Understanding forest-cover change in Yunnan with a combination of quantitative and qualitative methods

Dissertation

zur Erlangung des
Doktorgrades der Naturwissenschaften (Dr. rer. nat.)

der
Naturwissenschaftlichen Fakultät III
Agrar- und Ernährungswissenschaften,
Geowissenschaften und Informatik

der Martin-Luther-Universität Halle-Wittenberg

vorgelegt von

Herrn Frayer, Jens
Geb. am 23. November 1977 in Berlin

Gutachter:

1. Hr. Dr. Dr. h.c.. M. Frühauf
   Institut für Geowissenschaften und Geographie
   Martin-Luther-Universität Halle-Wittenberg
2. Hr. Prof. Dr. D. Schmidt-Voigt
   Mountain Society Research Institute
   University of Central Asia, Kyrgyz Republic
3. Hr. PD Dr. D. Müller
   Abteilung Betriebs- und Strukturwandel im Ländlichen Raum
   Leibniz-Institut für Agrarentwicklung in Transformationsökonomien, Halle/Saale

Verteidigung: 7. Juli 2016, Halle a.d. Saale

Summary

Changes in land use have affected the environment since humanity started to cultivate land. In particular, the clearances of forests, expansion of subsistence agriculture, and increasingly intensive farmland production have fundamentally shaped the Earth's surface. The consequences for the environment range from changing the atmospheric composition to the modification and loss of ecosystems. Recently, deforestation and agricultural emissions from livestock, soil, and nutrient management are responsible for nearly one quarter of the yearly green-house-gas (GHG) emissions. The changes in Earth system functioning in turn have pivotal effects on livelihoods of people who depend directly or indirectly on ecosystems and the services offered by them. Forested ecosystems play a particularly important role, as they provide crucial food, feed, and fiber for humanity, and many people rely on forested areas to secure their livelihoods. Moreover, forests store massive amounts of carbon and sequester carbon dioxide from the atmosphere through photosynthesis. However, forest cover has been decreasing in many countries, driven mainly by agricultural expansion and logging to secure timber. While forests continue to decline in many countries, industrialized and emerging economies in particular have recently experienced increases in forested area. China, which was able to reduce deforestation and increase its overall forest cover, is one of these countries. This work aims to increase the understanding of the proximate causes and underlying drivers of these forest-cover changes in China. Strict enforcement of forest protection and massive afforestation campaigns have contributed to a significant increase in China's forest cover since around 1995. At the same time, demographic changes in rural areas due to changes in reproduction patterns and the emigration of younger population segments have substantially affected land use strategies. By using household survey data and participatory approaches, I extract the salient proximate causes and underlying drivers that influence the decisions of farm households to plant trees on former cropland. This is approached with Bayesian networks, which allow the incorporation of causal relationships in data analysis and can combine qualitative stakeholder

knowledge with quantitative data. The structure of the network is defined with expert knowledge and in-depth discussions with land users and was calibrated and validated with data from a survey of 509 rural households in two upland areas of Yunnan province in Southwest China. The results substantiate the influence of land endowments, labor availability, and forest policies on switching from cropland to tree planting. State forest policies have constituted the main underlying driver to the forest transition in the past, but private afforestation activities increasingly dominate the expansion of tree cover. Farmers plant trees for private incentives mainly to cash in on the improved economic opportunities provided by tree crops, but tree planting also constitutes an important strategy to adjust to growing labor scarcities.

Further, the recognition of the importance of forests for local livelihoods, biodiversity, and the climate system have initiated a growing interest in understanding the factors that drive forest-cover change. Forest transitions, the change from net deforestation to net reforestation, may follow different pathways depending on a complex interplay of driving forces. However, most studies on forest transitions focus on the national rather than the local level. To better understand regional diversity in the pathways to the forest transition, case studies in ten villages were conducted to clarify the complex interactions among various pathways of forest transitions, derive insights into the underlying drivers that shaped the forest transitions, and determine the importance of changes in drivers over time.

In sum, I demonstrate that China's recent forest transition was caused by a range of interrelated pathways that were mediated by local circumstances. The degradation of forest ecosystem services caused by rampant deforestation and forest degradation created a scarcity of forest products and triggered state-initiated afforestation efforts, particularly in the 1990s, which continue to be important. More recently, economic development concomitant with smallholder intensification spurred reforestation, while the importance of state forest policy declined. The complexity of local land use changes demonstrates the difficulty of identifying distinct transition pathways and calls for a more diverse approach that recognizes the interdependence of local processes.

Zusammenfassung

Seit dem die Menschheit Landwirtschaft betreibt, haben Landnutzungsänderungen die Umwelt beeinflusst und geändert. Besonders das Roden ganzer Wälder, die Expansion der Subsistenzlandwirtschaft und die immer intensiver betriebenen landwirtschaftlichen Produktion haben die Erdoberfläche grundlegend verändert. Die Folgen für die Umwelt reichen hierbei von Änderungen in der Zusammensetzung der Atmosphäre bis zu der Vernichtung ganzer Ökosysteme. Gegenwärtig sind Abholzung, Emissionen aus der Tierhaltung und Landwirtschaft für annähernd ein Viertel der Treibhausgasemissionen verantwortlich. Diese Einflüsse auf die ökologischen Kreisläufe üben gleichzeitig Einflüsse auf die Lebensumstände der Menschen aus, die direkt oder indirekt von bestimmten Ökosystemen oder deren Nutzung abhängig sind. Hierbei spielen die Wald-Ökosysteme durch das Bereitstellen von Nahrung, Futter und Baumaterial als Lebensgrundlage für eine Großzahl von Menschen eine herausragende Rolle. Zudem speichern Wälder große Mengen an Kohlenstoff und binden atmosphärisches Kohlendioxid durch die Fotosynthese. Trotzdem ging in der Vergangenheit in vielen Ländern die Waldbedeckung als Folge der Ausweitung der Landwirtschaft und des Holzeinschlags zurück. Während in vielen Ländern dieser Rückgang anhielt, nimmt in manchen industrialisierten Ländern und aufstrebenden Volkswirtschaften gegenwärtig die Waldbedeckung wieder zu. Eines dieser Länder, welches es geschafft hat den Rückgang zu stoppen und die Waldfläche wieder zu vergrößern, ist China.

Ziel dieser Arbeit ist es, das Wissen zu den unmittelbaren Ursachen und den zugrunde liegenden Gründen für die erfolgreiche Wiederbewaldung zu erweitern. Ein wichtiger Aspekt für die erfolgreiche chinesische Wiederbewaldung ist das strikte Durchsetzten von Schutzmaßnahmen und massive Aufforstungsprogramme seit 1995. Zeitglich auftretende demographische Entwicklungen und emigrierende junge Bevölkerungsteile haben die Landnutzungsstrategien in den ländlichen Gebieten Chinas grundlegend verändert. Durch die Kombination von Daten einer umfassenden Haushaltsbefragung und qualitativer Forschungsansätze zeigt die vorliegende Arbeit die direkten und indirekten Faktoren, welche

die Entscheidung von Landnutzern beeinflussen auf landwirtschaftlich genutzten Flächen Bäume zu pflanzen. Diese Entscheidung wird mit einem Bayes'sches Netzwerk modelliert, welches es erlaubt, ursächlich Zusammenhängen in der Datenanalyse und qualitative Informationen betroffener Akteure mit quantitativen Daten in der Analyse zu kombinieren. Die Struktur diesen Netzwerkes wurde auf Basis von Expertenwissen und Interviews mit Landnutzern gebildet, und anschließend mit Daten von 509 untersuchtet Haushalten aus zwei Gebieten im Hochland Yunnans, Südwestchina, validiert und kalibriert. Die Ergebnisse bestätigen den Einfluss des verfügbaren Landes, der verfügbaren Arbeitskraft und Aufforstungspolitik auf den Landnutzungswechsel von Ackerland zu agroforstlicher oder rein forstlichen Nutzung. In der Vergangenheit hatte die staatliche Aufforstungspolitik den größten Einfluss auf Landnutzungsentscheidungen dieser Art. Jedoch hat die Bedeutung privater, nicht geförderter Aufforstung zugenommen und ist gegenwärtig wichtigste Ursache für den Landnutzungswechsel. Die Landwirte pflanzen die Bäume hauptsächlich aufgrund der neuen wirtschaftlichen Möglichkeiten, welche ihnen eine finanzielle Einkommensmöglichkeit bietet. Zudem stellt der Wechsel auf Früchte tragender Bäume eine wichtige Strategie dar, mit welcher dem zunehmenden Arbeitskräftemangel begegnet wird.

Die Wahrnehmung der Bedeutung von Wäldern als Lebensgrundlage menschlichen Daseins, für die Biodiversität und das weltweite Klima hat das Bestreben verstärkt, die weltweiten Änderungen in der Waldbedeckung zu verstehen. Die „Forest transition", das Wechseln einer zurückgehenden Waldbedeckung in eine wieder zunehmende Waldbedeckung, folgt in ihrer Entwicklung unterschiedlichen Verläufen, deren Muster von einer Verknüpfung und Abfolge ursächlichen Faktoren abhängt. Diese Muster wurden in der Vergangenheit hauptsächlich auf der nationalen Ebene betrachtet und beschrieben, wobei lokale Entwicklungen vernachlässigt wurden. Um die regionale Unterschiede in den Entwicklungsmustern zu verstehen, wurden zehn Dörfer als Fallstudien untersucht. Die hieraus erhaltenen Ergebnisse zeigen die engen Zusammenhänge zwischen den einzelnen Entwicklungsmustern, die Gründe für die Ausprägung der einzelnen Muster und belegen die Bedeutung der sich ändernden Rahmenbedingungen.

Zusammenfassend zeigt diese Arbeit, dass die Zunahme der Wälder in China durch eine Reihe miteinander verbundener Entwicklungsschritte und -muster begründet liegt, welche in ihrer Ausprägung von lokalen Bedingungen bestimmt werden. Als Folge der staatlichen Abholzung kam es zu einem Rückgang der ökologischen Dienstleistungen der Wälder, in

Form rasanter Entwaldung und Degradierung der verbliebenden Wälder. Die Folgen des massiven Holzeinschlages lösten umfangreiche Aufforstungsmaßnahmen in den 1990er Jahren aus, deren Bedeutung noch heute anhält. Gegenwärtig treten jedoch diese staatlichen Anreize für die Wiederbewaldung in den Hintergrund, während Änderungen in den wirtschaftlichen Rahmenbedingungen und kleinbäuerliche Intensivierungsmaßnahmen Hauptursache für die Wiederbewaldung sind. Die Komplexität lokaler Landnutzungswechsel zeigt die Schwierigkeiten bei der Identifikation einzelner unterschiedlicher und klar abgrenzbarer Entwicklungsmuster und begründet hierbei den Bedarf für weitgefasste und interdisziplinäre Forschungsansätze, welche die Abhängigkeiten und Zusammenhänge der lokalen Prozesse berücksichtigen.

Acknowledgements

Completing this dissertation would not have been possible without the help and support of several people. The first I thank is Daniel Müller, for being a motivating, patient, and reliable supervisor and his constant support throughout the last years.

In addition several other senior and junior scientists at the Leibniz Institute of Agricultural Development accompanied my way and supported me. Thanks go to Sun Zhanli, Omar Baqueiro Espinosa, Wiebke Meyer and Kristin Leimer for all the helpful discussions and building an inspiring environment at the IAMO, to Darla Munroe for her enthusiasm and all the constructive feedbacks and to Xu Jianchu and the members of the Center for Mountain Ecosystem Studies, Kunming, China, for supporting my work in the wonderful Yunnan.

Finally the biggest thank goes to my wife Petra and my son Nils, the both most important persons in my life. Without their patience, support and encouragement in good and not so good times, this would not have been possible.

