the paddy fields are connected by an irrigation network.

Implications for culture, health and autonomy

"Make the most of this place now because soon buildings will replace the trees. People forget what they want when they're in one place. Then they get what they think they want and realize they didn't want it in the first place. […] Paddy fields are vacant and people pay less attention to tree crops. We are now importing all of our food to Kerala, but we should not be relying so much on other states." – Woman with a large homegarden in Thamarassery

Loss of culture was another common theme emerging from farmers' discussions of implications arising from land-use change. The loss of traditional crops was a concern for some, and it was often the case that these crops were in conflict with less-traditional crops (e.g. removing a tamarind tree because it occupied too much of the canopy on a small plot; deciding to no longer have chickens because they tend to damage cardamom). Others worried that the ways in which communities have traditionally operated are under threat. As one farmer describes: *"Everything used to be shared in this area, but now there are 'walls of the mind'. We still share with our neighbours, but about 15 years ago most people stopped sharing. Now only money matters. Before, everyone helped each other build their house and till their land."*

Subsistence agriculture also appeared to have inherent value to farmers. While most homegardens have not been completely self-reliant for decades, if not centuries, homeowners nevertheless frown at the prospect of having to buy food as opposed to growing it themselves. While this comes partly out of a desire to keep with tradition, it seemed to relate more strongly to the prioritization of agricultural autonomy over dependence, both at the homegarden and at the state level. Homegardeners felt threatened by the state's increasing reliance on imported food, and expressed concerns related to food security as it relates to availability and quality. In general, homegardeners were highly conscious of the potential implications of commercial foods on their health. Most did not trust imported foods, and cited inadequate regulation of pesticide use in other Indian states. Overall, the mood surrounding the issue of integration into the global food market was pessimistic. However, some farmers did seem genuinely interested in increasing the capacity with which they were able to provide for themselves, especially by employing organic methods or by limiting dependence on chemical fertilizers and pesticides.

3.5.5 Overview of interview outcomes

Overall, Kerala's homegardeners witnessed a general decrease in both homegarden and plantation agriculture between 2003 and 2013. While homegardeners provided numerous explanations for the perceived shift away from agriculture, numerous recurring themes emerged in the interviews. The most common reasons given for declining agriculture were: 1) Changing environmental conditions (e.g. unreliable weather, increased problems with pests, etc.); 2) A shortage of affordable farm labour; 3) an increase in rural development; 4) Increase reliance upon and decrease access to inputs such as pesticides and fertilizers; 5) A preference for younger generations to engage in white-collar work, coupled with a stigma for agriculture; and 6) the availability of cheap imported goods.

Chapter 4 Concluding Discussion

The overall aim of my thesis was to quantify, describe, and explain recent trends in agricultural (especially agroforestry-related) land-use changes across Kerala. My research, which was motivated by anecdotal claims that traditional agroforestry-based homegardens are under threat from more profitable land uses, looked first at Kerala from the landscape scale using remotely sensed imagery, and then zoomed in to the scale of the homegarden with field research in order to obtain the perspective of homegarden farmers. An interdisciplinary approach provided a valuable means by which to investigate land-use dynamics in Kerala between 2001 and 2013. First, analysis of high resolution (IKONOS-2 and GeoEye-1) satellite imagery revealed that 1) agroforestry land cover in Kerala, while dynamic, seems to be neither increasing nor decreasing on average, 2) Kerala's wetlands, where paddy has traditionally been grown, have suffered losses in nearly 100% of documented cases, and 3) all areas of study witnessed dramatic increases in built surfaces such as roads and buildings.

The second phase of our study used quantitative surveys with homegardeners to reveal that 1) homegardens continue to play a small, albeit measurable subsistence role for the majority of homesteads, especially in the provision of tree crops such as coconut and jackfruit, 2) the vast majority of homegardens are a source of monetary income for homeowners, with areca, pepper, and timber being the most commonly sold products, 3) nearly every crop surveyed was grown in lesser quantities in 2013 compared to 2003, with the exception of rubber, curry leaf, and coffee, which did not change, and 4) livestock numbers plummeted dramatically, with the average number of cows per homestead across Kerala falling from 1.7 to 0.8, and the average number of chickens falling from 12.5 to 2.6.

