Impact of institutions on land cover change and landscape fragmentation in an Indian dry tropical forest landscapes

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Declaration by the candidate

I, Shivani Agarwal hereby declare that the thesis entitled **“*Impact of institutions on land cover change and landscape fragmentation in an Indian dry tropical forest landscapes*”** has been compiled by me under the supervision of Dr. Harini Nagendra, Ashoka Trust for Research in Ecology and the Environment (ATREE), Bengaluru. The thesis has not been previously submitted for the award of any degree, diploma, associateship, fellowship, or its equivalent to any other University or Institution.

(Shivani Agarwal)

Place: Bengaluru

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Certificate

This is to certify that the thesis entitled "***Impact of institutions on land cover change and landscape fragmentation in an Indian dry tropical forest landscapes***" submitted by Ms. Shivani Agarwal, for the award of Doctor of Philosophy for, Manipal University, Manipal, is a record of the research work carried out by her during the period of her study in this university under my guidance and supervision and the thesis has not formed the basis for the award of any degree, diploma or other similar titles.

Dr. Harini Nagendra

Signed by Guide with name and date

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List of Abbreviations

CFM	Community Forest Management
DBH	Diameter at Breast Height
DF	Dense Forest
ETM+	Enhanced Thematic Mapper Plus
FConn	Forest Connectivity
FD	Forest Department
FDCM	Forest Development Corporation of Maharashtra
FDens	Forest Density
FRA, 2006	Forest Rights Act, 2006
GBH	Girth at Breast Height
GIS	Geographic Information System
GLMM	Generalized Linear Mixed Models
JFM	Joint Forest Management
LiDAR	Light Detection and Ranging
LPG	Liquefied Petroleum Gas
MSS	Multispectral Scanner
NDVI	Normalized Difference Vegetation Index
NF	Non-Forest
NP	National Park
NTFP	Non-Timber Forest Product
OF	Open Forest
PF	Protected Forest
RF	Reserve Forest
RS	Remote Sensing
SD-NDVI	Standard Deviation of Normalized Difference Vegetation Index
TM	Thematic Mapper
TR	Tiger Reserve
USGS	United State Geological Survey
WGS84	World Geodetic System 1984
WLS	Wildlife Sanctuary

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Executive Summary

Protected Areas (PAs) have been a cornerstone of conservation efforts. However, PAs have become increasingly isolated with protection. Human pressure has shifted towards the forests located outside PAs, which serve as important corridors for wildlife movement. In densely populated countries like India, connectivity across vast landscapes is not possible solely by the expansion of the PA network and requires support from local communities. The importance of local institutions has been considerably ignored due to the focus on PAs, which have limited capacity to meet local demands as well as conservation objectives for vast landscapes.

This Ph.D. research integrates remote sensing, landscape ecology and institutional approaches to study social and ecological impacts of forest management institutions in a dry-deciduous forest landscape in the Vidarbha region of Maharashtra, India. The study area forms an important connection between Pench and Tadoba-Andhari Tiger Reserves. The study begins with a large-scale landscape view to study the impact of different forest management regimes on forest change and fragmentation. It then zooms in to compare state and community institutions that differ in traditional norms as well as levels of local participation, assessing their effect on forests and local communities.

Forest change is mapped using Landsat satellite images from 1977, 1990, 1999, and 2011. There has been a substantial increase in the number and areal coverage of PAs, from four in 1970 to nine currently. Within existing PAs, there have been increasing restrictions on forest access and use, and the resettlement of a number of villages outside PAs. Forests outside PAs have also been subjected to "institutional enclosure", with increasing enforcement of limits to forest access and extraction, and an increase in forest administrative units, concomitant with an increase in forest staff involved in patrolling.

The impact of this strategy on forest cover and connectivity has been positive within PAs, but negative on the overall landscape. The landscape has lost 1478km^2 of dense forest cover between 1977 and 2011. The increased level of strict conservation has led to forest protection within PAs.

Outside PAs, there has been a pressure shift outside PA boundaries to other less protected forests, which are now under even more severe threat than before. This is substantiated by community interviews in twenty randomly selected villages that represent rang of population density as well as different trajectories of forest change. These demonstrate the increased dependence of local communities living in this landscape on the forests for livelihood and non-economic uses. Forest fragmentation was also mapped using the Riitters fragmentation model. The results demonstrate that forest patches within PAs are well connected. However, forest patches outside PAs are highly fragmented, with the loss of many unconnected forests between 1999 and 2011.

This study also attempts to develop a better understanding of the relationship between spectral and ecological variability under the influence of local institutions. Landsat satellite data was used to explore the relationship between vegetation structure and forest management institutions. Forest condition was assessed using 450 randomly placed 10 m radius circular plots in forest patches of 15 villages selected using purposive sampling method, in forests with and without local institutions of forest management. Significant differences were found in the relationship between tree density and Normalized Difference Vegetation Index (NDVI) between villages with and without local forest institutions. However, the relationship between species richness and NDVI did not differ significantly.

In order to understand how these institutions function on ground in terms of rulemaking, monitoring and regulation, and motivation, focus group discussions and semi-structured interviews were conducted in the selected 15 villages. This study found that monitoring is an integral component of the local forest institutions. The sampled villages broadly comprised three different categories of monitoring: 1) Monitoring by the Forest Department (FD) 2) Local community participation in monitoring, and 3) No involvement of either the FD or the local community in monitoring. Vegetation surveys were also conducted in selected villages. Forests with monitoring had significantly higher tree density and vegetation species richness compared to forests without monitoring. However, which institution was carrying out monitoring was of lesser importance. The magnitude of the difference between monitoring by people and FD was always much less than that between monitored and unmonitored forest patches. The relative ranking of the three categories was consistent even after including other potential predictor variables.

Even though the difference in abundance and species richness were only slightly higher in people-monitored forests as compared to the FD-monitored forest patches, there were positive social outcomes in the villages with active participation in forest management. It was found that participation from local people was critical, especially from the point of view of rule-making and equitable management of resource use. In forests monitored by the FD, local communities indicated a feeling of alienation from the forest that weakened their motivation to protect the forest and wildlife.

This research addresses the need for a stronger focus on the functionality and socio-ecological outcomes of different forest management institutions to address the issue of forest conservation outside PAs. This research can help address larger questions of how different forested patches, governed by a variety of management approaches ranging from strict conservation to more open areas, can be integrated within regional landscape planning across large spatial extents, in order to facilitate forest conservation and connectivity over the long term. Recognition of local community rights is essential to achieve conservation goals and reduce social conflicts outside PAs, requiring collaboration between state and local institutions.

This research also demonstrates how information on spatial changes in pattern, derived from remote sensing coupled with forest change and fragmentation analysis, can be linked to social surveys to understand the underlying social drivers, establishing a clearer understanding of the pattern-process linkage. Such interdisciplinary research helps develop a better understanding of the human factors shaping deforestation at a regional scale and can help design solutions that go beyond the dominant PA-centric approach, to address the reality of conservation in the human-dominated contested landscapes of the tropics.

Chapter 1

Introduction

Human-driven changes in land cover and land use have had a tremendous impact on ecosystems. Large-scale conversion of natural land cover types such as forests, wetlands and grasslands to human-influenced land cover types such as agriculture, pastures and urban areas has taken place across the globe (Foley et al. 2005; Klein Goldewijk et al. 2011; Meiyappan and Jain 2012). Land use/land cover change (LULCC) has had tremendous impacts on ecology, constituting the most dominant driver of biodiversity loss globally (Fahrig 2003; Pereira et al. 2012), modifying ecosystem structure and function, and reducing the capacity for providing sustained ecosystem services for humankind (Gibson et al. 2013; Mace et al. 2012).

Human drivers of LULCC are the impact of complex interactions influenced by social, institutional, economic, demographic, technological and cultural variables interacting with the biophysical and ecological environment (Lambin and Geist 2008; Roy et al. 2015). Of these, greater attention has been paid to understanding the role of demographic and socio-economic drivers, while the influence of the institutions and governance is relatively less understood (Rounsevell et al. 2014; Turner et al. 1994). Similarly, attention has largely focused on changes that result in land cover transformation (e.g. deforestation) (Pereira et al. 2012; Turner et al. 1994), while there has also been a substantial increase in areas experiencing land cover modification e.g. forest degradation (Pereira et al. 2012) and fragmentation (Wade et al. 2003) that are less understood. This research aims to focus on these lesser researched issues, investigating the impact of institutions on land cover transformation, as well as land cover modification and fragmentation, which have important effects on biodiversity and conservation.

Drivers of Land Use/Land Cover Change (LULCC)

Land cover refers to biophysical attributes of the earth's surface, such as forest cover, while land use refers to human activities such as grazing or wood collection, that directly alter the physical environment (Geist and Lambin 2001a). Today, LULCC has transformed over half of the earth's ice-free land surface, with as much as 40% of land in agriculture, and urbanization constituting another rapid and growing driver of change (Lambin et al. 2003; Turner II 2002).

LULCC can be understood as a combination of land transformation and land modification (Lambin and Geist 2008). Land transformation refers to radical changes in land cover and land use, such as the conversion of forest to agriculture while land modification refers to lands retaining their base land cover but which undergoes some qualitative changes, such as forests that are degraded due to excessive wood harvest, or modified due to invasion of exotic species (Lambin and Geist 2008; Lambin et al. 2001; Turner et al. 2001). In general, land cover transformation (such as deforestation) is easier to detect and map, while land cover modification (such as forest degradation) is more difficult to identify because of fine-scale variations in the levels of tree density and cover that are not as easily detectable (Davidar et al. 2010; Lambin and Geist 2008).

The advent of satellite imagery has been very influential in stimulating research on LULCC (Geist and Lambin 2001a; Roy et al. 2015), leading to the emergence of a new field of enquiry such as Land Change Science, that is focused on mapping, measuring and understanding the drivers and consequences of LULCC (Geist and Lambin 2001a; Roy et al. 2015; Turner et al. 2007). Although the initial focus of land change science studies was on deforestation as a unidirectional process, there is now a growing recognition that landscapes are spatially and temporally variable, with some locations undergoing deforestation and degradation while other parts of the landscape may experience reforestation and recovery (Nagendra and Southworth 2010). New advances in remote sensing, with the emergence of high spatial resolution sensors, have led to major advances in the ability to accurately map and identify land cover transformations (Roy et al. 2015; Wang et al. 2010), yet the ability to map land cover modifications, especially in critical aspects such as forest degradation, remains constrained (Davidar et al. 2010).

Landscape fragmentation

One of the direct and visible impacts of anthropogenic LULCC is landscape fragmentation (Foley et al. 2005). While direct loss of natural land cover, for example forest clearing, is a primary concern - forest fragmentation issues also assume vital significance in the context of maintaining the ‘natural’ variability in the size, shape and distribution of the mosaic of patches which exists within a landscape with little human influence (Riitters et al. 2000). This variability is believed to be crucial in affecting the movement of species and flow of materials within a landscape (Forman 1995; Haddad et al. 2015; van Langevelde 2015). Thus the field of landscape ecology is founded on the recognition of the strong linkage between spatial pattern and ecological process (Fahrig 2003; Haines-Young and Chopping 1996; Turner et al. 2001). Landscape ecological research has contributed to the understanding of the impact of landscape fragmentation on ecological factors such as biodiversity distribution, wildlife gene flow, and long term habitat and population viability, relating these to the extent and configuration of natural lands (Gibson et al. 2013; Haddad et al. 2015; McGarigal et al. 2002). It is therefore very important to assess changes in landscape spatial connectivity and pattern, in addition to assessing change in land cover over time (Nagendra et al. 2010).

Thus, most existing studies of LULCC and landscape fragmentation have focused on understanding the human drivers of land cover transformation (Foley et al. 2005). The direct or proximate human activities that influence landscape change in tropical developing countries can be grouped into categories such as agricultural expansion, increase in infrastructure such as roads and railways, and wood extraction (Davidar et al. 2010; Geist and Lambin 2001b; Lambin et al. 2003). Of these, a large focus of most initial studies was on population as a major driver of LULCC. In recent times a number of large-scale studies e.g. (Geist and Lambin 2001b; Rudel et al. 2009) assert the issue is more complex, and that the impact of demography is modified by other influences. In particular, there is now increasing awareness about the important role that institutions play on shaping LULCC, with many new syntheses recognising the insufficiency of research on this topic (Ostrom and Nagendra 2006; Rudel et al. 2009).