Table of contents

List of tables

List of figures

1 Introduction

Changes in land use and therefore in ecosystems have affected the environment since humanity started to cultivate land (Turner II, Lambin and Reenberg 2007, Rudel 1998). Those changes include clearing forests, practicing subsistence agriculture, intensifying farmland production, and expanding inhabited places, which together have fundamentally shaped the world's surface (Foley et al. 2005). The environmental side effects of past land use changes range from changing the atmospheric composition to the modification and loss of ecosystems. The Intergovernmental Panel on Climate Change (IPCC) estimates the annual greenhouse-gas (GHG) emissions from agricultural production in 2000 – 2010 at 5.0 – 5.8 $GtCO_2eq$ / yr while annual GHG flux from land use and land use change activities accounted for approximately 4.3 – 5.5 $GtCO_2eq$ / yr. Deforestation and agricultural emissions from livestock, soil, and nutrient management are thereby responsible for nearly one quarter of the yearly anthropogenic GHG emissions (Smith et al. 2014). Land use changes affect regional climates through changes in surface energy and water cycles, and anthropogenic inputs from fertilizers and other pollutants have widespread impacts on water quality (Kalnay and Cai 2003). Moreover, land use and land use changes are the main sources for the degradation of soils and marine ecosystems (Tolba and El-Kholy 1992) and have caused massive biodiversity decline through the loss or modification of habitats (Pimm and Raven 2000). In sum, land use and land-cover changes substantially affected Earth system functioning (Lambin et al. 2001), and the changes to the Earth system in turn have pivotal effects on livelihoods of people who depend directly or indirectly on the ecosystems and the services offered by them.

The number of publications covering the topics of land use and land use change, land cover change, and forest-cover change prove that these topics are emerging as important research areas, combining diverse scientific disciplines and methodologies (Müller and Munroe 2014). Geographers, environmental scientists, landscape ecologists, and agricultural economists are seeking answers to the question of what drives land-cover and land use change (Bürgi, Hersperger and Schneeberger 2005, Geist and Lambin 2001, Kaimowitz and Angelsen 1998). Many factors have been identified as being important for land use change. Kates, Turner, and Clark (1990) pointed out that theories of human-environment relationships have to include the relations among the driving forces of human-induced change, processes, and activities among them, as well as human behavior and organization. Therefore, the web of driving forces forms a complex system of dependencies, interactions, and feedback. To understand such a complex system it is necessary to explore the relationships and connections between people and their environment (Bürgi et al. 2005).

A detailed division of the drivers, as by Brandt, Primdahl, and Reenberg (1999) or Lambin and Meyfroidt (2010), is useful. They separated the drivers into socioeconomic, political, technological, and cultural driving forces. Socioeconomic drivers are often caused by economic causal chains Market economies, with regionally and globally interlinked connections, have a strong influence on forms of land use and are often the strongest determinant of land use decisions. The effects of the market forces are mediated by another set of factors (Lambin et al. 2001). Adding the basic needs of people, which are the strongest factors affecting landowners and their land use decision, makes this group of factors the most important driver. Political drivers, translated into laws and programs, vary broadly. This ranges from crop quotas to taxes or global agreements to mitigate greenhouse gas emissions. Another kind of government intervention is state-initiated payments for ecosystem services (PES), which honor an environmentally beneficial behavior with a monetary or in-kind compensation.

Infrastructural innovations and developments, such as railways and highways, are subsumed as technological drivers, which often have a strong impact on the many factors influencing land use decisions by altering market access and affecting job opportunities outside the farm. The access to information, defined by availability of telephone lines or internet, is closely related to this category.

Natural drivers can be separated into two categories. The first are place-specific endowments that shape the location of land use change that is defined by soil characteristics, climate, topography, and natural disturbances (Geist and Lambin 2002). These site factors are typically stable in the short term but might change in a longer perspective. The second category are fast-acting natural disturbances, including landslides, fires, or hurricanes, which can affect the land use substantially, while slowly acting disturbances such as soil degradation, salinization of agricultural land, or climate changes are similarly strong but may permit a gradual adaptation to changing circumstances (Bürgi et al. 2005).

Finally, culture is also a very important albeit very complex factor. Natural and cultural drivers affect each other; often the recent landscape is a consequence of long lasting land use patterns that are typical for the prevailing culture and natural conditions. However, as cultural values change, existing land use patterns adapt to these appreciations. On the other hand, cultural values are also able to prevent changes if they contradict cultural habits (Nassauer 1995, Bürgi et al. 2005).

It is particularly important to understand changes in forested ecosystems because forests provide crucial food, feed, and fiber for humanity, and many people rely on forested areas to secure their livelihoods (Sunderlin et al. 2008). Moreover, forests store massive amounts of carbon and sequester carbon dioxide from the atmosphere through photosynthesis (Malhi and Grace 2000). However, forest cover has been decreasing in many countries, driven mainly by agricultural expansion and logging to secure timber (Chomitz 2007, Geist and Lambin 2002). While forests continue to decline in many countries, industrialized and emerging economies in particular have recently experienced increases in forested area (Lambin and Meyfroidt 2010). A better understanding of the drivers underlying deforestation and reforestation is important to assess likely future trajectories of forest-cover change and to steer forest use onto sustainable pathways.

1.1 Forest transition – pathways and local variety

A forest transition describes the process in which the trend of decreasing forest area (deforestation) changes to expanding forest area (reforestation) (Mather 1992). The classic cycle begins with low deforestation in early stages when little pressure on forest resources is exerted by humans (Figure 1). In later stages, deforestation starts to accelerate in so-called agricultural frontier areas where expansion of land use is the dominant strategy to satisfy consumption needs (Angelsen 2007). Later, deforestation has often been shown to decrease, arguably because agricultural expansion ends, population growth rates slow down, or changing political climates protect forest resources. Due to this combination of decelerating rates of deforestation and accelerating rates of afforestation, the total area of forest starts to recover (Mather 1992). At this point in time, when the forest area changes from net deforestation to net reforestation, the turning point of the forest transition is reached (Figure 1) (Rudel et al. 2005). However, typically natural forests are depleted and replanted, with managed forests replacing the pristine forest in the course of the forest transition (Mather 1992), and societies increasingly rely on resources from secondary forests to satisfy their consumption needs. Such secondary forests often lack original, pristine biodiversity and provide fewer ecosystem services, such as carbon storage and sequestration.

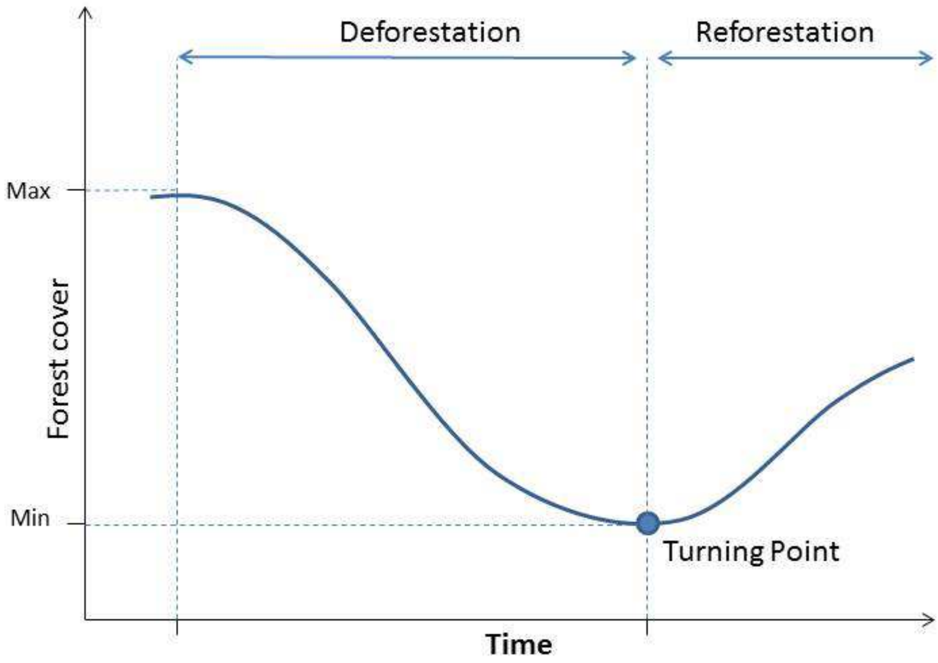

Figure 1: The forest transition: Forest regrowth after a period of forest decline
Source: Adpated from Mather (1992)

The sequence of deforestation followed by later reforestation has been observed in many countries over the course of time. For example, forest transitions have been documented in several European countries such as Scotland (Mather 2004), France (Mather, Fairbairn and Needle 1999), and Switzerland (Mather and Fairbairn 2000). More recently and for quite similar reasons, forest transitions have also been observed in some tropical countries such as Costa Rica (Calvo-Alvarado et al. 2009), Vietnam (Meyfroidt and Lambin 2009), and China (Mather 2007, Xu et al. 2007).

Most of these studies focus on country-level data, but within-country variation of changes in forest cover can be substantial. For example, the timing of the turning point of changes from deforestation to reforestation varies substantially across the former Soviet Union, with some regions turning in the late 18th century while others have not yet experienced the turning point (Kuemmerle et al. 2015). In all of these cases decreasing population growth, urbanization following industrialization, and growing agricultural productivity, as well as the decrease in deforestation and eventually the increase in forest cover, have been mentioned as driving factors.

While empirical studies prove the occurrence of forest transitions in countries in Europe, North America, and recently in tropical countries, a similarity in the patterns of forest-cover change does not automatically imply that the causes and reasons for the observed transitions are the same (Lambin and Meyfroidt 2010). Rudel describes the transition, which took place in several European countries and North America (Lambin and Meyfroidt 2010), as follows: During the first phase increasing labor shortages in cities and parallel increasing wages pull workers out of agriculture and reduce the profitability of agricultural enterprises. As a consequence, remote and less fertile parts of agricultural land get abandoned and revert slowly back to forest. As the initial labor force shortage is caused by the economic development, this sequence of events is called the economic development path.

A different situation occurs when a limited availability of forest products spurs increases in prices of forest products. Because of the high prices and increased profitability, landowners plant trees instead of perennial crops. In this case, the scarcity of forest causes the limited availability of forest products in a sequence that is called the forest scarcity pathway to the forest transition. This development is enforced by political activities supporting reforestation to increase the provision of ecosystem services, such as water mitigation or erosion control. These developments are subsumed in the forest scarcity pathway (Lambin and Meyfroidt 2010, Rudel 2009).

Recent case studies have revealed three other types of forest transition paths. The state forest pathway describes cases in which national forest policies are the main cause for the forest transition. The implementation of such policies may be triggered by scarce forests or limited provision of ecosystem services provided by forests, but the underlying reasons comes from outside the forestry sector. In such cases the transition is a side effect of the political willingness to modernize the economy and land use, the integration of marginal social groups, or the attempt to create a “more green” picture of a country (Lambin and Meyfroidt 2010, Rudel 2009).

The recently increasing integration of national economies into global markets has lessened the importance of national boundaries by increasing trade of commodities, labor, and capital flows (Kastner et al. 2012). In comparison to historical forest transitions, modern economies are strongly integrated into global market structures and are affected by globalization. As a consequence of the globalization, processes such as neo-liberal market reforms, labor migration, the implementation of international conservation ideas, and growing tourism are taking place and affect national societies and policies, and thereby the national forest cover (Geist and Lambin 2002, Lambin and Meyfroidt 2010). However, as the increasing possibility and opportunity to migrate globally enables migrants sending back remittances, affects the decision to migrate directly, one of the core arguments of the economic pathway, and a clear differentiation between these two pathways does not seem possible. Another factor showing how global markets affect national forests is the displacement of deforestation. The global timber trade allows countries to decrease their own timber harvestings and to increase the import of timber from other countries (Laurance 2008, Mayer et al. 2005).