In the third phase of this study I conducted brief semi-structured interviews with homegardeners in order to identify the drivers of agricultural land-use change on the homegarden as well as in the region of study. The vast majority of homegardeners perceived declines in agriculture both on their land as well as in the panchayat in which they lived, and Kerala in general. While the explanations for why agriculture was declining were varied, multiple themes recurred with farmers across Kerala, including: 1) Access to inputs such as labour, pesticides, and fertilizers; 2) Changing weather and climate; 3) Increased prevalence of pests and disease; 4) Declining profit margins alongside increased risk; 5) the presence of more appealing opportunities; 6) increased housing demand and a strong real estate market; 7) a general shift to a more educated, white-collar society. When these themes are arranged into sets of immediate and ultimate drivers of land-use change, they are able to explain the major land-use changes observed in both the remote sensing and quantitative survey portions of this study (Figure 4-1).

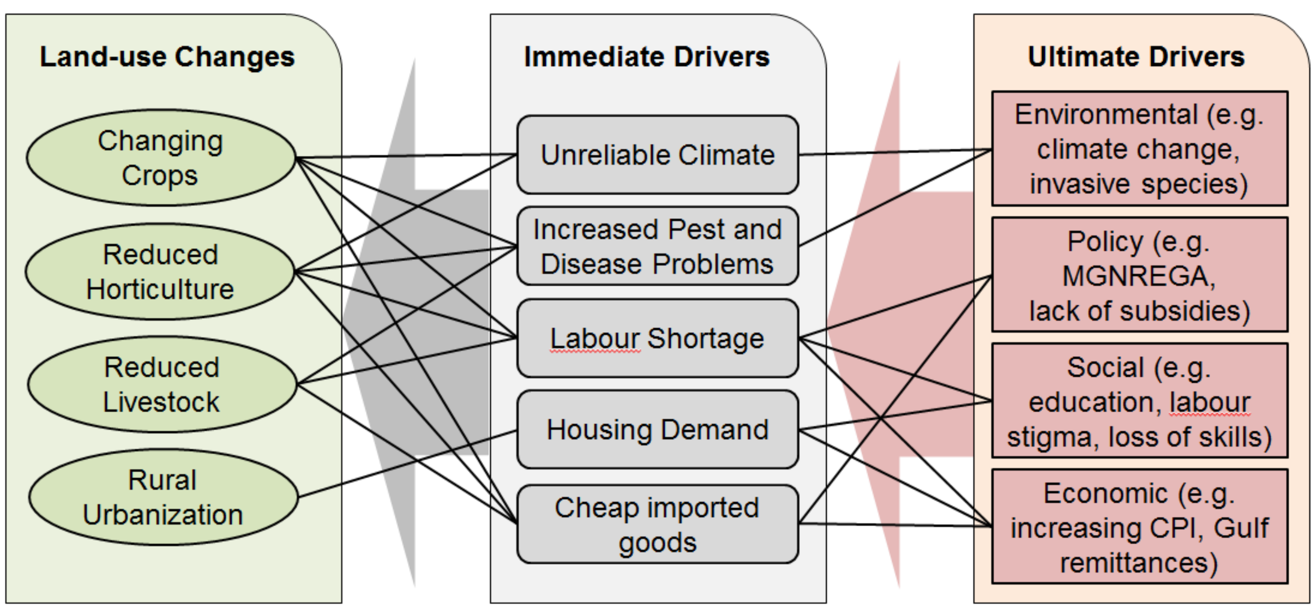

Figure 4-1. Observed land-use changes and their drivers according to combined findings from chapters two and three. Arrows indicate direction of influence and black lines indicate a causal relationship between variables. CPI = Consumer Price Index.

Taken together, the diverse results from this research depict a consistent picture of homegarden land-use change in Kerala. Satellite imagery analyses indicate that agroforestry land cover is in a state of dynamic equilibrium. Wetlands have declined considerably in all areas, as evidenced by both remote sensing and quantitative survey results. As farmers seem hesitant to build on wetlands, widespread wetland losses have occurred almost exclusively to agroforestry or to bare land (the latter is a precursor of future agroforestry land cover). Meanwhile, the dramatic increase in built surfaces occurred almost entirely at the expense of agroforestry. In economic terms, real estate and construction, which are the most profitable land uses, are replacing agroforestry, which is in turn more valuable than (and replacing) wetlands, where cultivation of paddy is no longer economically viable. This account of land-use change in Kerala also explains the dynamic equilibrium characterizing the agroforestry land cover, as agroforests are being removed from where they have traditionally grown and simultaneously planted anew on wetlands. Furthermore, agroforestry declined the most in Kalikavu, the only panchayat without wetlands. These losses occurred almost exclusively due to new built surfaces.