Institutions and LULCC

Forests are embedded within institutional and governance settings, which have the capacity to significantly influence outcomes of change (Campbell et al. 2005). Discussions of institutions and governance structures are therefore essential to an understanding of forest-cover change, especially for shaping effective policies (DiGiano et al. 2013; Nagendra 2007; Sikor 2006). Institutions can be defined as a combination of the formal constraints (rules) and informal constraints (norms) that structure human interactions (Vatn 2005). Field research in many locations indicates the importance of institutions in shaping human decisions on forest change (Chhatre and Agrawal 2008; DiGiano et al. 2013; Nagendra and Southworth 2010). It is also increasingly being recognized that formal designations of institutional boundaries can hide a lot of variation in actual rules in use (Cox et al. 2010).

Thus, a mere documentation of formal institutions and management boundaries is not sufficient (Agrawal 2014; Cox et al. 2010). Within what is formally designated as a particular institutional management category, such as a Tiger Reserve (TR) or community forest, there is often substantial variation in the actual practices of management, rules in use, and institutional structures that impact the outcomes of forest management (Gibson et al. 2000; Hayes 2006). For instance, factors such as the involvement of local forest users in crafting rules of management, group size and the degree of local monitoring are known to impact forest condition and change (Chhatre and Agrawal 2008; Nagendra 2007; Shyamsundar and Ghate 2011). Examinations of multiple institutions at a landscape-scale are limited however. Some studies in Nepal and Indonesia indicate that landscape-scale approaches that incorporate different institutional types including strict Protected Areas (PAs) and community forests, can strengthen the resilience of forest corridors and promote biodiversity (Linkie et al. 2006; Wikramanayake et al. 2011). Yet there is limited research on institutions within a landscape context in other parts of the world, and a particular gap from India (Ostrom and Nagendra 2006). Detailed examinations of land cover change across different tenure regimes and rule systems can help to provide policy inputs for appropriately managing LULCC, landscape fragmentation and ecosystem services at a landscape-scale (Ostrom and Nagendra 2006; Persha et al. 2011). Figure 1.1 provides a conceptual diagram of the role of institutions and other human drivers of change on LULCC and landscape fragmentation.

The Indian Context

Forest conservation is particularly important in a developing, densely populated country like India, with high population densities coexisting with bio-diverse, threatened forests in a very fragile yet important balance (Karanth and DeFries 2010). In recent decades, forests across India have witnessed accelerated rates of clearing and degradation (Davidar et al. 2010). Forest protection is threatened by high levels of poverty, rapid economic growth and industrialization (Karanth and DeFries 2010).

PAs have been the cornerstone of Indian conservation efforts for decades, but multiple recent studies indicate that Indian PAs are becoming very isolated e.g. (DeFries et al. 2010; Nagendra et al. 2010).

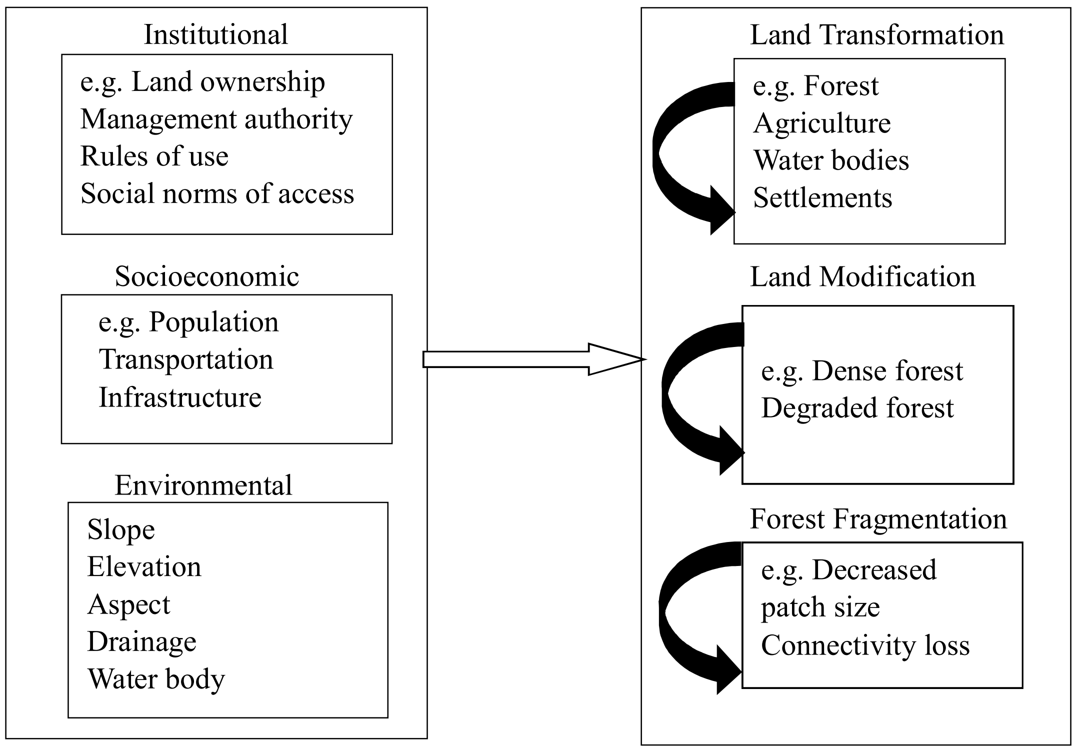

Figure 1.1. A conceptual diagram depicting the role of different types of human impacts on land cover transformation, land cover modification and landscape fragmentation

Such isolation impacts ecological processes of connectivity that are important for long term species survival and persistence (DeFries et al. 2005; Karanth et al. 2009; van Langevelde 2015). Greater connectivity cannot be provided solely by expansion of the PA network, given constraints on land availability (DeFries et al. 2007). Most of the forest patches located outside PAs in India are Reserve Forests (RFs) and Protected Forests (PFs). Research by Ramesh et al. (1997) in the Western Ghats of India, and Menon et al. (2001) in Arunachal Pradesh concludes that RF areas are likely to experience the greatest threats of future forest conversion, due to their less protected status as well as their proximity to human habitations, plantations and encroachments. Ravindranath and Sukumar (1998), in a national assessment of the susceptibility of Indian forests to climate change, conclude that forests located outside of PAs and RFs (i.e. protected, village and private forests) are likely to face the greatest threat of forest conversion to agriculture, and degradation due to firewood extraction and livestock grazing.

Participatory conservation with local communities offers possibilities for protection of forest corridors in RF and PF patches connecting PAs, especially in contexts like India where forests are surrounded by densely populated landscapes of forest dependent people (Karanth and DeFries 2010; Shahabuddin 2010). The debate on forest conservation has thus broadened in India to include issues of local participation in forest management in areas outside parks, ranging from Joint Forest Management (JFM) (Ravindranath and Sudha 2004; Sarin et al. 2003) to the recent implementation of the Forest Rights Act, 2006 (FRA, 2006), which amongst other things also provides local communities with a recognition of formal rights for sustainable management of their local forests (Sarker 2011). These initiatives have provided scope for an increased recognition of the potential for enabling community management in the vast expanse of forests outside of PAs in India (Ghate et al. 2013). Such community protection, if planned at a landscape-scale in conjunction with PA management, can provide more comprehensive, distributed, resilient conservation planning at landscape and regional-scales. Research in India examining community forestry shows strong potential for success, depending on the rules used, and the biophysical and ecological context within which forests are located (Chhatre and Agrawal 2008; Ghate et al. 2009; Ghate and Nagendra 2005). JFM seems to have mixed impacts on forests depending on the specific institutional and socio-economic context (Bhattacharya et al. 2010; Ghate et al. 2009; Ghate and Nagendra 2005; Ravindranath and Sudha 2004).

Encompassing a range of institutional mechanisms at a regional-scale, including PAs, community forests and other institutional categories can be useful to address the social, economic and cultural needs of forest inhabitants, as well as enabling conservation objectives (Ostrom and Nagendra 2006; Porter-Bolland et al. 2012). This research aims to develop a better understanding of the role of institutional structure in impacting forest landscape change at a regional-scale to provide better insights for policy.

Overall Objective

The overall objective of this study is to understand the role of institutions in shaping land cover transformation, land cover modification, and landscape fragmentation in central Indian dry tropical forests, which represent a highly threatened landscape in India (Nagendra et al. 2010) as well as globally (Lambin and Geist 2008).

Specific objectives

1. To understand land cover modification and transformation within and outside PAs and the reasons associated with the change.
2. To understand patterns of forest fragmentation in different forest management regimes and impacts of institutional enclosure on local communities.
3. To understand the relationship between spectral heterogeneity and vegetation variability in the forest with and without local institutions.
4. To understand socio-ecological impacts of forest monitoring by state and village institutions.

Study Area

The study was conducted in a dry deciduous central Indian forest landscape connecting two important TRs of central India: Pench and Tadoba-Andhari TR, in Eastern Maharashtra. There are nine PAs in the selected region with the two TRs, six Wildlife Sanctuaries (WLSs), and one National Park (NP). Four PAs, namely, Pench TR, Nagzira WLS, Navegaon NP and Tadoba-Andhari TR have existed since 1970s (some have changed management designations and boundaries over years), whereas Mansinghdeo, Koka, Umred-Kandarla, New-Nagzia and Navegaon WLSs were established after 2010 (Figure 1.2).

The PAs covers around 17% of the total forest area in this region. The total forest area in this region is around 11,000km^2 out of which around 1350km^2 is covered by PAs and the rest of the forest area acts as the corridor, which connects these PAs. The vast expanse of forest outside the PA also has direct relevance to formal conservation goals as these may serve as potential corridors for wildlife (Ghate et al. 2013; Joshi et al. 2013). There are a range of formal institutional arrangements including TR, WLS, and NP under the PAs (Table 1.1 and Figure

1.2). The Forest Department (FD) also maintains the forests outside the PAs under categories such as RF and PF. Some forest patches are managed by the Forest Development Corporation of Maharashtra (FDCM) for commercial, rotational harvest (Table 1.1 and Figure 1.2).

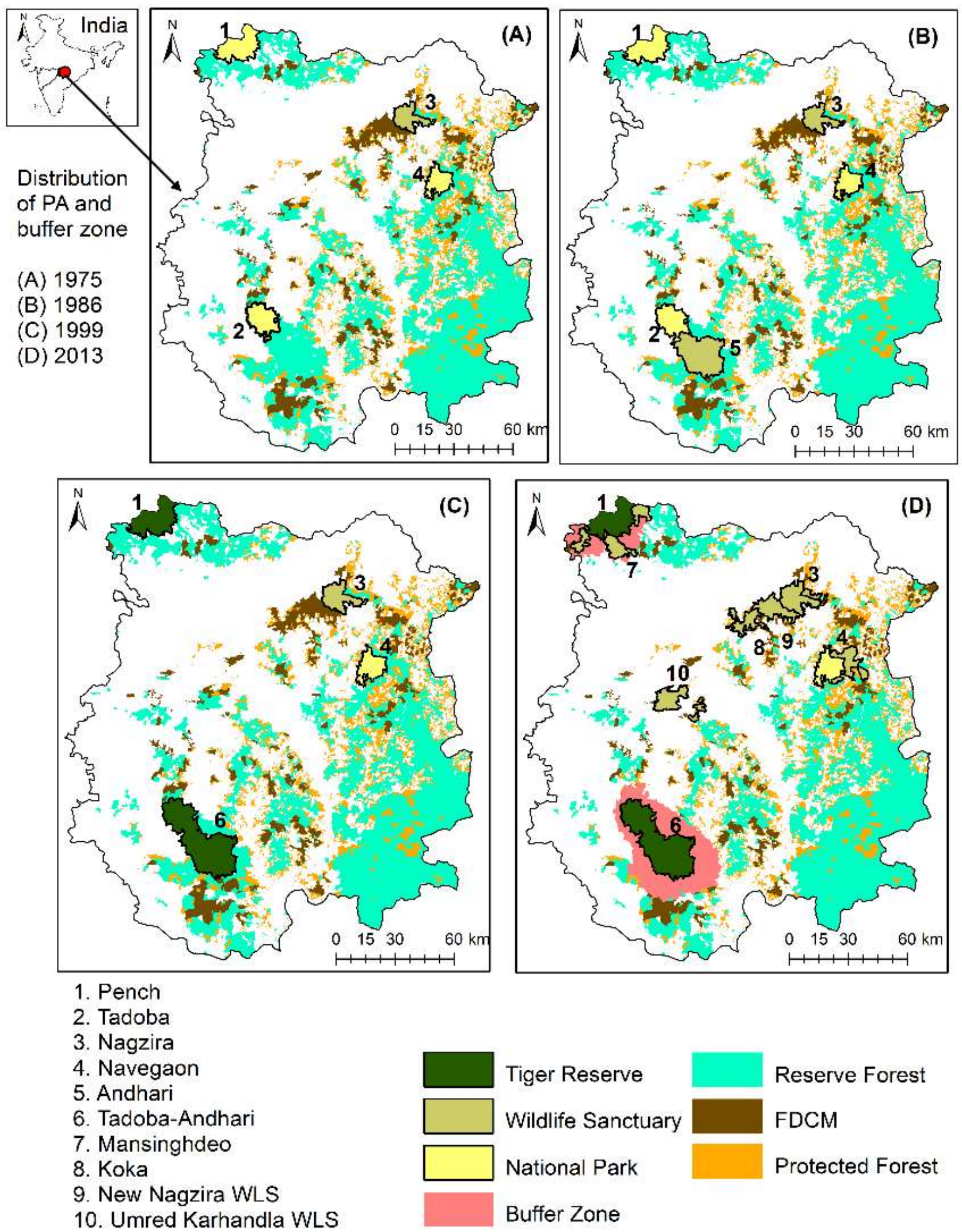

Figure 1.2. Distribution of PA and buffer zone in four time periods in the study site

(Note: Forest Department of Maharashtra has provided the spatial layers in shapefile format, which have been used to create these maps).