A fifth pathway is characterized by an expanding tree cover on agricultural land and orchards in the form of agroforestry systems or fruit orchards. Such landscape mosaics are characterized by agricultural lands intersected by trees, which create a continuity between planted and natural forests. The reasons for planting trees are often to reduce vulnerability to economic and environmental shocks and diversify income sources and agricultural labor demand (Ediger 2006, Meyfroidt and Lambin 2009). Such agro-forests can be seen as land use intensification, as an initial increase of inputs in the form of labor and capital is necessary. At later stages the labor demand might be smaller than in agriculture. The motivation for farmers to plant trees is not driven by forest scarcity but by innovations in land use systems and changing availability of household assets, which makes the difference between this path and the forest scarcity pathway (Lambin and Meyfroidt 2010).

The pathway framework is useful for categorizing, comparing, and understanding the processes underlying the forest transition as it links changes in forest area to the underlying causes, but this should not hide the fact that the form and timing of the transition vary from case to case. As the causes for the deforestation are at least partly specific to localities, so also are those of the forest transition (Mather 1992). Because of the national focus of many empirical studies (see, e.g., Farley 2010, Mather 2007a), national statics are utilized to explain the forest transition which neglects local characteristics (Klooster 2003, Perz 2007). By the use of data aggregated on the national level, special local developments or anomalies are neglected as their importance on national level becomes blurred. However, focusing on the local scale can better highlight the many interactions of different processes and their impacts on forest cover, including through disentangling the effect of the implementation of national policies, land use conflicts, and different socioeconomic endowments. Moreover, spatial characteristics remain clearly visible and do not average out as they do at the aggregated level. For example, forest cover may decline in a region and recover in a neighboring region (Perz 2007), or local natural endowments may result in different land use strategies and in spatially varying reforestation patterns (Klooster 2003). Therefore improved knowledge of forest-cover change at local level offers the opportunities to understand the impact of interacting and simultaneously ongoing processes on the forest transition (Farley 2010, Klooster 2003).

1.2 Research questions and methodical approach

The overarching goal guiding the research presented in this dissertation is to shed light on the drivers that shape the forest transition in Yunnan province, China. The research is focused on the local level in order to understand the underlying drivers for land use decisions of farmers and their processes, how these vary across villages and regions, and what drives the observed changes. The empirical work was based on data collected in field work at the village level in Yulong and Longyang.

The research is presented in two parts. The first part (Chapter 4) uses a predominantly quantitative approach and household survey data collected in the field to analyze the factors that shape land use decisions of households. The research questions of Chapter 4 are:

- What are the main drivers that influence the *decision* of farmers to plant trees on former cropland?
- Which drivers are the most influential in explaining how farmers decide on the *area* planted with trees?

The quantitative approach offers the advantage of comparing a large number variables for a representative cross-section of cases. The outcome measures the importance of several factors in the decision of converting agricultural land and joining state-led afforestation programs. It sheds light on the variables affecting the decision to join an afforestation program, as well as the circumstances that affect the area that is converted.

Chapter 5 scales out the information and knowledge gained in Chapter 4 to the village level and shows the complex interactions among the different pathways of forest transition. The qualitative analysis of the ten case study villages derives insights about the underlying drivers that shaped the forest transitions across all study villages and over a time horizon of 50 years. The key research questions in this chapter are:

- What differences can be observed between the ten cases?

- How did the main drivers of the forest transition change over time?

- What parallel driving forces can be observed in the different villages?

The results show that the pathways of forest transition are not predetermined but change over space and time. In particular it is shown how the main underlying drivers vary among the villages and how changes in political, economic, and social framework conditions shape subsequent forest-cover changes.

1.3 Structure of this dissertation

This dissertation includes five thematic chapters. After this introduction, I will assess historic changes in Chinese forest cover in Chapter 2, offer a description of the study region and data collection in Chapter 3, followed by two research chapters that present the analysis of primary data for Yunnan province. I will then discuss the results of these chapters in Chapter 6, followed by final conclusions.

The two research chapters have been published in peer-reviewed international journals listed in the Web of Science of Thomson Reuters:

Chapter 4: Frayer, J., Sun, Z., Müller, D., Munroe, D.K., Xu, J., 2014. Analyzing the drivers of tree planting in Yunnan, China, with Bayesian networks. *Land Use Policy* 36: 248-258. doi:10.1016/j.landusepol.2013.08.005

Chapter 5: Frayer, J., Müller, D., Sun, Z., Munroe, D., Xu, J., 2014. Processes Underlying 50 Years of Local Forest-Cover Change in Yunnan, China. *Forests* 5(12): 3257-3273. http://dx.doi.org/10.3390/f5123257

2 The forest transition in China

In the past China's forests went through periods of deforestation and forest recovery. Based on historic developments nearly no primary or undisturbed forest remains. The last times China experienced massive deforestation were the periods of the Great Leap Forward from 1958 to 1961 and the Cultural Revolution from 1966 to 1976 (Zhang et al. 2000, Song and Zhang 2010). Management and natural regeneration shaped the remaining forest over decades. Only in remote areas did natural forest remain undisturbed. Following official Chinese data on forest cover, total forest cover in 1949 was 8.6%. During this time, timber was an important resource, the price of which was not set by its scarcity but by the government. The amount of timber harvested was barely compensated by forest regrowth in the form of plantations. As a result the forest resources were almost depleted and the structure of the forests was altered significantly. Song (2010) characterized three stages of the Chinese forest development: stage I, the unstable stage; stage II, the recovery stage; and stage III, the stage of expansion. Stage I reflects the first years of forest exploitation described above. Stage II, started in the early 1980s, is characterized by the harvesting of timber plantations, which allowed the natural forest to recover and resulted in a slow forest cover increase. At the same time the Chinese government started its first ecological programs aimed at environmental protection and implemented the "Three Fixes Policy," which transferred the responsibility and benefits of forest management to local communities and rural households, thereby increasing the possibilities and incentives for private households to engage in afforestation (Xu and Jiang 2009). Consequently the forest decrease slowed down and forest cover started to increase, resulting in a change from net deforestation to net reforestation. According to data from national forest inventories, conducted every five years in China, the lowest point of forest cover was 12% in 1981 (Song and Zhang 2010). The reversal of forest decline to forest cover increase was not a result of market forces as in other countries. It was induced by governments' efforts to mitigate the increasing ecological impacts as consequence of forest depletion. The expansion stage (III) started in the late 1990s and is shaped by the rapidly increasing forest cover as consequence of massive investments in forest recovery and the implementation of six forest-related policies.

The Chinese government implemented policies aimed at natural restoration beginning at the end of the 1970s, but due to poor site and seed preparation and poor care of planted seedlings, the programs clearly failed (Yin and Yin 2010). The programs implemented in the 1990s, with their financial investments and areas targeted by the programs, represent a chapter of new quality in Chinese forestry. The implementation of the programs was a direct reaction to historical dry outs of the Yellow River and floods of the Yangtze River, both of which clearly proved the failure of efforts to fight ecological problems of the historic timber exploitation. Therefore the State Forest Administration (SFA) promoted its first program, the Natural Forest Protection Program (NFPP), in 1998 to protect natural forests, followed by the Sloping Land Conversion Program (SLCP) in 1999. Together with the Desertification Combat Program around Beijing and Tianjin (DCBT), the Shelterbelt Network Development Program, the Wildlife Conservation and Nature Reserve Program, and the Industrial Timber Plantation Program, these programs were named as the “Six Priority Forestry Programs” of ecological restoration and resource expansion. The name ”Forestry Programs” does not refer to a clear forest orientation of all programs but because they all are managed by the SFA. In detail, the six programs are:

1. The National Forest Protection Program (NFPP):

After a pilot phase the program was officially launched in 2000 and had the goals of reducing annual timber harvest from natural forest from $32m^3$ in 1997 to $12m^3$ by 2003; conserving nearly 90 million ha of natural forest and re-vegetating an additional area of 8.7 million ha by 2010. As a side effect, many workers in the timber supply chain were retired, laid off, or displaced to forestation and forest management (Liu et al. 2008).

2. The Sloping Land Conversion Program (SLCP):

The SLCP had a pilot phase of two years, after which it was implemented in two phases. The first period from 2001 to 2005 intended to get control over fragile ecological situations region by retiring and converting over 11 million ha of sloping farmland and deserted fields. During the second phase from 2006 to 2010 an additional 7 million ha were afforested and re-vegetated.

Farmers participating in the program received compensation, including financial and grain subsidies and free seedlings, depending on the duration of two to eight years from the compensation from the forest category into which the land was converted. This included (I) ecological forest, primarily providing ecological functions and services; (II) commercial forests, producing timber, fruits, or nuts; and (III) grass cover. By 2010 the vegetation cover was expanded to 86.7 million ha and the periods of compensation were extended (Yin and Yin 2010).

3. The Desertification Combat Program around Beijing and Tianjin (DCBT):

After numerous sandstorms in northern China, the SFA developed a project to inhibit the encroachment of desertification and to improve the natural environment around Beijing. The main objective of the DCBT was to treat more than 10 million ha desertified land, of which half was to re-vegetate between the implementation in 2001 and 2010. This included the conversion of cropland to forest, grassland rehabilitation, selective banning of open grazing, integrated watershed management, and ecological resettlements (Yin and Yin 2010).

4. The Shelterbelt Network Development Program (SNDP):

Covering the huge “Three Norths” (i.e., the Northwest, North, and Northeast) and both the Yangtze River and Zhujiang River basin, the SNDP was developed to engage public agencies and civil society in shelterbelt development and maintenance. The program was intended to develop a shelterbelt 700 km wide and 4,500 km long, often called “The Great Green Wall.” The aim of the shelterbelt was to mitigate wind erosion and landslides and to protect grassland. Due to its limited financial investments of 70 billion yuan from 2001 to 2010, the program needed local support in the form of investments and labor contributions (Yin and Yin 2010).

5. The Wildlife Conservation and Nature Reserve Program (WCNR):

The WCNR aimed to expand nature reserves and enhanceme wildlife protection. Therefore the number of reserves was increased to 1800 in 2010 and will further increase to 2000 in 2030. Moreover, the management of critical areas was assigned to the central government, where the control of smaller areas was managed by the municipal and county governments. The total investment will reach a sum of 135 billion yuan in the total planning time of 30 years (Yin and Yin 2010).

6. Industrial Timber Plantation Program (ITPP):

The ITPP is a major market-driven program aimed at increasing the domestic timber supply. To encourage private investments in timber plantations, as much as 70% of investments come from loans subsidized by the National Development Bank, including tax incentives. The target area is 13 million ha by 2015 and the total investment by the government amount 71.8 billion yuan (Yin and Yin 2010).

In addition to these national programs, a number of regional programs that supported and encouraged farmers to voluntarily plant trees on cropland were initiated by local governments and implemented at local scales (Ediger and Chen 2006). Partially these programs were co-financed by private companies, such as the walnut processing industry in Yunnan. By providing free seedlings and support, this program increases the availability of walnuts in the future. However, privately initiated tree planting on cropland has become more common in recent years. Recently the implementation of the Collective Forest Tenure reform has increased the incentives for private tree planting by providing secure land rights for forest land. As a result of state and private initiatives, forest area has increased on former cropland, with multiple impacts on household economies and the environment (Ediger and Chen 2006).

The exact point at which the Chinese forest transitioned from deforestation to reforestation is difficult to pinpoint. Actually the transition might have happened later than the data revealed because measurement methods, and even the definition of “forest,” were inconsistent across the seven national inventories. The official definition of “forest” in China in was changed from a minimum of 30% canopy cover to 20% in 1994 (Zhang and Song 2006). Thus, reported forest cover artificially increased in later inventories (Wilson 2006, Zhang 2000). In 2010, forest cover in China reached 20.4% according to official statistics (China Statistical Bureau 2010), and a further increase in forest cover is still a policy priority. The Chinese government is aiming to achieve a forest cover of 23% in 2020 and 26% in 2050 (SFA 2009).