So why do farmers perceive a decline in the production of most food and commercial crops on their homegardens if agroforests are simply being relegated from the homestead to the wetlands? First, recently planted agroforests are likely to be less developed in terms of species composition, while mature agroforests can be expected to have greater diversity. Second, only certain crops are able to grow successfully in wetland areas. For the most part, these crops are areca, coconut, and banana, which are predominantly grown as monocultures or simply polycultures. Rubber, which is typically grown on hillslopes to encourage runoff of rainwater, does poorly in wetland condition as it prefers drier soils. Third, wetlands are almost always farther away from homesteads than homegardens. This distance means that farmers are less likely to grow certain species, such as ornamental, medicinal, or even non-commercial food species (e.g. jackfruit, mango) because they would require additional labour and would not be immediately accessible for use in the home.

While over 95% of homegardeners reported declining agriculture on their homegardens, only 30% of homegardens witnessed the construction of new built surfaces. Therefore, roughly 65% of homegardens experienced agricultural decline independent of changes in homegarden area or built surfaces. In other words, most of the changes occurring to homegardens are in terms of quality, not extent. This finding is consistent with those of (Peyre et al. 2006), who described a trajectory of change among Kerala's homegardens from a traditional to a modern state. According to Peyre, this shift is characterized by a greater reliance on external inputs, a decline in tree and shrub diversity, and an eventual reliance on a few commercially viable crops that lead to the homogenization of homegarden structure. Guillerme et al (2011) describe this as a conversion process in which homegardens are gradually replaced by plantations. The conversion, they argue, is characterized by the filling in of paddy fields, which are first planted with annual crops (e.g. banana), and soon after with woody perennials (e.g. coconut, areca). Meanwhile, Guillerme claims that the homegarden is gradually replaced by some sort of monoculture crop (usually rubber).

Although it is probable, even expected, that homegardens are undergoing a process of modernization (Peyre et al. 2006), my findings do not support the hypothesis that homegardens are being replaced by plantations (Guillerme et al. 2011). Not only do plantation crops across Kerala fail to show signs that they are increasing within homegardens (Figure 3-4), but the majority of homegardeners claim that all forms of agriculture are decreasing in Kerala. Furthermore, with the measured increase in the number of buildings in Kerala's countryside, along with the high population pressures present on Kerala's landscapes (Devi and Kumar 2011), it is likely that there are now more, albeit smaller, homegardens in Kerala than ever before. Nevertheless, smaller homesteads are less likely to have plantations because they are 1) subject to spatial constraints, limited production potential, and economies of scale, and 2) more likely to be occupied by those who do not consider agriculture as their primary source of income. Furthermore, it has been shown in both Kerala and Sri Lanka that smaller homegardens have higher cultivated species richness per unit area (Kumar 2011a; Mattsson et al. 2014). This is likely due to the fact that homegardeners prioritize having at least one or a few of each important species, and become more likely to use land less efficiently or to have simple plantation-style agroforests as they own more land.

Are Kerala's traditional homegardens under threat by more economically viable land uses, such as plantations and built environments? I don't believe that they are. While homegardens may be managed less intensively, these ancient agroforestry systems remain an important manifestation of cultural identity for the people of Kerala. As they have done in the past with the introduction of new species and technologies, it must be expected that homegardens will continue to change with time. If anything, I would wager that Kerala's homegardens will outlive its plantations.

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Appendix A: Pixel-based classification results

I conducted preliminary supervised classifications for Avinissery to determine whether this approach would be sufficient for answering the study questions. First, I compared various supervised classification algorithms for Avinissery in order to identify the most accurate method. The comparisons revealed that, of the various pixel-based approaches, ENVI's maximum likelihood classifier provided the best results (Table A-0-1). The maximum likelihood classifier was then used to classify Avinissery imagery from both 2001 and 2012. While the results for the classification of GeoEye-1 imagery in Avinissery in 2012 were satisfactory, overall accuracy for the 2001 IKONOS-2 imagery did not surpass 65%, with user's accuracies being particularly low (Table A-0-2). Furthermore, comparisons between the maximum likelihood classifier and the more trusted manual approach revealed inconsistent results (Table A-0-3). These inconsistencies are likely the result of context-driven decisions made during the manual classification, whereby shadows, trees obscuring buildings and roads, and wetlands at various stages of fallow or cultivation were all properly classified. All validations were conducted using points collected from the imagery, as reliable field data were not available for either of the two time periods. If the features of interest are easily identifiable by eye (as they are in this case), using high resolution imagery such as GeoEye-1 (Wickham et al. 2013), IKONOS-2 (C. Huang et al. 2009), or even RapidEye (Potapov et al. 2014) is considered a reliable means by which to conduct a validation.

Table A-0-1. Comparison of various pixel-based classification methods for Avinissery panchayat. Reported are producer's accuracy (Prod), user's accuracy (User), commission error (Com), and omission error (Omi), as well as overall accuracy.