The study landscape contains a number of rural and isolated forested settlements, as well as growing small towns, with national highways, roads and other infrastructural growth that additionally impacts forest change. The population density is about 250 people/km^2, of which 33% of the population belongs to tribal communities (http://censusindia.gov.in/). The tribal as well as non-tribal communities are highly dependent on forests for subsistence and economic livelihoods. Thus, it is very important to understand the interface between local communities, forest use, and conservation of the forest corridor in this region (Vatn and Vedeld 2013). At the village level, the communities have informally devised rules and regulations for harvesting, managing and protecting the forest resources. At the same time, initiatives of the state such as JFM schemes and the FRA provide limited recognition of rights to local communities for utilization and management of forest patches in their vicinity. Understanding the interplay between these institutions and extent of vegetation within this corridor is very important for maintaining a viable wildlife population.

Previous research in the Tadoba-Andhari TR indicated that the park was largely effective in maintaining forest cover within its boundaries, although it experienced forest clearing and fragmentation outside (Nagendra et al. 2010). Vaidyanathan et al. (2010) further examined annual changes in vegetation within this park, finding that in addition to institutions and human pressure, climatic regimes played a role in impacting forest change. Mondal and Southworth (2010) similarly report the importance of PA boundaries in limiting forest change from a study focused on the Pench TR and its buffer zone.

In addition, they emphasize the importance of commercial forest management regimes in maintaining forest connectivity outside the park boundary. Less research has been conducted in other parts of the landscape, although Ghate and Nagendra (2005) and Ghate et al. (2009) have examined the role of institutional structure within different institutions managed under JFM within the forest corridor connecting the two parks. All the above studies have been conducted in isolation, and there is a lack of connected research at a larger-scale examining the impact of PAs as well as other types of institutions on forest change and fragmentation in the corridor. Further, existing research does not directly compare the relative impact of institutions on LULCC, forest fragmentation and tree diversity. The research will build on existing knowledge to provide a basis for developing larger-scale landscape-level insights into the role of institutions on managing land cover transformation, land cover modification and landscape fragmentation.

Table 1.1. Types of forest management regimes and the rules of use and access

Different Types of Management Regimes	Rules
Tiger Reserve (TR) 880.52km^2	TRs have completely inaccessible core areas, increased restrictions in terms of forest resource use and entry, and check points at all entry points. People cannot collect any resources from the forest, including dead wood. Grazing is completely prohibited. Villages inside many TRs have been relocated. However, tourism is allowed on specified routes. Local communities use the forest in the buffer area around the reserve, and may receive some indirect benefits from tourism.
Wildlife Sanctuary (WLS) 898.69km^2	WLSs are PAs created for the conservation of particular faunal and floral species. There are restrictions on timber and fuelwood extraction from these areas. Hunting is also banned. Check points are located at all entry points. Grazing is also banned inside WLSs. However, local communities use the forest in the buffer area around the reserve, and may receive some indirect benefits from tourism.
National Park (NP) 129.55km^2	NPs are areas demarcated for conservation. There are restrictions on timber and fuelwood extraction from the forest. Hunting is also banned. However, local communities around the forest use the forest for their livelihood.
Buffer Zone (BZ) 1585km^2	An area of around 5-10 km distance from the park is demarcated around TRs as a buffer zone. Local communities use the forest in the buffer area around the reserve, and may receive some indirect benefits from tourism. Eco-development programs have been initiated by the FD in the buffer zones.

Different Types of Management Regimes	Rules
Reserve Forest (RF) 6400km^2 (approximate)	There are much fewer restrictions in terms of using forest resources in RFs as compared to TRs, WLSs, NPs, and buffer zones. Within RFs, plantation, beat cutting (rotational felling of trees above a specified girth in the selected coupe/beat, followed by plantation) and other forest related work is conducted according to five year plans of the Forest Department. There are restrictions on logging and hunting. Local residents can collect fuelwood only through headloads. Use of bullock-cart, bicycle, and axe for wood collection is prohibited.
Forest Development Corporation of Maharashtra (FDCM) 1150km^2 (approximate)	Some RF compartments are leased to the FDCM for afforestation, timber extraction, and sale. Local communities work in FDCM forests for daily wages, but are not allowed to access forest resources for their livelihood. They are sometimes allowed to use resources that are not commercially useful for the FDCM department.
Protected Forest (PF) 2200km^2 (approximate)	PFs are similar to RFs; however there are fewer restrictions on village residents in terms of using the former as compared to the latter. The term PF is sometimes interchangeably used with village forest. Village residents are allowed to collect fuelwood, timber, and other non-timber forest products (NTFPs).
Community Forest Management (CFM)	Some patches of RFs and PFs are informally managed by local communities, who formulate rules and regulations on use and management. Some of these community associations later received formal recognition through JFM, with forest patches continuing to be managed by the local community but with limited authority, under the overall control of the FD. Recently, some local communities have claimed rights over forest patches through the Community Forest Rights section of the FRA, 2006.

Chapter outlines

In chapter 2, forest change is mapped using Landsat satellite images from 1977, 1990, 1999, and 2011. Forest transformation and modification were mapped in different forest management regimes within and outside PAs. Focused group discussions with residents of 20 randomly selected villages, 10 each in deforested and reforested change categories, were employed to understand the reasons behind the forest change.

In chapter 3, the Riitters fragmentation model was used to understand patterns of forest fragmentation in different forest management regimes. Forests outside PAs have also been subjected to "institutional enclosure", with strict rules on access and extraction. Focus group discussions were conducted in 20 villages to study the impact of institutional enclosure on forest fragmentation. This research demonstrates how information on spatial changes in pattern, derived from remote sensing coupled with fragmentation analysis, can be linked to social surveys to understand the underlying social drivers, thereby establishing a clearer understanding of the pattern-process linkage.

In chapter 4, relationship between vegetation structure and forest management institutions was explored, in order to assess the efficacy of local institutions in management of forests outside PAs. The methods proposed by this study evaluate the status of forest management in a forest corridor using remotely sensed data and could be effectively used to identify the extent of vegetation health and management status.

Chapter 5 addresses the need to understand the functionality and socio-ecological outcomes of different forest management institutions. The two main forest management institutions were the FD and local communities managing forest resources. Vegetation surveys and focus group discussions were conducted based on presence or absence of active protection and monitoring of forest resources by either FD or local people.

Chapter 6 synthesizes the finding of all the previous chapters and links them to the overall objective of the thesis which is to understand the role of forest institutions in landscape transformation, modification and fragmentation. The thesis demonstrates the importance of integrated landscape and institutional research for better forest conservation and management practices.

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Chapter 2:

The influence of forest management regimes on forest cover transformation and modification in a central Indian dry deciduous forest landscape

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Chapter 2:

The influence of forest management regimes on forest cover transformation and modification in a central Indian dry deciduous forest landscape

Introduction

The densely populated landscapes of India pose a challenge for conservation, with high population densities coexisting with biodiverse, threatened forests. In recent decades, forests across India have witnessed accelerated rates of clearing and degradation (Davidar et al. 2010). Forest protection within and outside Protected Areas (PAs) is threatened by high population densities, high levels of poverty, rapid economic growth, industrialization, and urbanization (Karanth and DeFries 2010). Although PAs have been the cornerstone of Indian conservation efforts, multiple studies indicate that PAs have become increasingly isolated (Karanth and DeFries 2010; Nagendra et al. 2010). Such isolation impacts ecological processes of connectivity that are important for long term species survival and persistence (DeFries et al. 2005; Karanth et al. 2013).

The number of PAs in India has steadily increased from approximately 100 in the 1970s to 733 in 2016, covering 4.89% of India's terrestrial area (http://www.wiienvis.nic.in/Database/Protected_Area_854.aspx). Along with the increase in the number of PAs with a large number of villages, relocation of a number of villages from within the PAs to outside has added to the pressure on forests outside PAs (Lasgorceix and Kothari 2009). As parks expand in area, increase in number, and restrict the use of forest products within these PAs, forests outside PAs are being increasingly used by forest dependent communities (Guha 1983; Guha 2000). These forested landscapes are multifunctional, providing livelihood and cultural support to the local communities, and are also used by the state for revenue generation. Dewi et al. (2013) have shown that PAs are surrounded by these multifunctional forested landscapes, where deforestation and fragmentation is high due to economic, social, urbanization, and industrial pressure. Conserving forests outside PAs is important, as they act as corridors for wildlife movement, but these forests are undergoing rapid change, especially in densely populated countries like India where there is substantial economic and political pressure on forests (DeFries et al. 2010; Karanth and DeFries 2010; Shahabuddin and Rangarajan 2007). Studies have shown that institutional processes of governance play an important role in the management of forest patches within as well as outside PAs (Ghate and Nagendra 2005; Nagendra et al. 2006).

A large proportion of India's forest land is located outside the PA network (DeFries et al. 2010; Karanth and DeFries 2010). These forests are also legally under the formal control of the Indian Forest Department. In the state of Maharashtra, for instance, which is the focus of this study, forests outside PAs are managed under different categories such as of Reserve Forest (RF), Protected Forest (PF), and Forest Development Corporation of Maharashtra (FDCM). However, many forest patches are also informally managed by local communities through informal institutions such as sacred groves, as well as by traditional norms that circumscribe hunting and harvesting of forest resources (Fleischman 2015). Recently, through the Joint Forest Management (JFM) and the Indian Forest Rights Act, 2006 (FRA, 2006) local communities have received partial *de jure* (formal) rights to access and maintain forest patches (Ghate and Nagendra 2005; Sarin et al. 2003). However, community struggles over forest resource use continues, because of inadequate policy support, and due to poor implementation (Nayak and Berkes 2008; Sarin et al. 2003). Forest areas form landscapes of contrast, where long standing traditional institutions of forest management coexist with large scale forest logging, and strictly managed PAs are located alongside clearings for large infrastructure projects (Shahabuddin and Rao 2010).

An examination of the overall picture of forest management in India over several decades (West et al. 2006) reveals a steady increase in the number of PAs, and in the restrictions on use of the forest by local communities within PAs. In forests outside PAs as well, there is a visible influence of the Forest Department (FD) in the management of forest resources through measures such as plantation projects, JFM policies, and park buffer zone management, enforced by the routine monitoring of forest guards (Torri 2011). These interventions have led to increase in restrictions on forest use by local communities (Shahabuddin 2010). These have also led to a deterioration in indigenous norms and local institutions, as policy makers have neglected the intrinsic motivation and traditional norms of communities (Vollan 2008). The policy and institutional environment for forest governance is thus highly challenging in the Indian context. High population densities around forests, as well as the high dependence on forests for livelihoods, require conservation policies to work with local communities for maximum effectiveness. Greater connectivity cannot be provided solely by expansion of the PA network, given constraints on land availability (DeFries et al. 2007). Conservation needs to encompass a diversity of mechanisms for forest protection, from strict conservation to engagement with local communities (Ostrom and Nagendra 2006; Porter-Bolland et al. 2012). Therefore, a landscape level study on a large scale, encompassing multiple forest management regimes, will help to understand the impact of policy interventions on forest Land Use and Land Cover Change (LULCC).

The objective of this study is, therefore, to understand forest cover transformation and modification within and outside PAs in a larger forested landscape, which is governed by a variety of different management regimes. Forest management regimes were used as a proxy to understand the processes of deforestation (forest cover transformation) and degradation (forest cover modification) in this area, and to relate these to the social consequences of strict conservation, in an effort to understand the implications for forest policy.