Despite the reported success of a rapidly increasing forest area, the ecological quality of the Chinese forest transition is questionable. Afforestation efforts have not been overly successful in recovering the ecological functions of natural forest cover (Xu and Ribot 2004, Xu 2011). The tree choice was often limited, not reflecting the natural vegetation. Further, the limited species composition of planted forests might increase the provision of ecological services compared to the prior land use, but it remains clearly behind natural forests.

3 Study region and data collection

3.1 Study region

The province Yunnan is located in southwestern China and borders Myanmar, Laos, and Vietnam. Located in the eastern part of the Himalayas, it is dominated by deep river valleys and steep slopes. This results in a wide range of different landscapes and climatic conditions, from tropical forest in the southwest to permanent glaciers on the high mountain peaks in the northwest, where the Yangtze, Salween, and Mekong Rivers flow. As a consequence of this diverse landscape and biophysical conditions, Yunnan is widely hailed as a global biodiversity hotspot (Conservation International 2007).

Yunnan is home to 25 ethnic minorities (out of the total 56 minorities in China) that make up 38% of the Yunnan's total population. Land use and livelihoods vary from agro-pastoral practices by Tibetans, to upland agriculture by Yi and Naxi, to shifting cultivation and paddy rice by the Dai, Hani, and Jinuo in the South (Xu et al. 2007). Since over 20% of Yunnan's population, or approximately 10.2 million people, lives under the poverty line at one dollar per day, Yunnan is one of China's most poverty-stricken provinces (Hu 2012).

The high reliance on agriculture, the forest cover, and the cultural variety and its landscape make Yunnan an ideal showcase for exploring the reasons for forest-cover change. The importance of agriculture guarantees a certain degree of comparability to other rural areas in China that also rely on agriculture. As national forest-related policies arguably play an important role in the forest transition it is important, that all relevant forest-related policies are implemented, as they are in Yunnan (Liu et al. 2008). Finally, cultural and landscape variety result in a large range of land use strategies, as both cultural factors and different natural endowments lead to different land use strategies. These different land use strategies are especially important for the comparison of case studies, as they depict the range of possible reactions to changes in factors affecting decisions on land use.

Within Yunnan, two study sites were selected, Yulong County and Longyang Disrict. In both cases villages were selected based on their market distance. Two groups of samples were generated in each site, one located close to the market center and one a distance from the center of more than eight hours traveling time by car (see also Table 1).

Table 1: Sampled households

County	Township	Nr. of sampled villages	Nr. of sampled households
Yulong	Lashi	3	163
	Baoshan	2	130
Longyang	Yangliu	3	67
	Wama	2	149

Yulong County is part of Lijiang prefecture, located in northwestern Yunnan, and has an area of 6,392 km^2. The total population in 2002 was 207,983 people (density 31.5/km^2). The main ethnic minorities are, besides the Han majority , Naxi, Bai, Yi, Tibetan, and Pumi (Figure 2). 21% of the population was represented by the Naxi, who have their main territory there. The average annual temperature is 12.6°C, the average precipitation is 953.9 mm, and the average frost-free period is 294 days. The whole prefecture has a broad range of topography (Figure 3). The highest elevation is the Yulong Mountain (5596 m) and the lowest elevation is the valley of the Shilong River (1015 m) (Lijiang Statistical Bureau 2005).

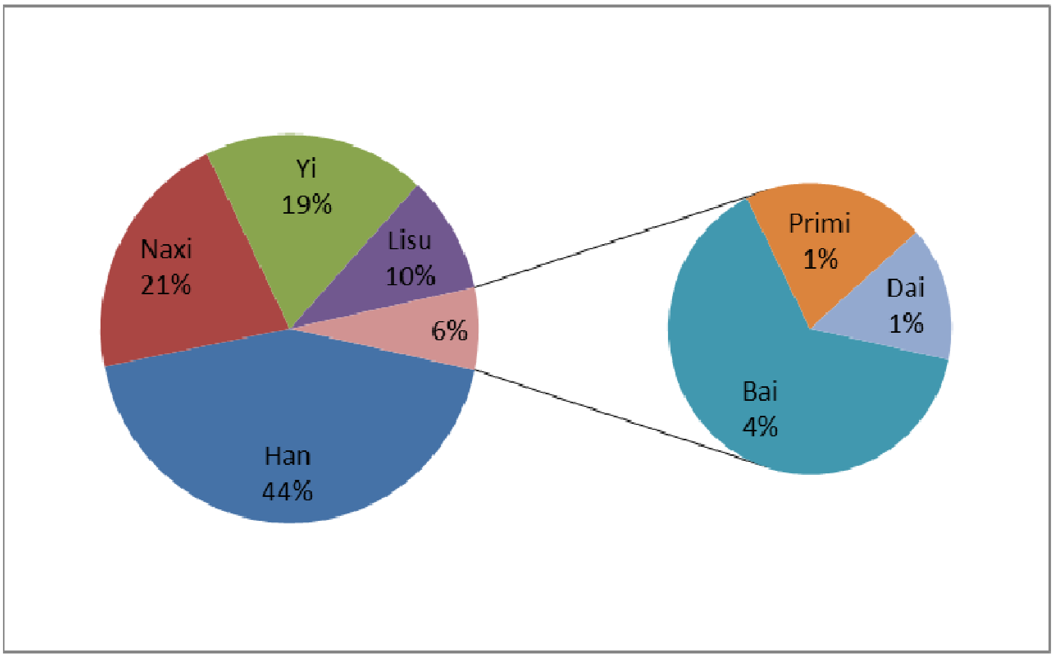

Figure 2: Ethnic composition of Lijiang
(Source: Lijiang Statistical Yearbook)

Figure 3: Terraces and tree-planting in Yulong

Longyang County is located in the center of Baoshan County. Its western border are the Gaoligongshan Mountains. The landscape is defined by the Gaoligongshan and Nushan Mountains, which stretch across the province from north to south, and further by the Lancang, Nu, and Dayingjian Rivers (upper reach of the Irrawaddy River). The forest coverage in 2005 was 38% (Baoshan Statistical Bureau 2005). Baoshan produces around 7.7% of Yunnan's leaf tobacco yield. Tobacco is a generally important product, as it provides around half of Yunnan Province's fiscal revenue (Shen et al. 2010)

The major food crops are rice, wheat, corn, and beans, and the major cash crops are sugar cane, coffee, tobacco, and tea (Figure 4). The major forestry products are walnuts and chestnuts (Figure 5). In 2005 the total population was 853,800 people (density 170/km^2), of which 86% were registered as agricultural population. The main ethnic minorities are the Bai, Yi, and Dai (Figure 6). The climate, summarized as subtropical monsoon climate, varies broadly. The average temperature ranges from 14.8°C to 21.3°C, the period of frost-free days range from 238 to 336 days, and the annual precipitation ranges from 1463 millimeters to 2095 millimeters (Baoshan Statistical Bureau 2005). Influenced by the Indian monsoon, wet and dry seasons are usually clearly distinct, precipitation is mainly concentrated in May-October, and rainfall is highly irregular. From January to April, almost all farmers suffer from water shortages due to decreasing rainfall and increasing competition and demand for water resources from villagers living upstream. Afforestation, the construction of small-scale irrigation systems, and the introduction of new crop types are common responses for many communities in the mountainous areas to water stress and hazards in the context of climate change (Su, Li and Fu 2009).

Figure 4: Typical land use pattern in Baoshan

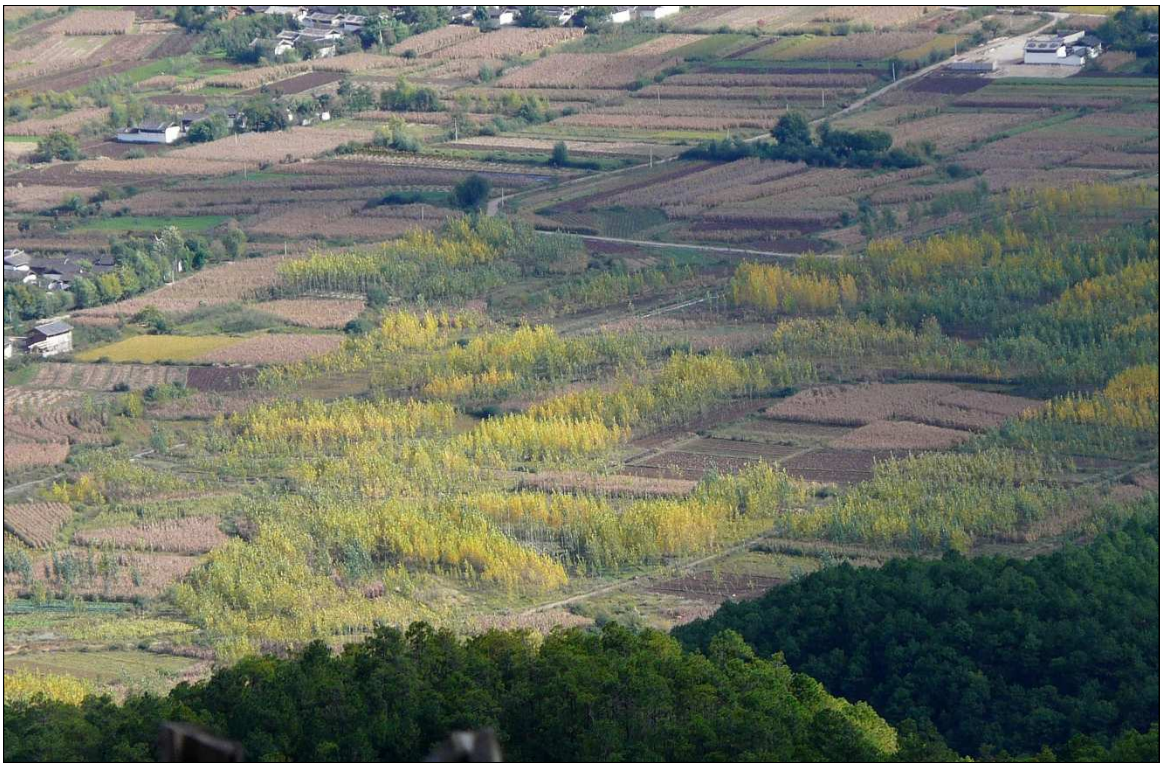

Figure 5: Combination of agro-forest and cropland

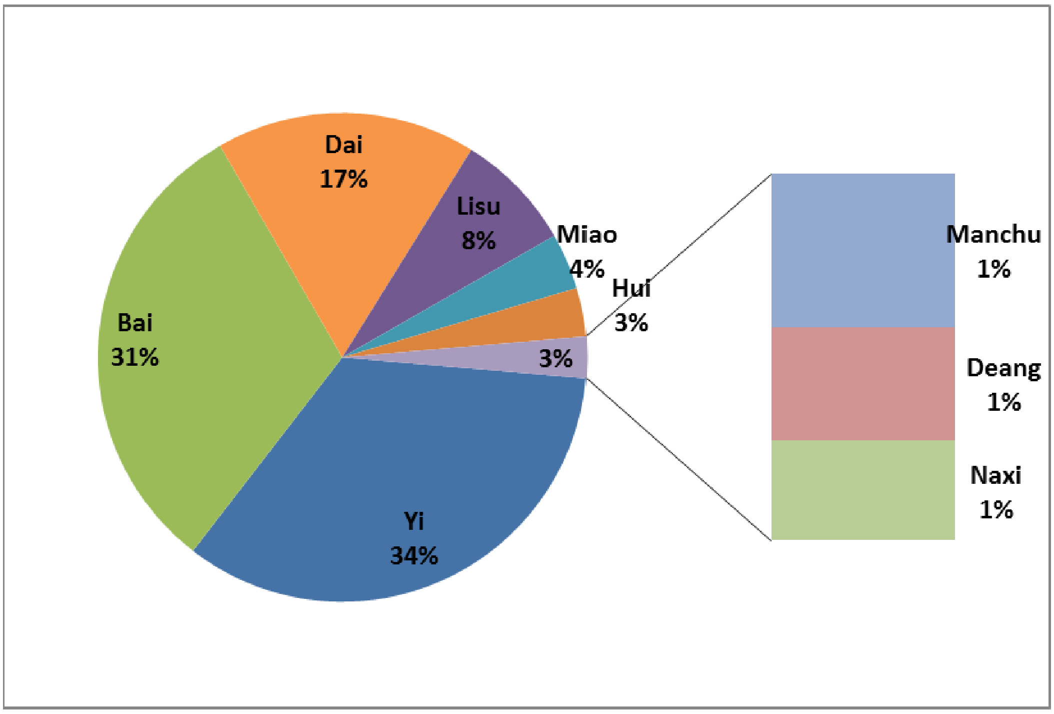

Figure 6: Ethnic minorities in Longyang

(Source: Baoshan Statistical Yearbook)

3.2 Data collection

The data this work is based on were collected during two field surveys in 2009 and 2010. The first survey aimed to collect detailed data on decision processes at the household level. For this purpose a questionnaire was designed covering social, economic, and financial characteristics, as well as land endowments, experiences with implemented forest-related policies, and future expectations. Data from 509 households were collected, offering information on more than 150 variables per household.