	Accuracy		Error			
	Prod	User	Com	Omi	Overall	Kappa
MinDist					**59**	**0.37**
agroforest	74	51	49	26		
bare	82	59	41	18		
built	42	95	5	58		
water	100	56	44	0		
wetland	44	66	34	56		
Mahalanobis					**66.8**	**0.5**
agroforest	86	58	42	14		
bare	84	66	34	16		
built	56	96	4	44		
water	100	53	46	0		
wetland	50	81	19	50		
NeuralNet					**79.8**	**0.67**
agroforest	90	82	18	10		
bare	89	78	22	11		
built	38	100	0	62		
water	30	91	9	70		
wetland	85	77	23	15		
Support Vector Machine					**85.9**	**0.78**
agroforest	92	79	21	8		
bare	88	86	14	12		
built	83	92	8	17		
water	100	96	4	0		
wetland	80	90	10	20		
Maximum Likelihood					**92.8**	**0.88**
agroforest	99	99	1	1		
bare	94	39	61	6		
built	83	41	59	17		
water	90	100	0	10		
wetland	92	98	2	8		

Table A-0-2. Contingency tables (in percent) for maximum likelihood classifications in Avinissery panchayat in 2001 (IKONOS-2) and 2012 (GeoEye-1).

2001	Predicted Class					Producer's
Training Class	agroforest	bare	built	water	wetland	accuracy
agroforest	99	0	0	0	14	**99**
bare	0	94	5	0	2	**94**
built	0	0	72	16	19	**72**
water	0	0	0	84	4	**84**
wetland	1	5	23	0	60	**60**
User's accuracy	**34**	**68**	**10**	**9**	**98**	

*Overall Accuracy = 64.7%; Kappa Coefficient = 0.32

2012	Predicted Class					Producer's
Training Class	agroforest	bare	built	water	wetland	accuracy
agroforest	99	0	0	0	0	**99**
bare	0	94	5	0	6	**94**
built	0	6	83	7	2	**83**
water	0	0	0	90	0	**90**
wetland	1	0	12	4	92	**92**
User's accuracy	**99**	**39**	**41**	**100**	**98**	

*Overall Accuracy = 92.9%; Kappa Coefficient = 0.88

Table A-0-3. Comparison between maximum likelihood (ML) and manual classification (MAN) approaches in subsamples. Reported for Avinissery, Kalikavu, and Poothrikka panchayats in percent cover for the same areas.

	Avinissery		**Kalikavu**		**Poothrikka**	
	ML	MAN	ML	MAN	ML	MAN
agroforest	46.0	48.2	83.6	85.7	58.1	76.4
bare	3.6	9.5	8.9	4.5	1.0	4.1
built	11.5	14.6	7.3	7.2	12.6	6.6
water	0.6	0.6	0.1	1.1	0.1	0.2
wetland	38.2	27.1	-	-	28.2	11.3

Appendix B: Consent form

Consent Form
This form will be presented in Malayalam.

Title of Research: Agroforestry land use dynamics in Kerala, India

Principle Investigator: Thomas Fox, MSc Student, Department of Geography, McGill University
Supervisors: Jeanine Rhemtulla and Navin Ramakutty
Contact Information: thomas.fox2@mail.mcgill.ca

Outline of Research and Participant Consent

Homegardens have existed as sustainable forms of agriculture in Kerala for over 4000 years. However, with the introduction of conventional forms of agriculture, the landscapes of southern India are beginning to change. We are interested in finding out how quickly agricultural land is changing from one type to another. We would like to ask if we would be able to take some measurements of your garden and to ask you a few questions.
Your participation will consist of a short oral interview lasting approximately 10 minutes, which can be conducted either now, or at some point in the future that is convenient for you. In the interview, you will be asked about how your agricultural land has changed over the last 5-10 years, as well as about how you think it might change in the future. We are also interested in knowing what it is that you think is causing these changes in land use. If you agree, we will also take measurements of your homegarden to determine the current size. We are also interested in the kinds of tree species that are growing on your land, and these will also be recorded.

Your participation is completely voluntary and you may choose to end the survey at any time. You may also refuse to answer any question, or you may agree to not participate in one of either the questionnaire or the physical measurements of the homegardens. However, please note that your answers and identity will be protected and kept confidential at all times. Neither your name or the location of your homegarden will be shared with anybody else. Information pertaining to the location of your homegarden will be coded for anonymity. The information will be kept on a password-protected computer and in a locked office at McGill University in Canada. Only myself and my supervisors (Drs. Navin Ramankutty and Jeanine Rhemtulla) will have access to this information.