This study also contributes to the societal applications of Remote Sensing (RS) for land change research, by examining the impact of changing forest management regimes on forests in a dry deciduous forested landscape in India using Landsat images. RS and Geographic Information System (GIS) techniques enable us to study LULCC at large scales that otherwise requires extensive field data collection across decades (Kerr and Ostrovsky 2003). The effectiveness of forest polices on conservation can be studied using RS techniques, integrated with field information on the social and ecological context (Mondal and Southworth 2010). Landsat images, freely available from the United State Geological Survey (USGS), provide an invaluable uninterrupted archival dataset from the 1970s that is relatively easy to process and analyze. RS methods are particularly valuable for studies in inaccessible terrain, whether for reasons of security of access or physical constraints of inaccessibility. They permit the rapid and relatively inexpensive analysis of data across large spatial scales and long timeframes with reliable accuracy (Hansen and Loveland 2012).

This study assess forest cover transformation and modification over three decades from 1977 to 2011, using satellite RS combined with GIS maps of forest management boundaries, relating different categories of forest protection to forest change outcomes. Based on information obtained from twenty villages that are representative of the diversity in population and forest access, this study further investigates the impacts of forest management on local tribal communities inhabiting this landscape.

Materials and Methods

Data Processing and Analysis

In order to identify changes in the numbers and the boundaries of PAs and administrative forest sub-divisions outside PAs such as forest ranges, rounds, and beats; data and maps depicting the changes in the boundaries (since the 1970s) were collected from eight forest division offices. Old maps were scanned and geo-referenced using reference points from toposheets and existing boundaries in geographic latitude/longitude World Geodetic System 1984 (WGS84) projection, after which the boundaries were digitized using ArcGIS (10.4, Environmental Systems Research Institute (ESRI) Inc., Redlands, CA, USA) software.

Satellite Image Analysis

Cloud free geo-referenced images were downloaded from the USGS website (http://www.glovis.usgs.gov). Images were selected from 2011 from Landsat Thematic Mapper (TM), which did not have striping errors that Landsat Enhanced Thematic Mapper Plus (ETM+) images from this time period are subject to. The study area covers four paths and rows of Landsat TM, ETM+, and Multispectral Scanner (MSS) data. Thus, it was not possible to analyze the entire area using images from a single date. Images from the dry pre-monsoon season were selected to reduce the impacts of seasonality on the forest change analysis to the extent possible. There was a maximum of three months difference between the images across years; however the focus was on the identification of three broad categories of land cover, i.e., Dense Forest (DF), Open Forest (OF), and Non-Forest (NF), and the variation in dry deciduous forest cover is not substantially different during the season of study. The images described in Table 2.1 were downloaded and used to map forest cover. An image overlay function was conducted along with careful visual comparisons to verify that the co-registered images overlapped exactly across image dates, and that there were no sliver areas of misregistration (Jensen 2000).

Table 2.1. Description of Landsat image, path and row and date of acquisition

Landsat Sensor	Path and Row	Date of Acquisition
MSS	154-45 and 154-46	28 January 1977
MSS	155-45 and 155-46	29 January 1977
TM	144-45 and 144-46	5 November 1989
TM	143-45 and 143-46	17 November 1990
TM	144-45 and 144-46	1 January 1999
ETM+	143-45 and 143-46	4 December 1999
TM	144-45 and 144-46	3 February 2011
TM	143-45 and 143-46	12 February 2011

The earliest Protected Areas were established before 1970 in this landscape – at a time when satellite images were not available. The remaining protected areas have been established at different points in time – given the variability in dates of establishment, and challenges of image availability of good quality, appropriate season, availability of images of nearby dates in neighbouring paths, and lack of cloud cover, it was difficult to synchronize date of image acquisition with the establishment date of Protected Areas. The used combination of images were the best possible available Landsat images for this large region (Table 2.1), which were somewhat close to establishment of the different PAs, keeping a time period close to a decadal gap between the years.

Relative and absolute radiometric calibration was not conducted on this dataset due to the lack of availability of unpolluted deep water bodies in this region to act as reliable dark targets (Hall et al. 1991). Images were classified using supervised classification (Jensen 2000) based on red, green, blue, and near infrared bands. Each of the four images belonging to one time period were classified separately, after which images were mosaicked (Jensen 2000). Ground training data for the 2011 image was collected during a field visit in August–September 2012, and verified using Google Earth imagery from the same season as the image. 30% of the ground control points kept aside for the accuracy assessment were not used in the classification. In order to provide estimates of the changes in total forest area for quantification of the impact of different forest management regimes, soft classification methods using vegetation indices (Krishnaswamy et al. 2009; Mondal 2011) was not used.

For images from 1990 and 1999, classifications were performed using information from visual assessment of images and information from local residents about land cover during previous time periods. Questions regarding the location of plantations, forest clearing for agriculture, forest regeneration due to local community efforts, degradation due to excessive harvest of forest resources, and of sacred forests that remained protected were asked during focus group discussion. This information was digitized and used as an input for image classification and accuracy assessment of areas of stable forest, forest clearing and degradation, and forest regrowth. For the 1977 image, ground training data was collected from a set of 58 Survey of India topographic sheets of 1:50,000 scale covering the study area, dating from the early 1970s.

Classification was performed using the ERDAS Imagine™ (9.2, ERDAS Inc., Norcross, GA, United States) software, classifying the landscape into eight land cover categories - DF (canopy cover above 40%), OF (canopy cover between 10% and 40%), agriculture, grassland, settlements, water, river bed, and fallow land. DF is defined as a forest area with a high number of tall mature trees with closed canopy cover, greater than 10-20 trees per $100m^2$. OF is a forest area with fewer trees and open canopy cover, less than 10 trees per $100m^2$, with additional scrub vegetation. Images from each path within a specific time period were classified separately, and then mosaicked after classification to minimize issues of image to image compatibility (Jensen 2000). As the focus of this analysis was on the evaluation of the impact of management regimes on forest change, this study focused further on the forests. Accordingly, all NF categories were subsequently collapsed into a single category of NF (agriculture, grassland, water, riverbed, fallow land, and settlements).

As the study area covered 4 scenes of the Landsat image, there were overlap areas between these scenes. Similarly, some ground truth points for accuracy assessment also overlapped between the images. In order to deal with the overlapped areas, the scenes were classified separately, and then the 4 classified images were mosaiced. Later the mosaiced image was clipped using the shape file of the study site. Post-processing of the classified image including recoding and accuracy assessment was performed on the clipped image. Therefore, for each selected year there is one classified image for which accuracy assessment was performed. Accuracy assessment was performed using an independent set of points – i.e. there was no overlap between the ground truth points used for classification, and those used for accuracy assessment.

After classification, Landsat TM and ETM+ images of 30 m spatial resolution were downgraded to 60 m to facilitate comparison with Landsat MSS images, which are provided at a resampled resolution of 60 m (http://landsat.usgs.gov/band_designations_landsat_satellites .php). Classified images were overlaid on each other to delineate land cover change trajectories highlighting the dominant land cover trends for 1977–1990, 1990–1999, 1999–2011, and 1977–2011.

The following land cover change classes were analysed:

1. stable forest (forested in both images)
2. stable non-forest (devoid of forest cover in both images)
3. deforestation (DF or OF in the first time period but NF in the second time period) – Forest transformation
4. degradation (DF in the first time period and OF in the second time period) – Forest modification
5. reforestation (NF in the first time period but converted to DF or OF in the second time period) – Forest transformation
6. regrowth (OF in the first time period, DF in the second time period) – Forest modification

The trajectories of land cover change between successive dates were also analyzed by combining information from the four classified images of 1977, 1989-90, 1999, and 2011. There are 3 classes in each of the four classified images i.e. DF, OF, and NF resulting in a total of 81 change trajectories across four dates. The area of each change trajectory was calculated, following which we focused on those change categories that occupied more than 1% of the total area.

Stratified Random Selection of Field Sites for In-Depth Analysis

The objective of this analysis was to understand the reasons for deforestation and reforestation in areas of the landscape outside PAs. The forest outside PAs was separated into two sections:

- Fringe (areas of forest located within a distance of 1 km from the outermost forest boundary)

- Interior (areas of forest that are not part of the fringe)

The study focused on the time period, from 2000 to 2011, which generated the most recent and hence reliable information on drivers of forest change via discussions with local communities. There were 583 villages located in the fringe. As the focus of the study is to understand drivers of deforestation and reforestation, villages where the forests had experienced at least 80% change in land cover were selected. Based on this definition, 61 villages were identified that had predominantly experienced deforestation and 27 villages that had predominantly experienced reforestation. This sample constituted 15% of the total number of villages in the fringe. In the forest interior, forest change was much less extreme. Thus, in the 376 villages located in the forest interior, villages which exhibited over 50% deforestation or over 50% reforestation were selected, ensuring a similar proportion of villages (Figure 2.1).

The selected villages were divided into population ranges based on population density per square km: 0–100; 100–500; 500–1000; 1000–1500, and above 1500. One village in each category was randomly selected, giving us a final sample set of 20 villages (Figure 2.1). These represented categories of deforestation and reforestation distributed across the interior and fringe areas, and came from diverse population densities, ensuring that the sample represented the diversity of villages in the study area.

Semi-structured focused group discussions of 3–5 hours were conducted in the selected villages at public meeting places. People representing different groups, typically a mix of elderly men (aged 70–80 years) and young to middle aged men (25–50 years old) were present. Women were interviewed separately to ensure adequate representation. Questions focused on the constitution and functionality of local institutions, including rules and norms followed to use the forest resources, and formal and informal institutions involved in forest activities. Questions relating to peoples' perceptions regarding the condition of the forest in the past and present; and their perceptions of the reasons for the changes observed in the forest were asked. Questions on the traditional norms of forest use, and the cultural importance of forests for communities were also included. General village information such as population, development activities, and forest and agricultural area from the village office was also collected.

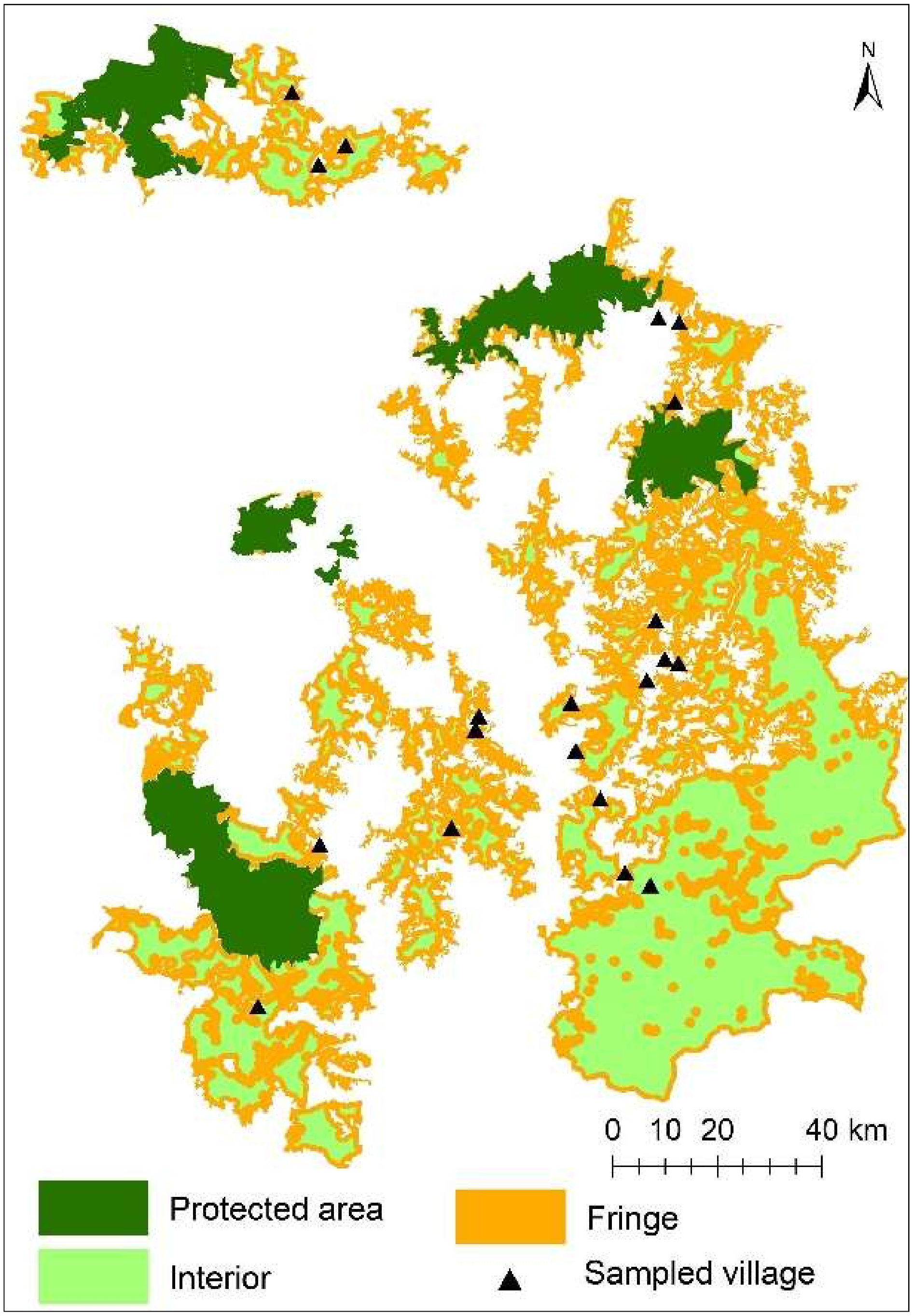


Figure 2.1. Distribution of interior and fringe forests in the landscape along with locations of 20 selected villages

Results

Increased state protection over time

There has been a substantial increase in the number and size of PAs over time. In the 1970, there were only four PAs and currently, there are nine. Five Wildlife Sanctuaries (WLSs): Mansinghdeo, Umred-Karhandla, Koka, New-Nagzira, and Navegaon; were formed between 2010 and 2013 (Table 2.2). There is also a transition of some PAs to stricter management categories. Tadoba-Andhari WLS became a Tiger Reserve (TR) in 1993 and similarly Pench National Park (NP) was declared a TR in 1999 (Table 2.2).