The study region and villages that were chosen in the two regions were similar enough to allow a comparison of the results but also offer different situations to gain some breadth in the data. Therefore it was necessary that both regions relied on agriculture, had similar natural endowments, and implemented the same forest-related policies. The regions were separated a second time by their distance to market. Based on expert interviews, it is assumed that market distance is a crucial shaping factor for land use decisions and household income when considering both the breadth and the depth of data. Using a large number of cases, a breadth base for the statistical analysis was built. The additional usage of case studies offers very useful and enlightening information on specific topics. With this combination of breadth and deep information, it is possible to justify findings of the data analysis and offer explanations for unexpected outcomes (Heimer and Thøgersen 2006).

3.3 Bayesian network

A Bayesian network (BN) is used to analyze decision making on the household level. A BN is a statistical tool that relies on Bayesian inference to deduce the influence of explanatory variables on an outcome variable of interest by calculating conditional dependencies within the network (Heckerman, Mamdani and Wellman 1995b, Pearl 2009). Such networks are particularly suited for modelling the decision-making, as they allow the inclusion of causal and hierarchical dependencies, as well as the combination of quantitative and qualitative data (Newton et al. 2006, Ticehurst, Curtis and Merritt 2011, Marcot et al. 2001). It allows interaction between variables and an accounting for nonlinearity in relationships, as well as an integration of stakeholders in the process of building and validating the model (Sun and Müller 2013) .

A BN is built of two parts or layers: The first and visible part is a directed acyclic graph (DAG), which defines the structure of a BN by representing hierarchy and interdependence among the nodes, depicting the variables that are connected with directed arrows. The second layer is built by conditional probability tables (CPTs), also known as parameters of a BN. The data within the tables define the probability distributions of nodes conditioned upon the values of their parent nodes. The CPT of a hierarchical following node, also known as a child node, and thus contains the conditional probability of being in a specific state, given the states of its parent node. When a node has no parent, the CPT is simply its prior probability distribution (Jensen 2002, Pearl 2009). The conditional probability of a variable is also known as the belief for this state of the variable (Charniak 1991).

The structure of the network is based on a literature review and expert knowledge. The resulting network is populated with the qualitative information attained from expert interviews, village-level group discussions, and data from a large household survey.

3.4 Participatory approaches

Qualitative methods typically refer to a range of data collection and analysis techniques that employ purposive sampling, participant observation, and semi-structured, open-ended interviews. In opposition to quantitative methods, the sampling is directed by the search for contrast to clarify the analysis by achieving an optimum number of identifications of emergent categories. Thus, particular samples are selected to identify and illustrate specific phenomena (Glaser and Strauss 1967). These methods offer model cases and examples that allow understanding of individual definitions and perceptions. The aim is to capture and understand individual definitions, descriptions, and meanings of events. Qualitative techniques allow for an in-depth analysis of social, political, and economic processes (Dudwick et al. 2006).

The open-ended questioning and focus group discussions that were used in this research are particularly appropriate in community settings to allow respondents to identify and articulate their priorities and concerns free from researchers' restrictions and assumptions. One of the key issues related to qualitative research is whose voices and opinions are heard and communicated to outsiders as a consequence of the research (Chambers 1997). In a village community, different groups may have overlapping or contrasting experiences of social norms, networks, and management processes. With the help of qualitative methods researchers can explore the different views of homogeneous as well as very diverse groups of people in order to help reveal the variety of perspectives within a community. Furthermore, the integration of non-scientific knowledge, values, and preferences through social discourse will improve the quality of research by giving access to practical knowledge and experience and to a wider range of perspectives and options (van Asselt Marjolein and Rijkens-Klomp 2002).

4 Analyzing the drivers of tree planting in Yunnan, China, with Bayesian networks

Jens Frayer[1], Daniel Müller [1,2], Zhanli Sun [1], Darla K. Munroe [3] and Jianchu Xu [4] (2014)

Land Use Policy, Volume 36, Pages 248-258

http://www.sciencedirect.com/science/article/pii/S0264837713001555

1 Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Theodor-Lieser-Str. 2, 06120 Halle (Saale), Germany

2 Geography Department, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany

3 Department of Geography, Ohio State University, 1036 Derby Hall, 154 N. Oval Mall, Columbus, OH 43210, USA

4 World Agroforestry Centre, East Asia Node, 132# Lanhei Road, Heilongtan, Kunming 650201, Yunnan, China

Abstract

Strict enforcement of forest protection and massive afforestation campaigns have contributed to a significant increase in China's forest cover during the last 20 years. At the same time, demographic changes in rural areas due to changes in reproduction patterns and the emigration of younger population segments have affected land use strategies. We identified proximate causes and underlying drivers that influence the decisions of farm households to plant trees on former cropland with Bayesian networks (BNs). BNs allow the incorporation of causal relationships in data analysis and can combine qualitative stakeholder knowledge with quantitative data. We defined the structure of the network with expert knowledge and in-depth discussions with land users. The network was calibrated and validated with data from a survey of 509 rural households in two upland areas of Yunnan province in Southwest China. The results substantiate the influence of land endowments, labor availability and forest policies for switching from cropland to tree planting. State forest policies have constituted the main underlying driver to the forest transition in the past, but private afforestation activities increasingly dominate the expansion of tree cover. Farmers plant trees on private incentives mainly to cash in on the improved economic opportunities provided by tree crops, but tree planting also constitutes an important strategy to adjust to growing labor scarcities.

Keywords: Payments for ecosystem services; forest transition; SLCP; afforestation; land use change; Bayesian belief network; China.

5 Processes underlying 50 years of local forest-cover change in Yunnan, China

Jens Frayer[1], Daniel Müller [1,2], Zhanli Sun [1], Darla K. Munroe [3] and Jianchu Xu [4] (2014)

Forests **2014**, Volume *5*, Pages 3257-3273

http://www.mdpi.com/1999-4907/5/12/3257

1 Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Theodor-Lieser-Str. 2, 06120 Halle (Saale), Germany
2 Geography Department, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany
3 Department of Geography, Ohio State University, 1036 Derby Hall, 154 N. Oval Mall, Columbus, OH 43210, USA
4 World Agroforestry Centre, East Asia Node, 132# Lanhei Road, Heilongtan, Kunming 650201, Yunnan, China

Abstract

Recognition of the importance of forests for local livelihoods, biodiversity and the climate system has spurred a growing interest in understanding the factors that drive forest-cover change. Forest transitions, the change from net deforestation to net reforestation, may follow different pathways depending on a complex interplay of driving forces. However, most studies on forest transitions focus on the national level rather than the local level. Here, case studies from ten villages in Yunnan, China, are used to clarify the complex interactions among various pathways of forest transitions, derive insights on the underlying drivers that shaped the forest transitions, and determine the importance of changes in drivers over time. The results demonstrate that China's recent forest transition was caused by a range of interrelated pathways that were mediated by local circumstances. The degradation of forest ecosystem services caused by rampant deforestation and forest degradation created a scarcity of forest products and triggered state-initiated afforestation efforts, particularly in the 1990s, which continue to be important. More recently, economic development concomitant with smallholder intensification spurred reforestation, while the importance of state forest policy declined. The complexity of local land use changes demonstrates the difficulty of identifying distinct transition pathways and calls for a more diverse approach that recognizes the interdependence of local processes.

Keywords: Forest transition; reforestation; agroforestry; land use change; China.

6 Synthesis

This work offers detailed information on the reasons for the forest regrowth in Yunnan by combining the outcome of the Bayesian network that gathered information on the reasons farmers converted cropland to forest and the qualitative comparison of the forest transition pathways of ten villages. Existing literature proves the importance of the Chinese forest-related policies for forest regrowth in China. By analyzing detailed information of more than 500 households, this work provides further evidence that the participation of rural households in afforestation programs is a very important reason for the afforestation. It additionally shows that the decision to afforest and the resulting area converted to forest depends on a number of underlying reasons and has consequences for subsequent decisions on land use.

The quantitative analysis shows that participation in the SLCP and other afforestation programs is without doubt the main reason for the increase of the forest cover by a conversion of cropland to forest. Hereby the SLCP plays two important roles. First, the compensation offered by the program was the main financial incentive for the conversion and therefore its main cause. Secondly, the SLCP and other forest-related policies triggered a land use change, as they showed the advantages of planting trees to farmers who did not yet participate in one of the programs. The decision to convert cropland is influenced by many variables, such as household endowments, financial background, and cultural and social factors. The framework for the decision-making is also variable, as market access and policies vary locally. During the process of building the Bayesian network a number of variables were tested, and due to their insignificant effects they were removed from the model (see also **Fehler! Verweisquelle konnte nicht gefunden werden.**). The reasons for joining an afforestation program, however, are various. Ethnicity, the area of cropland, education, and area of marginal land have substantial influences on the decision to join such a program. Given the variety of reasons and the uniqueness of each household, the knowledge that social background and land endowments affect the decision-making helps to explain the forest-cover change.

The household survey also proves that taking advantage of emerging economic opportunities from tree crops has obviously become a viable and preferred strategy for the generation of cash income and for dealing with increasing on-farm labor shortages and the resulting vulnerability of aged households to income gaps resulting from reduced labor availability. Furthermore, it allows households to explore new income sources, as the use of cropland with trees sets labor free, which can be utilized in more effective income opportunities (cf. 4.5).

This land use adaptation to the scarcity of rural labor started with a delay of several years after the first implementation of the first afforestation programs, in which farmers recognized the advantages of tree crops compared to the traditional forms of land use. In the first years after the implementation of the SLCP, the benefits of participation and the land conversion had to be established successfully. In a next step, this success was recognized by peers and trickled down to other famers in the region. More and more villagers realized the advantages of the land conversion and either followed neighboring households by joining one of the state-initiated forestry programs or even converted cropland by planting trees as private initiatives. This process proceeded with changing intensity over time and space. As shown, the availability of cash crops or land scarcity slows down the rate of cropland conversion to a minimum. In places where available land resources can be used more efficiently by other cash crops or where land resources are scarce, the conversion from cropland to forests is limited to the demanded state quota and to land that cannot be used in other ways. Moreover, in some areas such a loss of cropland would increase the vulnerability to famine or would endanger the subsistence production. Obviously, tree plantations or agroforestry systems offers advantages compared to traditional land use. These advantages are the reduced labor demand in care and harvest, higher income opportunities, an income source from land use for aged households, and a kind of extensive land use, which prevents the land from reallocation.