The information that we collect during the interview and survey will be disseminated in the form of conference presentations and research articles in peer reviewed academic journals. However, in order to further ensure anonymity, only aggregate data will be used, and information related to your individual homegarden will not be published. You will not benefit directly from this study, but the information gathered may help to better understand and promote sustainable agricultural systems in both Kerala and the rest of the world.

Are you willing to participate in this research (please circle)?
Yes No

We are happy to answer any questions that you might have about this research. Feel free to contact us be phone, email, or regular mail.

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If you have any questions or concerns regarding your rights or welfare as a participant in this research study, please contact the McGill Ethics Officer at 514-398-6831 or lynda.mcneil@mcgill.ca.

Appendix C: Questionnaire

PART A - Demographics and Land Use Name :

Date/time: District: Code : LatLong :

Address : Homegarden Age :

Main source income : Agriculture/Business/Service/other : ____________________ Subsidiary income : ______________________

Size of family : Adults ___/___ Children : ___/___ Sources of domestic energy :

Fuelwood/cropresidues/biogas/other :______________

Land owned (acres) : Homestead_________ Wetland :________ Other :_______ Fuelwood costs (Rs) : ___________/___________

1. How long have you owned this homegarden?
2. Have there been any changes in ownership in the last 10 years (to any part of the land)?
3. What is current garden area?
4. Do you own any plantation? If so, how long has the plantation been there? How long have you owned it? What was there before?
5. Has garden area increased, decreased, or stayed the same in the last 10 years? By how much?
6. If there was a decrease in homegarden area, what has replaced it?
7. If there was an increase in homegarden area, what has it replaced?
8. Why did these changes in homegarden size occur?
9. What do you think will be on this land in 10 years? 50 years?
10. Do you know what was here 50 years ago? 100 years ago
11. What do you want to grow in the future? What do you want to stop growing? Why?
12. Do you plan to sell some or all of your land? Do you want to buy more land? How much?
13. What pest/disease problems do you have in your homegarden?

PART B – Agricultural Trends

1.

	Do you grow	Do you ever buy…		10 years ago, did you grow more or less…			Do you ever sell…		10 years ago, did you sell more or less…		
Spices											
Curry leaf		Yes	No	More	Same	Less	Yes	No	More	Same	Less
Pepper		Yes	No	More	Same	Less	Yes	No	More	Same	Less
Cardamom		Yes	No	More	Same	Less	Yes	No	More	Same	Less
Staple Foods											
Rice		Yes	No	More	Same	Less	Yes	No	More	Same	Less
Plantation Crops											
Coconut		Yes	No	More	Same	Less	Yes	No	More	Same	Less
Coffee		Yes	No	More	Same	Less	Yes	No	More	Same	Less
Tea		Yes	No	More	Same	Less	Yes	No	More	Same	Less
Rubber		Yes	No	More	Same	Less	Yes	No	More	Same	Less
Areca		Yes	No	More	Same	Less	Yes	No	More	Same	Less
Food Crops											

Mango		Yes No	More Same Less	Yes No	More Same Less
Bananas		Yes No	More Same Less	Yes No	More Same Less
Papaya		Yes No	More Same Less	Yes No	More Same Less
Tamarind		Yes No	More Same Less	Yes No	More Same Less
Jackfruit		Yes No	More Same Less	Yes No	More Same Less
Pomegranate		Yes No	More Same Less	Yes No	More Same Less
Cashew		Yes No	More Same Less	Yes No	More Same Less
Fuelwood		Yes No	More Same Less	Yes No	More Same Less
Timber		Yes No	More Same Less	Yes No	More Same Less

2. a) How many cows do you have? How many 10 years ago?
   b) Do you ever buy milk?
   c) Do you sell milk?
   d) Did you sell more or less milk 10 years ago?

3. a) How many chickens do you have? How many 10 years ago?
   b) Do you ever buy eggs?
   c) Do you sell eggs?
   d) Did you sell more or less eggs 10 years ago?

4. How many banana plants do you have?
5. How many banana varieties do you have?
6. How many mango varieties do you have?
7. Are there any new buildings on this land in the last 10 years? Details if so.

PART C – Semi-structured Interview

Leading question: Has agriculture increased or decreased on your land and/or in this region?

Examples of possible follow-up questions:

- Why have these increases or decreases occurred?
- Why has agriculture become less affordable?
- Why are people no longer interested in farming?

Leading question: Why did you grow more or less of the crops reported in Part B?

Examples of possible follow-up questions:

- Why are you buying foods instead of growing them?
- Why do you have less land now?
- Why is agriculture too much work now?