Table 2.2. Year of establishment as well as transition to different forest management regimes along with the respective and cumulative areas under PA and buffer zone

Notification Year	Protected Area	Area km^2	Total Area under PA and Buffer
±1955	Tadoba NP	116.55	371.67
±1955	Pandit Jawaharlal Nehru NP	255.12	
1970	Nagira WLS	152.58	653.8
1975	Navegaon NP	129.55	
1975	Pandit Jawaharlal Nehru NP changed to Pench NP	255.12	
1986	Andhari WLS	508.85	1162.65
1993	Tadoba Andhari WLS changed to Tadoba Andhari TR	625.4	1162.65
1999	Pench NP changed to Pench TR	255.12	
2010	Buffer zone for Tadoba Andhari TR	1101.77	1585.73
2010	Buffer zone for Pench NP	483.96	
2010	Mansingdeo WLS	182.59	1908.76
2012	New Nagzira WLS	151.33	
2012	Navegaon WLS	122.76	
2012	Umred-Karhandla WLS	189.3	
2013	Koka WLS	100.13	

The numbers of forest administrative sub-units—forest ranges, rounds, and beats—outside PAs have increased over time. Ranges have increased from 45 to 70, rounds from 235 to 304, and beats from 1060 to 1243 in the past four decades. Concomitant with the decrease in the area of forests located outside PAs, this clearly indicates that the size of these administrative sub-units has decreased substantially. Each range, round, and beat has an associated range officer, round officer, and beat office, with a proportional number of forest guards. Thus, a larger number of FD staff now monitors smaller areas of forests. The restrictions have increased through various plantation projects, regular monitoring by forest guards, buffer zone establishment, increase in number of administrative sub-units, and also through polices of the JFM.

Forest Cover Change Analysis

Figure 2.2 shows forest cover in 1977, 1989-90, 1999, and 2011. The overall classification accuracy for image classifications, verified using an independent data set of 194 points, is above 89% for all dates, indicating confidence in the analysis (Table 2.3). As the final analysis focused on forests, the accuracy assessment was conducted for three collapsed categories of DF, OF, and NF.

Table 2.4 describes the changes in land cover from 1977 to 2011. Overall, there has been a decrease of 1478km^2 of DF area in the study area between 1977 and 2011, which works out to around 43.47km^2/year. The period from 1977 to 1990 saw the greatest loss amounting to 77.07km^2/year. DF cover in TRs reduced from 89% in 1999 to 87% in 2011 and from 95% to 93% in WLSs. NPs compensated somewhat for these losses, showing an increase in DF cover from 88% to 90% during the same time period. In contrast, there has been a consistent decline in DF cover outside the PAs. RFs, which constitute a substantial proportion of the forest area, have declined slightly in DF cover from 70.5% to 69.5%. PFs, which have the second largest share of the total forest area in the study area, have the sharpest decline in DF cover during this time period, from 40% to 37% (Table 2.4, Figure 2.3, and 2.4). Such decline has taken place despite increased efforts at forest protection outside TR, WLS, and NP.

Figure 2.3 and 2.4 shows that the total area under TR, WLS, and NP increased while the percentage of the DF remained unchanged. However, outside these three categories of strict protection, the total area as well as the percentage of DF decreased over time (Figure 2.5). These findings can be understood as a pressure shift resulting from the areas within strict protection to forest patches with lower levels of protection (primarily RF and PF), as Figure 2.4 and Table 2.4 demonstrate.