The spatial and temporal variety of drivers of tree-planting mentioned above was also shown in the result of the qualitative analysis of the forest cover trajectories of ten villages made in Chapter 5. Besides the local differences, which can be attributed mainly to locally different natural and social endowments, which result in individual frameworks of decision-making, the temporal variety of driving forces is remarkable. The forest scarcity pathway, in which China is categorized due the importance of reforestation policies, was without doubt the pathway China took until the early 2000s, which led to the forest transition. However, this conclusion ignores the importance of the other driving forces of forest regrowth, subsumed in the remaining forest transition pathways and their changing importance over time. Before the forest scarcity-related policies, the management of China's state forest played the pivotal role in the development of the forest cover in China, although the importance of forests as economic resources for the state gradually decreased. This decline can mainly be attributed to the logging ban that was imposed and enacted by the NFPP in 1998 and the associated harvest reduction in state forest land (Yin et al. 2005). In parallel, the forest scarcity pathway became the dominant driver of forest-cover changes from the late 1990s, when the escalating scarcity of forest products and forest ecosystem services spurred the implementation of the logging ban and the SLCP.

In addition, the importance of these government programs in terms of land area and the number of farmers affected has changed over time, declining since the mid-2000s. The successful implementation of the SLCP and other programs made the advantages of agroforestry and planting tree crops visible and spurred private plantations of trees without compensation as land use options to existing land use forms. This response of smallholders to emerging economic opportunities in tree cropping is subsumed in the smallholder-intensification pathway, which gained an increasing importance. This changing importance of the pathways over time is depicted in Figure 7, which illustrates this change by assessing the importance of each factor over time in the study region. This picture underlines the simultaneity of pathways of the forest cover increase. Even in times when one factor dominates the forest regrowth, there are other factors with minor relevance at play that may contribute to some regrowth. The smallholder-intensification pathway, for example, is currently the most important pathway in the study site. However, in places in Yunnan where tree crops are not a suitable alternative for the traditional agriculture, the state-driven afforestation programs might be still the main driver for land conversion. As the changing framework conditions, such as politics, renewed land regulations, market developments, and land use innovations cause a constantly changing background for the decision-making of land users, though, this might change in the future. Possible changes in these conditions might transform the decision-making on land use in the future and thereby possibly change the relative importance of the pathways.

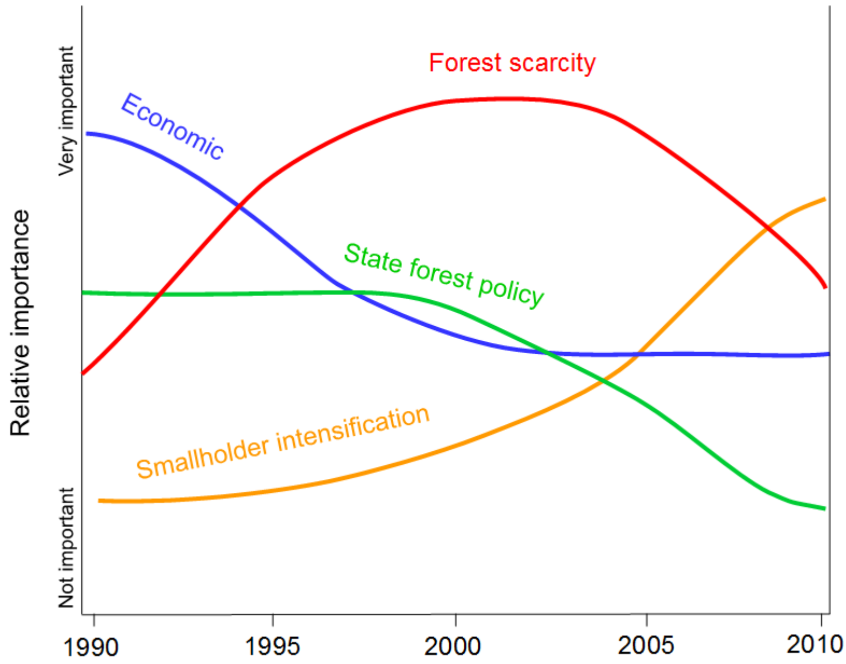

Figure 7: Relative importance of forest transition pathways in Yunnan

7 Conclusion

Due to both large-scale government afforestation programs and widespread private tree planting activities, the conversion of cropland to tree cover is an important land use change in Yunnan. To get a comprehensive picture of the reasons for this land use change, I combined qualitative and quantitative methods. The combination of such distinct analytical approaches can offer more information and thus contribute important insights into the ongoing debates on land use change.

By combining qualitative and quantitative data to analyze local land use decisions in 17 villages and the forest transition in ten villages in Yunnan province, this work uses the advantages of both methodical approaches. The Bayesian network, which integrates the qualitative knowledge of stakeholders and the quantitative survey data, allows conclusions to be drawn by using statistical methods and their resulting outcomes. Due to the participatory validation of the model, these outcomes offer a realistic view to the proximate causes and underlying drivers of the decision to plant trees on former cropland. The case study of ten forest transition curves on the village level shows different forest cover trajectories over recent decades. A qualitative analysis of these curves shows that an aggregation or conclusion of local developments into one national aggregation often fails and consequently represents only a simplified picture of recent dynamics.

The modeling results of the Bayesian network demonstrate the importance of government programs for the increase in the extent of tree planting on former farmland. Besides this state-driven conversion, the land conversion of private accounts with little or no external support is illustrated in the model. Main causes for the activities were the expectations of high economic returns from trees, the household’s response to the reduced availability of farm labor, and more secure forest tenure. This economic expectation and the land use resulting from it are crucial for the forest-transition pathway, which is a result of the main driver of land use change towards tree crops. As shown in Chapter 4, the process of decision-making is influenced by economic considerations. The household’s main income source and endowments are important factors influencing the land conversion. These factors also find expression in the recent local forest-transition pathways. As show in Chapter 5, these economic considerations are recently the main reason for land users' changing land use. The state support in the form of compensation was one of the most important reasons for households to convert cropland, as the Bayesian network showed. However, as the zenith of the SLCP as the main state program aiming for forest regrowth is exceeded and no payments for new conversion are paid, the influence of the programs on land use decision-making will likely decrease.

The process of the decision-making to plant trees on cropland, however, is driven by interrelated causal chains and can hardly conclude in a single explanation. The interplay of several causal explanatory frameworks suggests that the majority of households follow a mixture of forest-transition pathways. This mixture of forest-transition pathways or, in other words, the changing set of drivers is supported by the outcomes of the case-study analysis. The comparison of ten different localities shows that the forest transition took place at very similar points in time but that the trajectory and the drivers of forest-cover change after the transition have changed and vary substantially. The local forest transitions are contingent on the interactions of many factors, and they exhibit a path dependency

The results underline the importance of state policies as a key driver of forest-cover increases after periods of forest scarcity in the 1980s and 1990s. After halting the forest decrease and paving the road for a net forest-cover increase, the state forest programs were the initial trigger for the large-scale increase in tree cover beginning around the year 2000. Their impacts on local landscapes were modulated by local biophysical, cultural, and socioeconomic conditions, as well as the program contents, which defined plot selection and the area devoted to conversion. The scope and speed of these directly targeted environmental policy reforms are arguably unprecedented. This work illustrates how the impact of state policies is influenced by other contextual factors that often unfold over time. The recently implemented land use adjustments of smallholders are motivated by the improved economic opportunities and the changing relative availability of agricultural production factors, especially the rural labor scarcity caused by migration. Farmers increasingly changed land use away from traditional production modes and to planting trees on former croplands. These developments are quite different from the standard economic development pathway, which stresses migration as the main reason for rural labor shortages, which cause reforestation on abandoned croplands. In the study villages, only very limited amounts of cropland were abandoned; farmers substituted capital-intensive production for labor-intensive production while maintaining constant land inputs to maximize the economic return of the scarcest factor of production and optimize their land use to the given situation.

As shown by modelling the decision-making in land use and recapturing recent and historic forest-cover changes, the decision to change land use, and in this case the resulting forest-cover change, is a very complex process. The various combinations and interrelationships of explanatory processes, the shifts in driving forces over time, and the associated spatial variations should be emphasized and further explored.

Understanding this intermixed process of land-change trajectories is vital for informing land use policy and for an efficient targeting of government afforestation programs. This understanding is important because an increasing amount of trees in the landscape support local development by providing considerable long-term income and by balancing household labor allocation. A better understanding of the underlying causes of the tree cover transition in Yunnan can thus help guide land use policy.

8 References

Aalders, I. H. (2008) Modeling Land-Use Decision Behavior with Bayesian Belief Networks. *Ecology and Society*, 13**,** 16. [online] URL: http://www.ecologyandsociety.org/vol13/iss1/art16/.

Aguilera, P. A., A. Fernández, R. Fernández, R. Rumí & A. Salmerón (2011) Bayesian networks in environmental modelling. *Environmental Modelling & Software*, 26**,** 1376-1388.

Aitkenhead, M. J. & I. H. Aalders (2009) Predicting land cover using GIS, Bayesian and evolutionary algorithm methods. *Journal of Environmental Management*, 90**,** 236-250.

Alix-Garcia, J., T. Kuemmerle & V. C. Radeloff (2012) Prices, land tenure institutions, and geography: A matching analysis of farmland abandonment in post-socialist Eastern Europe. *Land Economics*, 88**,** 425-443.

Andam, K. S., P. J. Ferraro, A. Pfaff, G. A. Sanchez-Azofeifall & J. A. Robalino (2008) Measuring the effectiveness of protected area networks in reducing deforestation. *Proceedings of the National Academy of Sciences*, 105**,** 16089-16094.

Angelsen, A. 2007. *Forest Cover Change in Space and Time: Combining the von Thünen and Forest Transition Theories*. Washington, D.C.: The World Bank.

Arhonditsis, G. B., C. A. Stow, L. J. Steinberg, M. A. Kenney, R. C. Lathrop, S. J. McBride & K. H. Reckhow (2006) Exploring ecological patterns with structural equation modeling and Bayesian analysis. *Ecological Modelling*, 192**,** 385-409.

Baoshan Statistical Bureau. 2005. *Baoshan Statistical Yearbook*. Baoshan: Baoshan Statistcal Bureau.

Barbier, E. B., J. C. Burgess & A. Grainger (2010) The forest transition: Towards a more comprehensive theoretical framework. *Land Use Policy*, 27**,** 98-107.

Bennett, M. T. (2008) China's sloping land conversion program: Institutional innovation or business as usual? *Ecological Economics*, 65**,** 699-711.

Brandt, J., J. Primdahl & A. Reenberg. 1999. *Rural land-use and landscape dynamics-analysis of driving forces' in space and time*. Unesco.

Bromley, J., N. A. Jackson, O. J. Clymer, A. M. Giacomello & F. V. Jensen (2005) The use of Hugin® to develop Bayesian networks as an aid to integrated water resource planning. *Environmental Modelling & Software*, 20**,** 231-242.

Bürgi, M., A. Hersperger & N. Schneeberger (2005) Driving forces of landscape change - current and new directions. *Landscape Ecology*, 19**,** 857-868.

Calvo-Alvarado, J., B. McLennan, A. Sánchez-Azofeifa & T. Garvin (2009) Deforestation and forest restoration in Guanacaste, Costa Rica: Putting conservation policies in context. *Forest Ecology and Management*, 258**,** 931-940.

Central Intelligence Agency. 2013. The World Factbook.

Chambers, R. 1997. *Whose reality counts?: putting the first last*. London: Intermediate Technology Publications Ltd (ITP).

Charniak, E. (1991) Bayesian networks without tears. *AI Magazine,* 12**,** 50-63.
Chen, S. H. & C. A. Pollino (2012) Good practice in Bayesian network modelling. *Environmental Modelling & Software*, 37**,** 134-145.
Chen, X., X. Zhang, Y. Zhang & C. Wan (2009) Carbon sequestration potential of the stands under the Grain for Green Program in Yunnan Province, China. *Forest Ecology and Management*, 258**,** 199-206.
China Statistical Bureau. 2010. China statistical yearbook. Beijing: China Statistical Press.
Chomitz, K. M. 2007. *At Loggerheads? agricultural expansion, poverty reduction, and environment in the tropical forests*. Washington.
Conservation International. 2007. Mountains of southwest China.
Dlamini, W. M. (2010) A Bayesian belief network analysis of factors influencing wildfire occurrence in Swaziland. *Environmental Modelling & Software,* 25**,** 199-208.
Dudwick, N., K. Kuehnast, V. N. Jones & M. Woolcock. 2006. *Analyzing social capital in context: A guide to using qualitative methods and data*. Washington.
Ediger, L. 2006. Economic integration and rural transformation: State-driven afforestation in Yunnan, China and the implications for landscapes and livelihoods [PhD dissertation]. Athens, Geogia: University of Geogia.
Ediger, L. & H. Chen (2006) Upland China in Transition: The Impacts of Afforestation on Landscape Patterns and Livelihoods. *Mountain Research and Development,* 26**,** 220-226.
Fielding, A. H. & J. F. Bell (1997) A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation,* 24**,** 38-49.
Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Prentice, N. Ramankutty & P. K. Snyder (2005) Global Consequences of Land Use. *Science,* 309**,** 570-574.
Frayer, J., Z. Sun, D. Müller, D. K. Munroe & J. Xu (2014) Analyzing the drivers of tree planting in Yunnan, China, with Bayesian networks. *Land Use Policy,* 36**,** 248-258.
Geist, H. J. & E. F. Lambin. 2001. What Drives Deforestation? A Meta-analysis and Underlying Causes of Deforestation based on Subnational Case Study Evidence. 116. Louvain-la-Neuve: LUCC International Project Office.
Geist, H. J. & E. F. Lambin (2002) Proximate Causes and Underlying Driving Forces of Tropical Deforestation. *BioScience,* 52**,** 143-150.
Groom, B. & C. Palmer (2012) REDD+ and rural livelihoods. *Biological Conservation,* 154**,** 42-52.
Hanley, J. A. & B. J. McNeil (1982) The meaning and the use of the area under a receiver operating characteristic (ROC) curve. *Radiology,* 143**,** 29-36.
Heckerman, D. 1996. A Tutorial on Learning With Bayesian Networks. In *Technical Report*. Redmond, WA: Microsoft Research.
Heckerman, D., D. Geiger & D. Chickering (1995a) Learning Bayesian networks: The combination of knowledge and statistical data. *Machine Learning,* 20**,** 197-243.
Heckerman, D., A. Mamdani & M. P. Wellman (1995b) Real-world applications of Bayesian networks. *Communications of the ACM,* 38**,** 24-26.
Heimer, M. & S. Thøgersen. 2006. *Doing fieldwork in China*. University of Hawaii Press.
Author. 2012. Poverty standart rises to record high. *China Daily 05-25*.
Hyde, W. F., G. S. Amacher & W. Magrath (1996) Deforestation and forest land use: Theory, evidence, and policy implications. *The World Bank Research Observer,* 11**,** 223-248.

Jensen, F. 2002. *Bayesian Networks and Decision Graphs*. New York: Springer.
Kaimowitz, D. & A. Angelsen. 1998. *Economic models of tropical deforestation: a review*. Bogor, Indonesia: CIFOR.
Kalnay, E. & M. Cai (2003) Impact of urbanization and land-use change on climate. *Nature,* 423**,** 528-531.
Kastner, T., M. J. I. Rivas, W. Koch & S. Nonhebel (2012) Global changes in diets and the consequences for land requirements for food. *Proceedings of the National Academy of Sciences,* 109**,** 6868-6872.
Kates, R. W., B. L. Turner & G. L. Clark. 1990. The great transformation. In *The earth as transformed by human action,* eds. B. L. Turner, G. L. Clark, R. W. Kates, J. F. Richards, J. T. Mathews & W. B. Meyer, 1-17. Cambridge, UK: Cambridge University Press.
Kinzig, A., D. Starrett, K. Arrow, S. Aniyar, B. Bolin, P. Dasgupta, P. Ehrlich, C. Folke, M. Hanemann, G. Heal, M. Hoel, A. Jansson, B.-O. Jansson, N. Kautsky, S. Levin, J. Lubchenco, K.-G. Mäler, S. W. Pacala, S. H. Schneider, D. Siniscalco & B. Walker (2003) Coping With Uncertainty: A Call for a New Science-Policy Forum. *Ambio,* 32**,** 330-335.
Kotsiantis, S. & D. Kanellopoulos (2006) Discretization techniques: A recent survey. *GESTS International Transactions on Computer Science and Engineering,* 32**,** 47-58.
Kuemmerle, T., J. O. Kaplan, A. V. Prishchepov, I. Rylsky, O. Chaskovskyy, V. S. Tikunov & D. Müller (2015) Forest transitions in Eastern Europe and their effects on carbon budgets. *Global Change Biology,* 21**,** 3049-3061.
Lambin, E. F., H. J. Geist & E. Lepers (2003) Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources,* 28**,** 205-241.
Lambin, E. F. & P. Meyfroidt (2010) Land use transitions: Socio-ecological feedback versus socio-economic change. *Land Use Policy,* 27**,** 108-118.
Lambin, E. F., B. L. Turner, H. J. Geist, S. J. Agbola, A. Angelsen, J. W. Bruce, O. T. Coomes, R. Dirzo, G. Fischer & C. Folke (2001) The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change,* 11**,** 261-269.
Laurance, W. F. (2008) The need to cut China's illegal timber imports. *Science* 319 (5867)**,** 1184-1185.
Li, J., M. W. Feldman, S. Li & G. C. Daily (2011) Rural household income and inequality under the Sloping Land Conversion Program in western China. *Proceedings of the National Academy of Sciences*.
Lijiang Statistical Bureau. 2005. *Lijiang Statistical Yearbook 2005*. Lijiang Lijiang Statistical Bureau.
Liu, C., J. Lu & R. Yin (2010) An estimation of the effects of China's priority forestry programs on farmers' income. *Environmental Management,* 45**,** 526-540.
Liu, J., S. Li, Z. Ouyang, C. Tam & X. Chen (2008) Ecological and socioeconomic effects of China's policies for ecosystem services. *Proceedings of the National Academy of Sciences,* 105**,** 9477-9482.
Malhi, Y. & J. Grace (2000) Tropical forests and atmospheric carbon dioxide. *Trends in Ecology & Evolution,* 15**,** 332-337.
Marcot, B. G. (2006) Characterizing Species at Risk I: Modeling Rare Species Under the Northwest Forest Plan. *Ecology and Society,* 11**,** 10. [online] URL: http://www.ecologyandsociety.org/vol11/iss2/art10/.

--- (2012) Metrics for evaluating performance and uncertainty of Bayesian network models. *Ecological Modelling,* 230**,** 50-62.

Marcot, B. G., R. S. Holthausen, M. G. Raphael, M. M. Rowland & M. J. Wisdom (2001) Using Bayesian belief networks to evaluate fish and wildlife population viability under land management alternatives from an environmental impact statement. *Forest Ecology and Management*, 153**,** 29-42.

Marcot, B. G., J. D. Steventon, G. D. Sutherland & R. K. McCann (2006) Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. *Canadian Journal of Forest Research*, 36**,** 3063-3074.

Mather, A. (2004) Forest transition theory and the reforesting of Scotland. *The Scottish Geographical Magazine,* 120**,** 83-98.

Mather, A. & J. Fairbairn (2000) From floods to reforestation: the forest transition in Switzerland. *Environment and History,* 6**,** 399-421.

Mather, A., J. Fairbairn & C. Needle (1999) The course and drivers of the forest transition: the case of France. *Journal of Rural Studies,* 15**,** 65-90.

Mather, A. S. (1992) The forest transition. *Area*, 24**,** 367-379.

Mather, A. S. (2007) Recent Asian forest transitions in relation to forest-transition theory. *International Forestry Review*, 9**,** 491-502.

Mather, A. S. & C. L. Needle (1998) The forest transition: A theoretical basis. *Area,* 30**,** 117-124.

Mayer, A. L., P. E. Kauppi, P. K. Angelstam, Y. Zhang & P. M. Tikka (2005) Importing timber, exporting ecological impact. *Science,* 308**,** 359-360.

Metz, C. E. (1978) Basic principles of ROC analysis. *Seminar in Nuclear Medicin* 8**,** 283-298.

Meyfroidt, P. (2013) Environmental Cognitions, Land Change and Social-Ecological Feedbacks: Local Case Studies of Forest Transition in Vietnam. *Human Ecology,* 41**,** 367-392.

Meyfroidt, P. & E. F. Lambin (2009) Forest transition in Vietnam and displacement of deforestation abroad. *Proceedings of the National Academy of Sciences,* 106**,** 16139-16144.

Mullan, K. & A. Kontoleon. 2009. *Participation in Payments for Ecosystem Services programmes in developing countries: The Chinese Sloping Land Conversion Programme*. Cambridge.

Müller, D. & D. K. Munroe (2014) Current and future challenges in land-use science. *Journal of Land Use Science,* 9**,** 133-142.

Nadkarni, S. & P. P. Shenoy (2001) A Bayesian network approach to making inferences in causal maps. *European Journal of Operational Research,* 128**,** 479-498.

Nassauer, J. I. (1995) Culture and changing landscape structure. *Landscape Ecology,* 10**,** 229-237.

Newton, A. C., E. Marshall, K. Schreckenberg, D. Golicher, D. W. te Velde, F. Eduardo & E. Arancibia (2006) Use of a Bayesian Belief Network to Predict the Impacts of Commercializing Non-timber Forest Products on Livelihoods. *Ecology and Society,* 11**,** 144-160.

Newton, A. C., G. B. Stewart, A. Diaz, D. Golicher & A. S. Pullin (2007) Bayesian Belief Networks as a tool for evidence-based conservation management. *Journal for Nature Conservation,* 15**,** 144-160.

Netica Version 4.08.

Pearl, J. 2009. *Causality: Models, Reasoning, and Interference*. Cambridge: Cambridge University Press.

Perez, R. M., B. Belcher, M. Fu & X. Yang (2004) Looking through the bamboo curtain: An analysis of the changing role of forest and farm income in rural livelihoods in China. *International Forestry Review,* 6**,** 306-317.

Pimm, S. L. & P. Raven (2000) Biodiversity: extinction by numbers. *Nature,* 403**,** 843-845.

Pollino, C. A., O. Woodberry, A. Nicholson, K. Korb & B. T. Hart (2007) Parameterisation and evaluation of a Bayesian network for use in an ecological risk assessment. *Environmental Modelling & Software,* 22**,** 1140-1152.

Rudel, T. K. (1998) Is There a Forest Transition? Deforestation, Reforestation, and Development. *Rural Sociology,* 63**,** 533-552.

Rudel, T. K. (2009) Tree farms: Driving forces and regional patterns in the global expansion of forest plantations. *Land Use Policy,* 26**,** 545-550.

Rudel, T. K., O. T. Coomes, E. Moran, F. Achard, A. Angelsen, J. Xu & E. Lambin (2005) Forest transitions: towards a global understanding of land use change. *Global Environmental Change,* 15**,** 23-31.