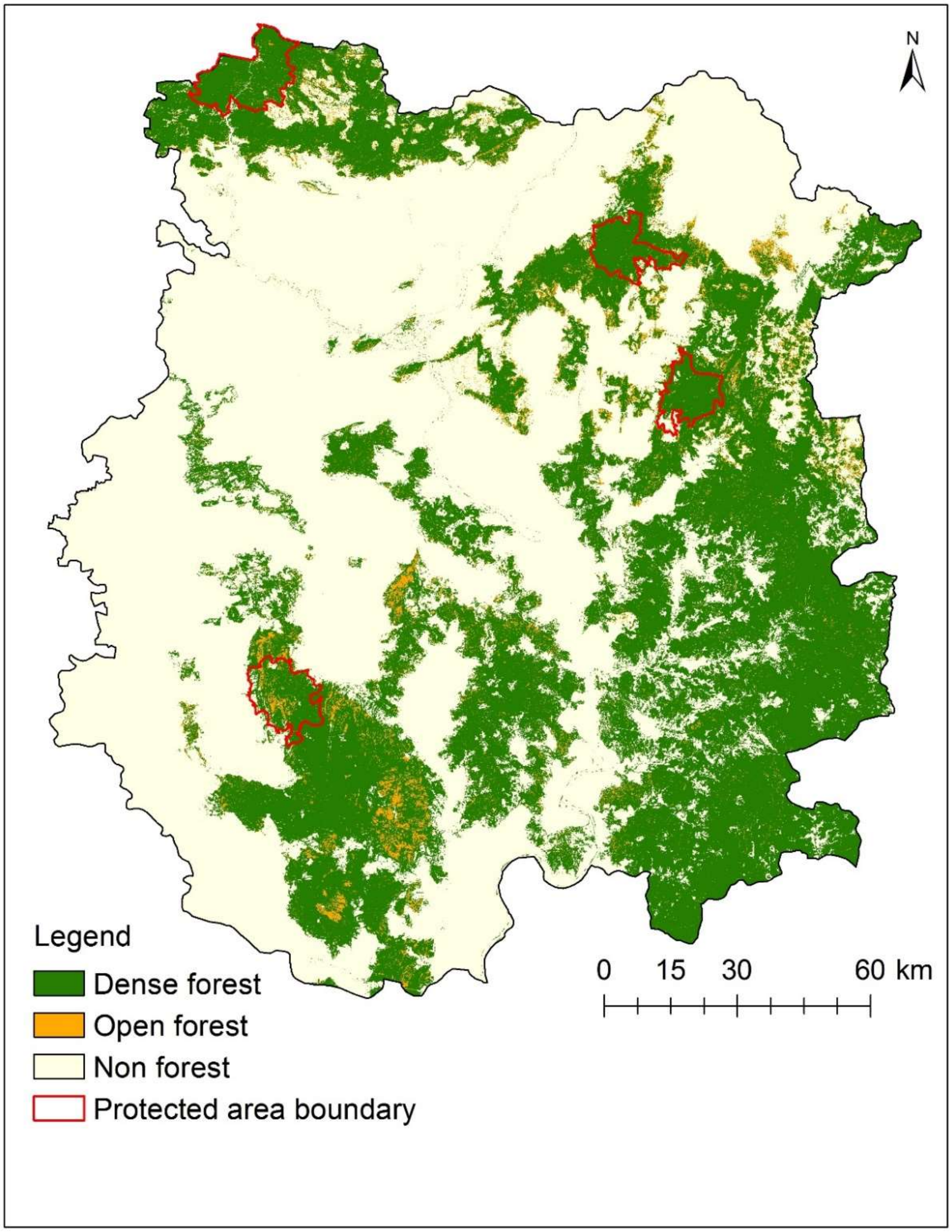


Figure 2.2.a. Land cover classes in 1977

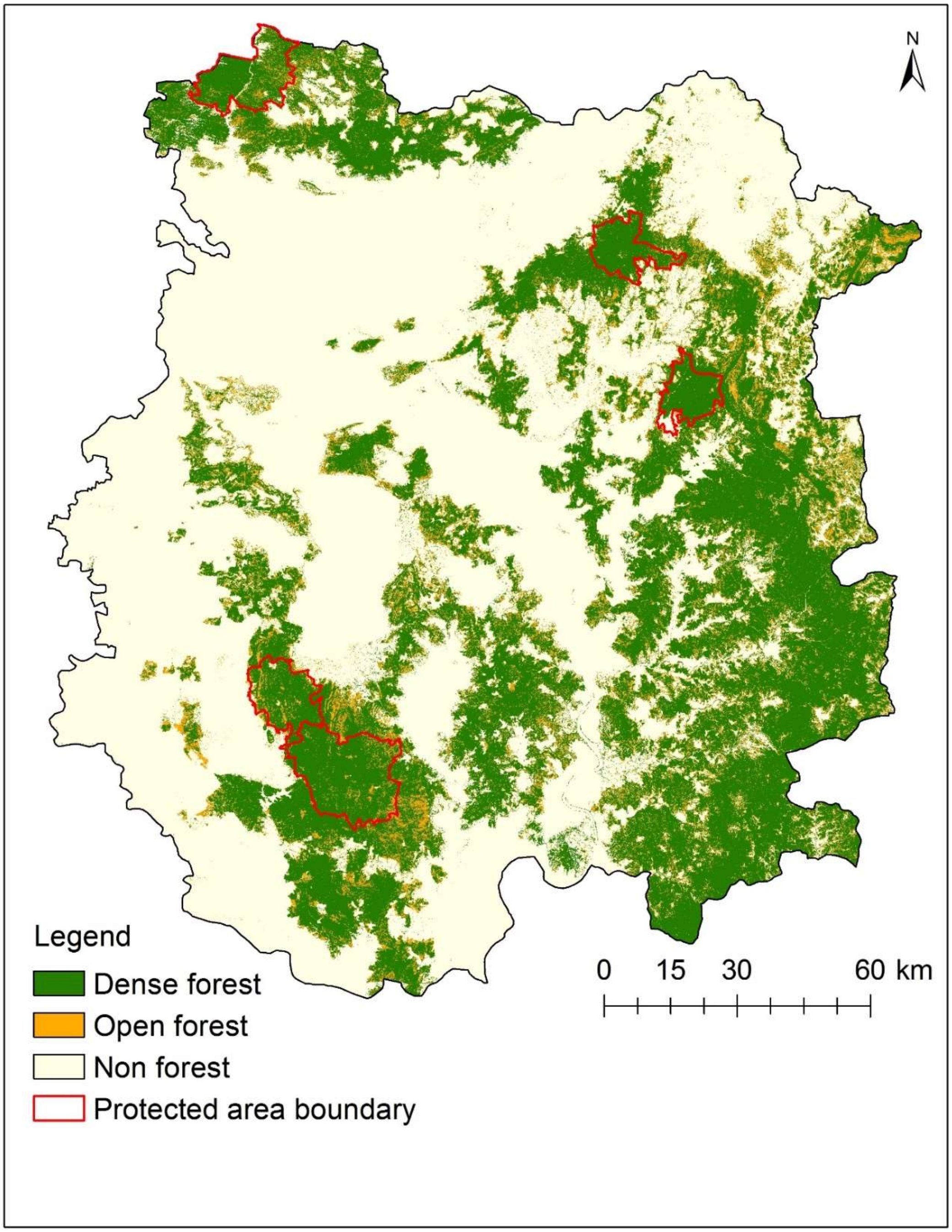


Figure 2.2.b. Land cover classes in 1989-90

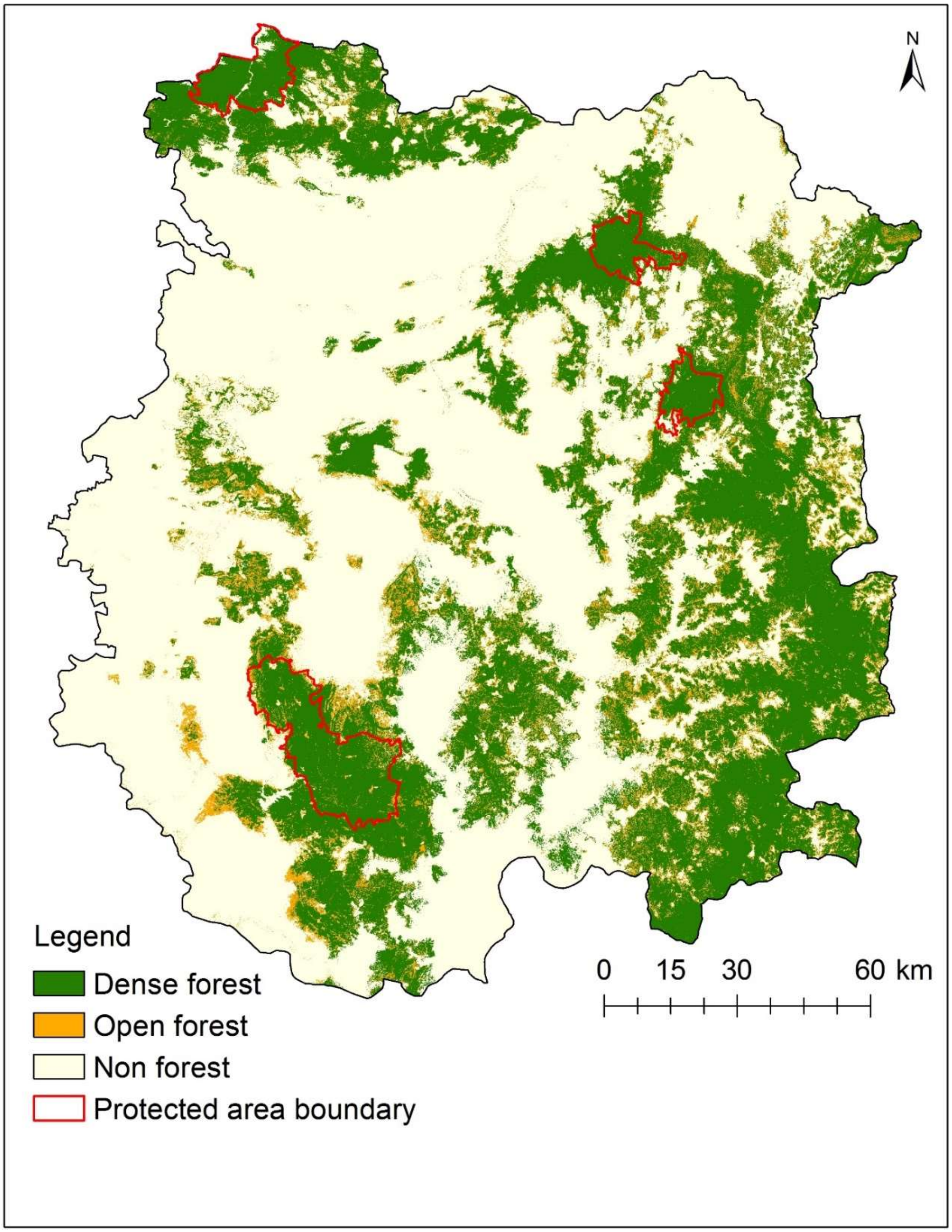


Figure 2.2.c. Land cover classes in 1999

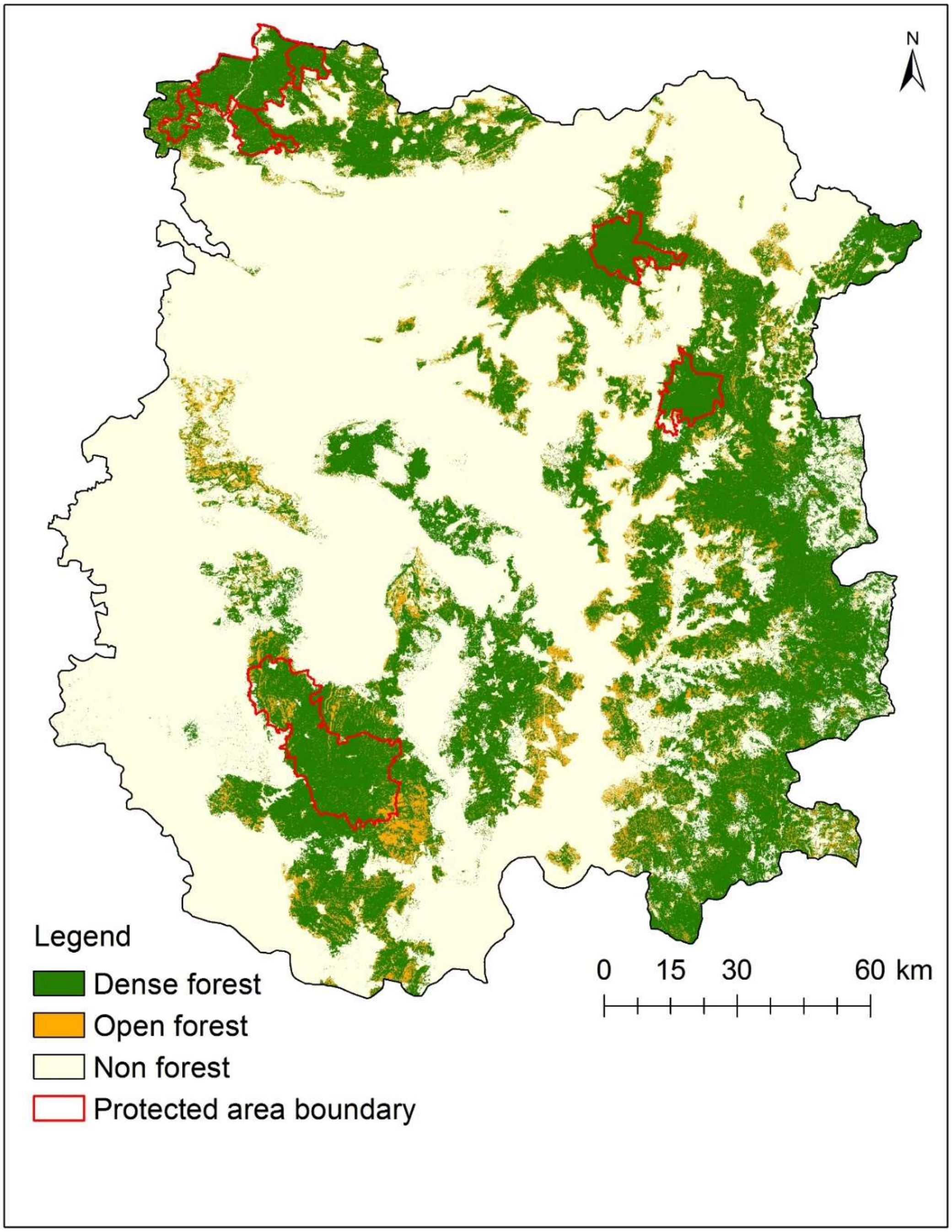


Figure 2.2.d. Land cover classes in 2011

Table 2.3. Accuracy assessment of classified images

Class Name	Reference Total	Classified Total	Number Correct	Producers Accuracy	Users Accuracy	Kappa Statistics
Accuracy Assessment 1977 Image						
DF	133	134	129	96.99%	96.27%	0.88
OF	17	14	13	76.47%	92.86%	0.92
NF	44	46	42	95.45%	91.30%	0.89
Total	194	194	184	Overall classification accuracy = 94.85%		Overall kappa statistics = 0.89
Accuracy Assessment 1990 Image						
DF	108	109	100	92.59%	91.74%	0.81
OF	40	37	34	85.00%	91.89%	0.89
NF	46	48	41	89.13%	85.42%	0.80
Total	194	194	175	Overall classification accuracy = 90.21%		Overall kappa statistics = 0.83
Accuracy Assessment 1999 Image						
DF	97	104	94	96.91%	90.38%	0.81
OF	37	35	30	81.08%	85.71%	0.82
NF	60	55	50	83.33%	90.91%	0.87
Total	194	194	174	Overall classification accuracy = 89.69%		Overall kappa statistics = 0.83
Accuracy Assessment 2011 Image						
DF	93	93	87	93.55%	93.55%	0.88
OF	37	38	33	89.19%	86.84%	0.84
NF	64	63	60	93.75%	95.24%	0.99
Total	194	194	180	Overall classification accuracy = 92.78%		Overall kappa statistics = 0.88

Table 2.4. Change in forest cover percentage over time across different management regimes

Management Regime	Time Period	DF Percentage	OF Percentage	NF Percentage
Overall study site	1977	36.62	3.32	60.06
	1989–1990	32.45	8.18	59.37
	1990	32.21	7.93	59.86
	2011	30.06	6.33	63.61
Tiger Reserve (TR)	1999	89.03	6.53	4.44
	2011	87.23	7.66	5.11
Wildlife Sanctuary (WLS)	1977	95.56	2.87	1.57
	1989–1990	90.45	8.56	0.99
	1999	94.75	3.59	1.66
	2011	92.69	4.29	3.02
National Park (NP)	1977	88.15	5.74	6.11
	1989–1990	82.33	10.81	6.86
	1999	88.1	3.81	8.09
	2011	89.75	2.14	8.11
Buffer Zone (BZ)	2011	54.01	12.26	33.72
Reserve Forest (RF)	1977	80.47	4.66	14.87
	1989–1990	71.49	13.16	15.35
	1999	70.55	13.84	15.62
	2011	69.49	11.23	19.28
Forest Development Corporation of Maharashtra (FDCM)	1977	80.97	8.35	10.68
	1989–1990	73.31	16.24	10.45
	1999	77.22	13.47	9.31
	2011	69.47	13.2	17.32
Protected Forest (PF)	1977	50.57	7.18	42.25
	1989–1990	42.33	16.85	40.82
	1999	40.37	16.04	43.59
	2011	37.07	11.43	51.5

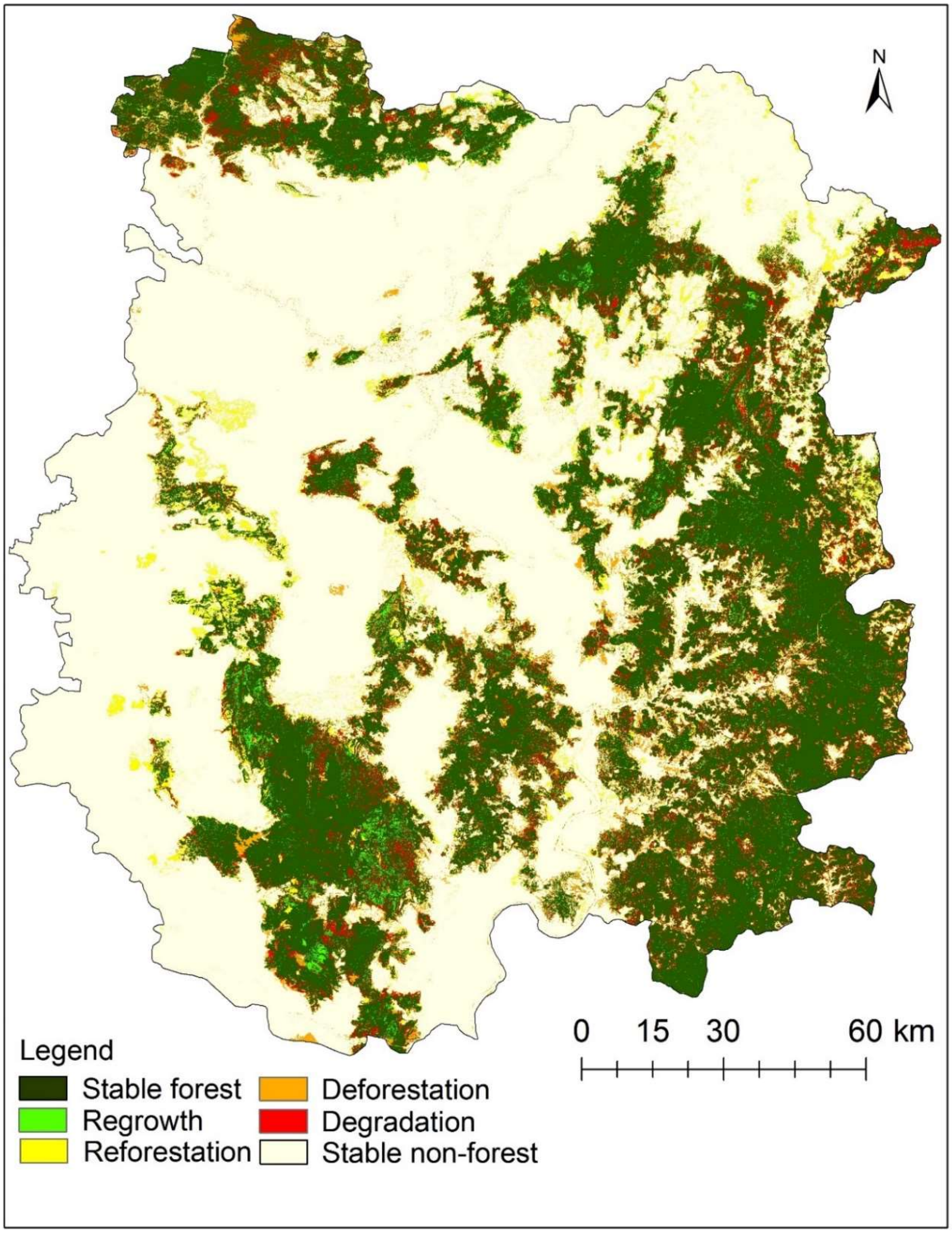


Figure 2.3.a. Forest change between 1977–1990

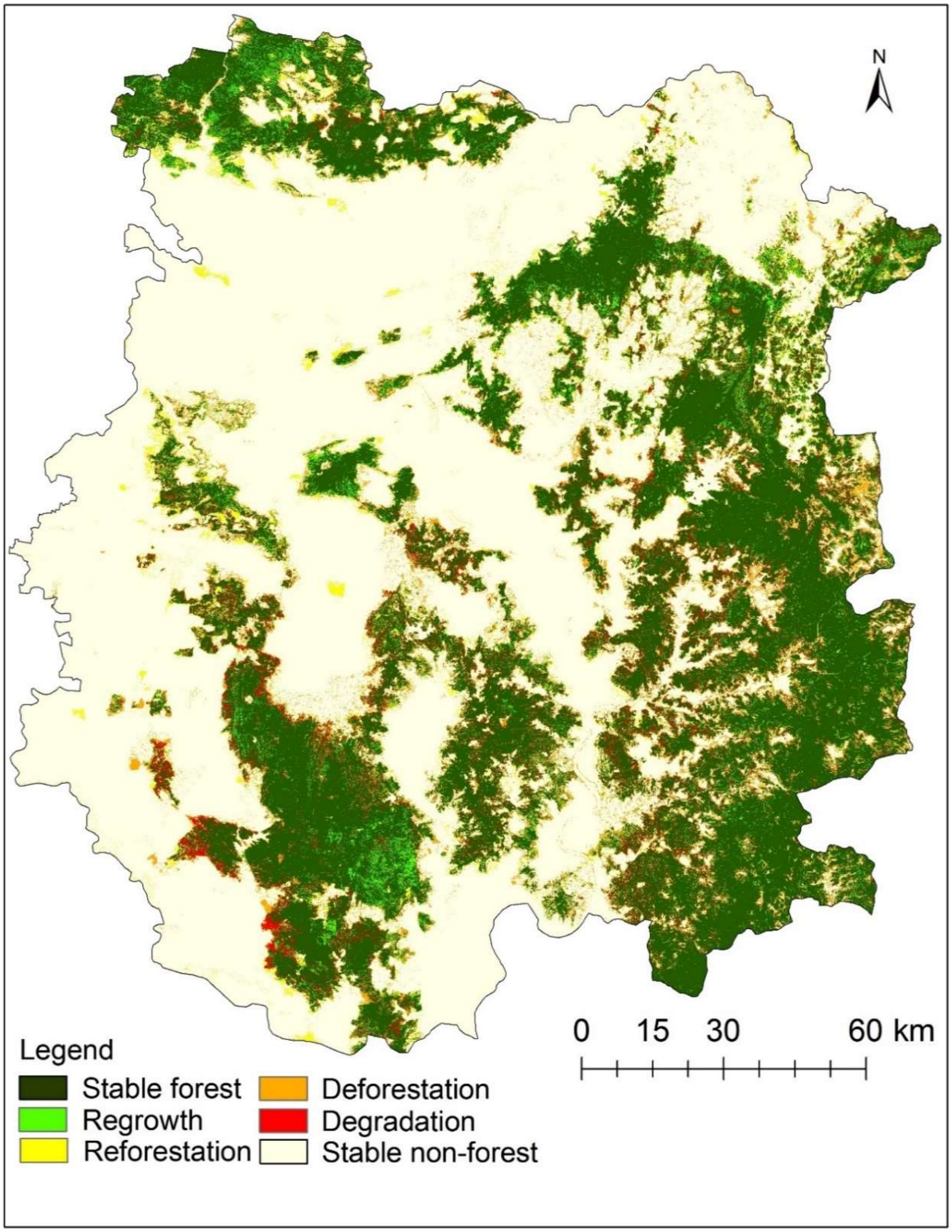


Figure 2.3.b. Forest change between 1990–1999

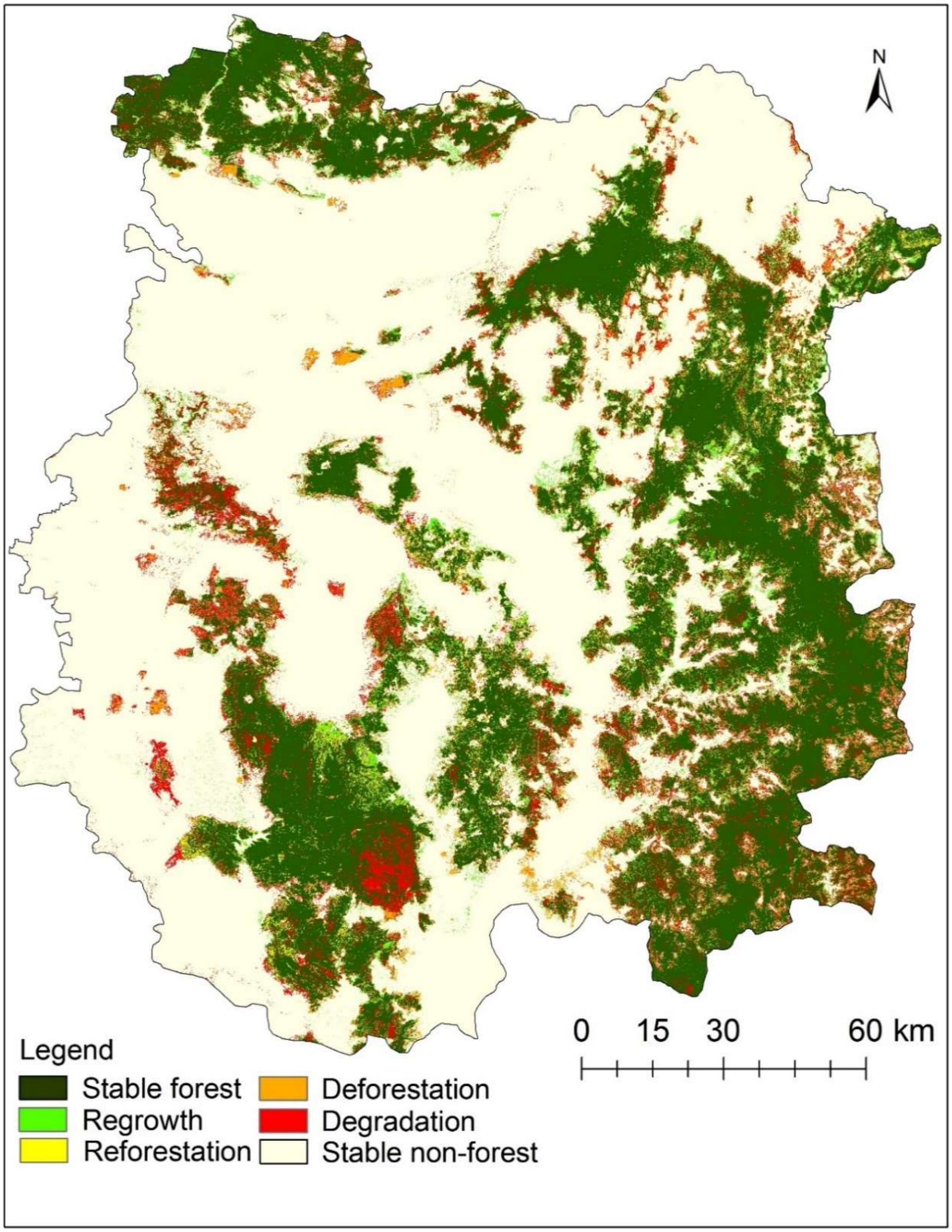


Figure 2.3.c. Forest change between 1999–2011

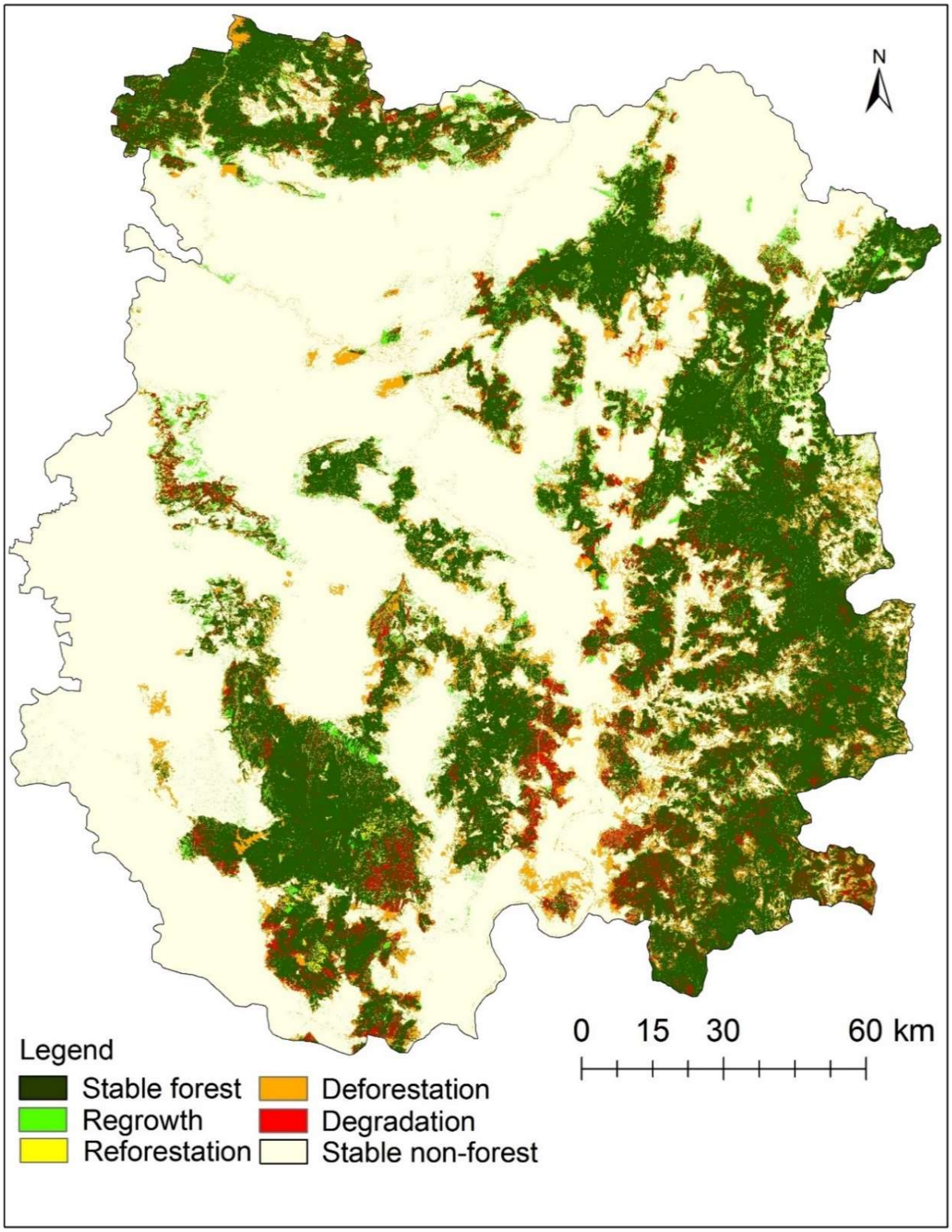


Figure 2.3.d. Forest change between 1977–2011

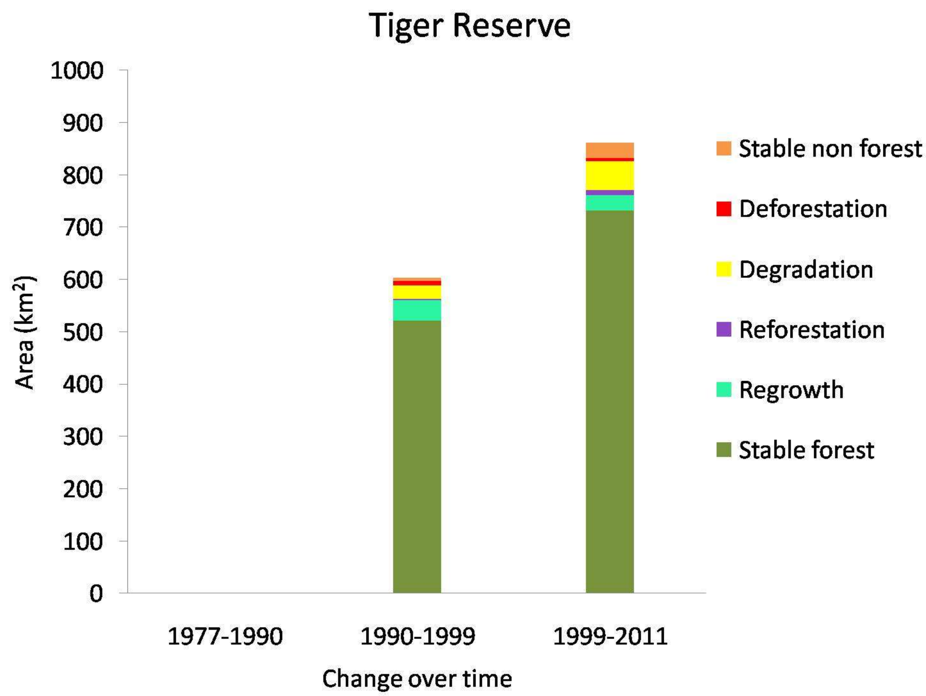


Figure 2.4.a. Change in area and land cover classes inside Tiger Reserve over time