SFA, State Forestry Administration People's Republik of China. 2009. People's Republik of China Forestry Outlook Study. In *Asia-Pacific Forestry Sectors Outlook Study,* ed. FAO. Bangkok: FAO.

Shen, S., A. Wilkes, J. Qian, L. Yin, J. Ren & F. Zhang (2010) Agrobiodiversity and Biocultural Heritage in the Dulong Valley, China: Impacts of and Responses to the Sloping Land Conversion Program. *Mountain Research and Development,* 30**,** 205-211.

Smith, C. S., A. L. Howes, B. Price & C. A. McAlpine (2007) Using a Bayesian belief network to predict suitable habitat of an endangered mammal – The Julia Creek dunnart (Sminthopsis douglasi). *Biological Conservation,* 139**,** 333-347.

Smith, P., M. Bustamante, H. Ahammad, H. Clark, H. Dong, E. A. Elsiddig, H. Haberl, R. Harper, J. House, M. Jafari, O. Masera, C. Mbow, N. H. Ravindranath, C. W. Rice, C. Robledo Abad, A. Romanovskaya, F. Sperling & F. T. Tubiello. 2014. Agriculture, Forestry and Other Land Use (AFOLU). In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* eds. O. Edenhofer, R., Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. v. Stechow, T. Zwickel & J. C. Minx. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Song, C. & Y. Zhang. 2010. Forest Cover in China from 1949 to 2006. In *Reforesting Landscapes,* eds. H. Nagendra & J. Southworth. Dordrecht: Springer.

Su, Y., Q. Li & Y. Fu. 2009. *Diversified livelihoods in changing socio-ecological systems of Yunnan province, China*. ICIMOD.

Sun, Z. & D. Müller (2013) A framework for modeling payments for ecosystem services with agent-based models, Bayesian belief networks and opinion dynamics models. *Environmental Modelling & Software,* 45**,** 15–28.

Sunderlin, W. D., S. Dewi, A. Puntodewo, D. Müller, A. Angelsen & M. Epprecht (2008) Why forests are important for global poverty alleviation: a spatial explanation. *Ecology and Society,* 13**,** 24.

Ticehurst, J. L., A. Curtis & W. S. Merritt (2011) Using Bayesian Networks to complement conventional analyses to explore landholder management of native vegetation. *Environmental Modelling & Software,* 26**,** 52-65.

Tolba, M. K. & O. A. El-Kholy. 1992. *The world environment 1972-1992: two decades of challenge*. London: Chapman & Hall.

Turner II, B. L., E. F. Lambin & A. Reenberg (2007) The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences,* 104**,** 20666-20671.

Uchida, E., S. Rozelle & J. Xu (2009) Conservation Payments, Liquidity Constraints, and Off-Farm Labor: Impact of the Grain-for-Green Program on Rural Households in China. *American Journal of Agricultural Economics,* 91**,** 70-86.

Uusitalo, L. (2007) Advantages and challenges of Bayesian networks in environmental modelling. *Ecological Modelling,* 203**,** 312-318.

van Asselt Marjolein, B. & N. Rijkens-Klomp (2002) A look in the mirror: reflection on participation in Integrated Assessment from a methodological perspective. *Global environmental change,* 12**,** 167-184.

Wilson, A. (2006) Forest Conversion and Land Use Change in Rural Northwest Yunnan, China. *Mountain Research and Development,* 26**,** 227-236.

Xu, J. (2011) Chinas new forests aren't as green as they seem. *Nature,* 477**,** 371.

Xu, J., X. Ai & X. Deng (2005) Exploring the spatial and temporal dynamics of land use in Xizhuang watershed of Yunnan, southwest China. *International Journal of Applied Earth Observation and Geoinformation,* 7**,** 299-309.

Xu, J. & X. Jiang. 2009. Collective forest tenure reform in China: Outcomes and implications. In *World Bank Conference on Land Governance*. Washington.

Xu, J. & J. C. Ribot (2004) Decentralization and accountability in forest management: A case from Yunnan, southwest China. *The European Journal of Development Research,* 14**,** 153-173.

Xu, J., Y. Yang, J. Fox & Y. Xuefei (2007) Forest transition, its causes and environmental consequences: Empirical evidence from Yunnan of southwest China. *Tropical Ecology,* 48**,** 137-150.

Yin, R., S. Yao & X. Huo (2013) China's forest tenure reform and institutional change in the new century: What has been implemented and what remains to be pursued? *Land Use Policy,* 30**,** 825-833.

Yin, R. & G. Yin (2010) China’s primary programs of terrestrial ecosystem restoration: Initiation, implementation, and challenges. *Environmental Management,* 45**,** 429-441.

Yunnan Government. 2012. Lijiang efforts to reduce poverty (in Chinese). Lijiang, China.

Zhang, P., G. Shao, G. Zhao, D. C. Le Master, G. R. Parker, J. B. Dunning & Q. Li (2000) China's forest policy for the 21st century. *Science,* 288**,** 2135-2136.

Zhang, Y. 2000. Deforestation and forest transition: Theory and evidence in China. In *World Forests from Deforestation to Transition?,* eds. M. Palo & H. Vanhanen. Dordrecht: Kluwer Academic Publishers.

Zhang, Y. & C. Song (2006) Impacts of afforestation, deforestation, and reforestation on forest cover in China from 1949 to 2003. *Journal of Forestry,* 104**,** 383-387.

Ziegler, A. D., J. M. Fox & J. Xu (2009) The rubber juggernaut. *Science,* 324**,** 1024-1025.

9 Appendix

Table A2: Descriptive statistics of the variables

Variable	States	Initial probability	Mean	Standard deviation
Total area planted trees	0 mu	8.22%	3.67	1.7
	0 to 3 mu	15.3%		
	More than 3 mu	76.4%		
Participation forestry program	Yes	81.6%		
	No	18.4%		
Asset value	¥0	77.9%	217	490
	¥0 to ¥1000	11.5%		
	More than ¥1000	10.6%		
Crop income	Less than ¥100	53%	235	390
	¥100 to ¥500	10.2%		
	More than ¥500	36.5%		
Cropland	Less than 6 mu	15.9%	13	7
	6 to 15 mu	39.9%		
	More than 15 mu	44.2%		
Labor force	Less than 3	36.95%	2.97	1.1
	3 to 4	30.65%		
	More than 4	33.34%		
Marginal land	0 mu	70.7%	0.928	1.7
	0 to 3 mu	13%		
	More than 3 mu	16.3%		
Private afforestation	0 mu	46.7%	1.72	2

	0 to 3 mu	22.4%		
	More than 3 mu	30.8%		
SLCP	0 mu	25.4%	3.61	3.1
	0 to 3 mu	23.1%		
	3 to 6 mu	19.9%		
	More than 6mu	31.6%		
Total income	Less than ¥1000	8.56%	5060	2800
	¥1000 to ¥5000	31.5%		
	More than ¥5000	60.0%		
Walnut program	0 mu	84.2%	0.592	1.5
	0 to 3 mu	3.94%		
	More than 3 mu	11.8%		
Education	Illiterate	2.95%		
	Primary school	28.3%		
	Middle school	46.0%		
	High school	14.1%		
	College above	8.64%		
Ethnicity	Han	11%		
	Yi	38.7%		
	Naxi	44.4%		
	Other	5.89%		
Major income source	Agriculture	33.6%		
	Animal husbandry	24.7%		
	Forest NTFP	5.41%		
	Off farm	23.5%		
	Other	12.8%		

Table A3: Changing importance of income sources

	2000	2009	2015
Agriculture	34.1%	11.8%	9.7%
Livestock	26.4%	18.7%	15.9%
Off-farm work	24.3%	47.1%	42.5%
Forestry, NTFP	4.7%	16.4%	23.4%
Other	10.3%	5.9%	8.3%

Source: Own survey data

NTFP: Non-timber forest products

Eidesstattliche Erklärung / Declaration under Oath

Ich erkläre an Eides statt, dass ich die Arbeit selbstständig und ohne fremde Hilfe verfasst, keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt und die den benutzten Werken wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

I declare under penalty of perjury that this thesis is my own work entirely and has been written without any help from other people. I used only the sources mentioned and included all the citations correctly both in word or content.

Jens Frayer,

Berlin, den 10. September 2015

Tabellarischer Lebenslauf

Zur Person

Name	Jens Frayer
Geboren	23.11.1977 in Berlin
Familienstand	Verheiratet, 1 Kind
Abschluss	Diplom-Geograph

Berufserfahrung

seit 04.2015	Angestellter Projektleiter bei der *Natur + Text GmbH*
07.2013 – 11. 2014	Freier Mitarbeiter bei der *Natur + Text GmbH*
09.2008 – 7.2013	Wissenschaftlicher Mitarbeiter am *Institut für Agrarentwicklung in Ost- und Mitteleuropa (IAMO)* in Halle/Saale im Rahmen des Projektes “The effects of payments for ecosystem services on human well-being and land use in Yunnan, China” in Kooperation mit *ICRAF China/Kunming* unter der Leitung von Dr. Daniel Müller.
06.2008 – 08.2008	Mitarbeiter des *InVeKoS*-Programmes bei der *EFATS GmbH* in Münster.
04.2007 – 06.2007	Projektmitarbeiter der von *VENRO e.V.* und Herbert Grönemeyer getragenen Kampagne „*Deine Stimme gegen Armut*“.
10.2004 - 09.2006	Mitarbeiter im Kundenservice der Firma *MyToys.de* GmbH.

10.2003 - 10.2004	Mitarbeiter des von der *DFG Projektes „Aktuelle Entwicklung der sozio-ökonomischen Situation von mobilen Tierhaltern im osttibetischen Hochland“* in Kooperation mit dem Chengdu Institute of Biology der Chinese Academy of Sciences und dem Zentrum für Entwicklungsländer-Forschung (ZELF) der Freien Universität Berlin.
07.2003 - 09.2003	Teilnehmer am *„2nd International Course on Watershed Management, Landscape Sensitivity of the Hare River Catchment”* in Arba Minch, Süd-Äthiopien.
04.2003 - 09.2003	Tutor im *Zentrum für Entwicklungsländer Forschung (ZELF)*, Arbeitsbereich Prof. Dr. Fred Scholz, FU Berlin.

<u>Studium</u>

04.1998 - 11.2006	Studium der *Geographie* an der Freien Universität Berlin Schwerpunkte: Ländliche Regionalentwicklung, Landnutzungswechsel und Ressourcenschutz. Nebenfächer: Agrarwissenschaften und Botanik
08.2006	Abgabe der Diplomarbeit: „Osttibetische Mobile Tierhalter - Änderung ihrer Lebensweise unter „Open Up The West“. Abschlussnote: 1,8
07.1990 – 05.1997	Besuch der Gustav-Heinemann-Gesamtschule. Abschließende Abiturnote: 2,8

Liste der Veröffentlichungen

Frayer, J., Müller, D., Sun, Z., Munroe, D., Xu, J., 2014. Processes Underlying 50 Years of Local Forest-Cover Change in Yunnan, China.
Forests 5(12): 3257-3273. http://dx.doi.org/10.3390/f5123257

Frayer, J., Sun, Z., Müller, D., Munroe, D.K., Xu, J., 2014. Analyzing the drivers of tree planting in Yunnan, China, with Bayesian networks.
Land Use Policy 36: 248-258. doi:10.1016/j.landusepol.2013.08.005

Frayer, J., Müller, D. (2011): Auswirkungen der Agrar-Umweltprogramme auf Landnutzung und Haushaltseinkommen in Südwestchina. Im: IAMO 2010 Jahresbericht.

Frayer, J./ Mirete, J. (2005): Landreformen in China. Eine Erfolgsgeschichte der Modernisierung? Berlin.