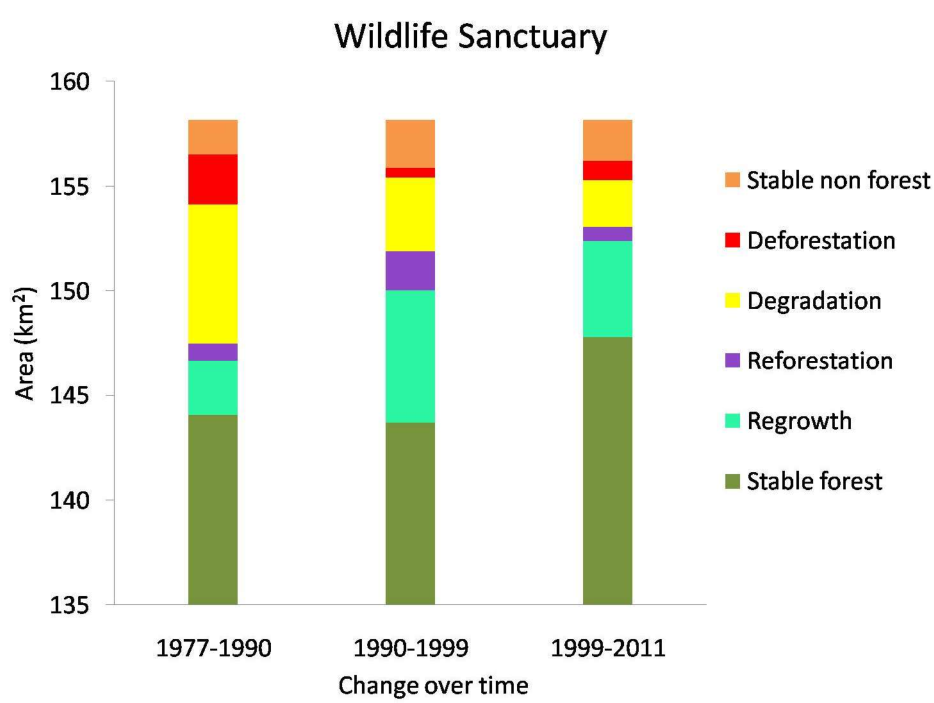


Figure 2.4.b. Change in area and land cover classes inside Wildlife Sanctuary over time

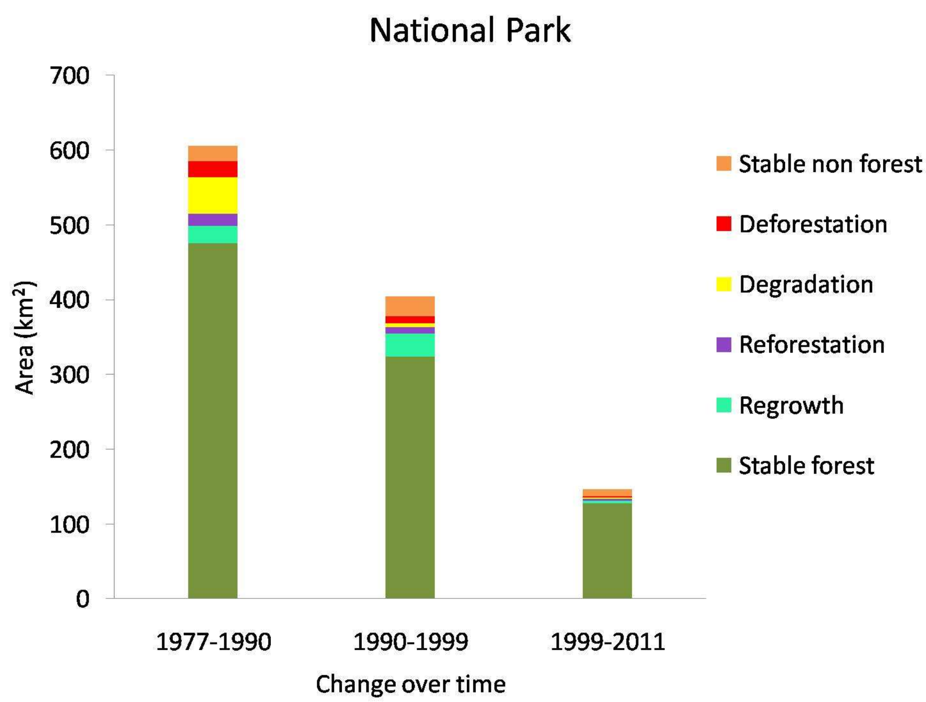


Figure 2.4.c. Change in area and land cover classes inside National Park over time

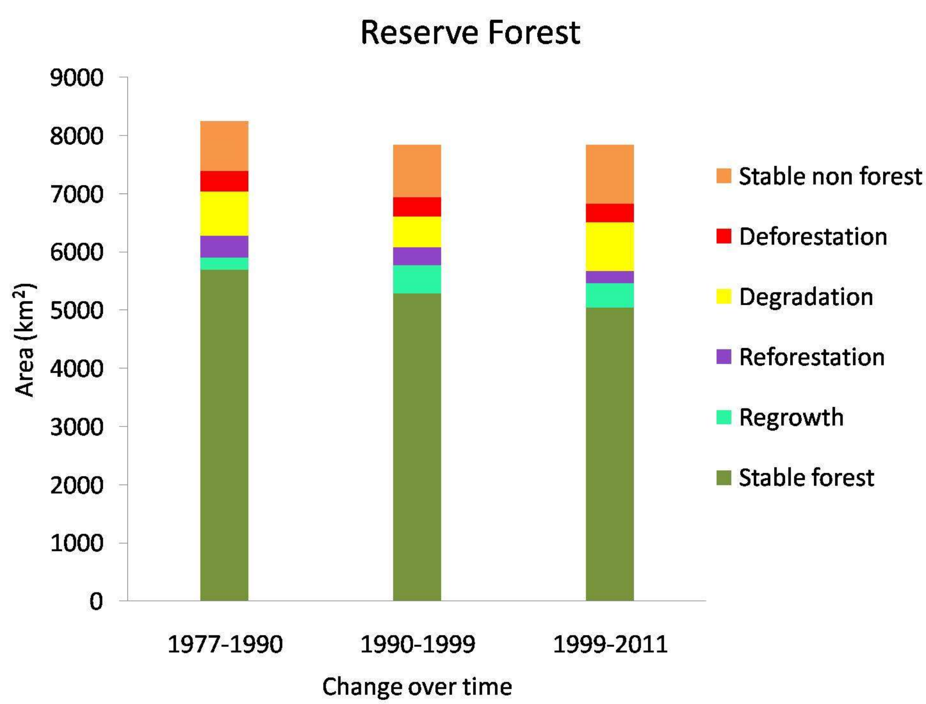


Figure 2.4.d. Change in area and land cover classes inside Reserve Forest over time

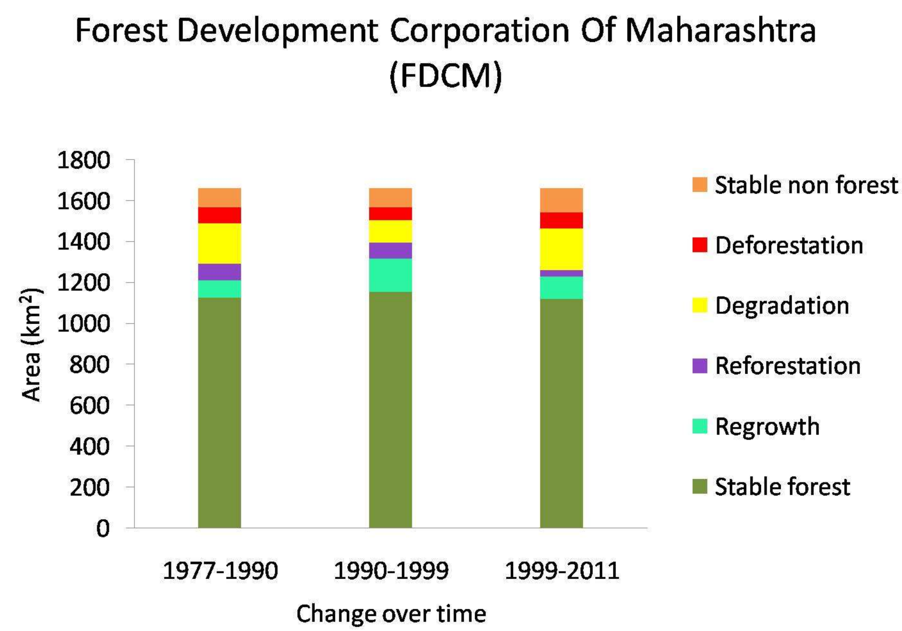


Figure 2.4.e. Change in area and land cover classes inside Forest Development Corporation of Maharashtra over time

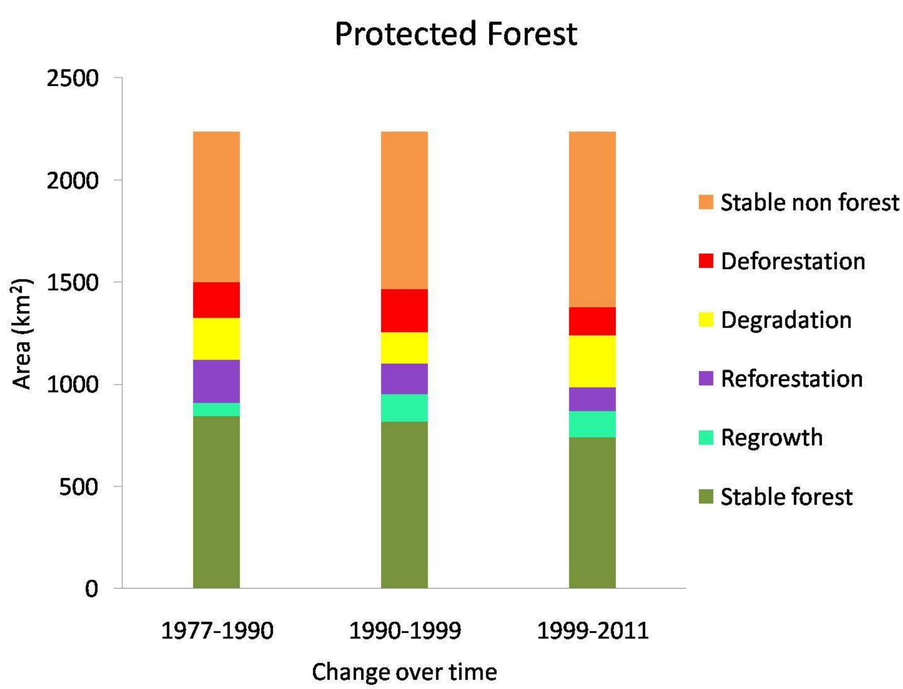
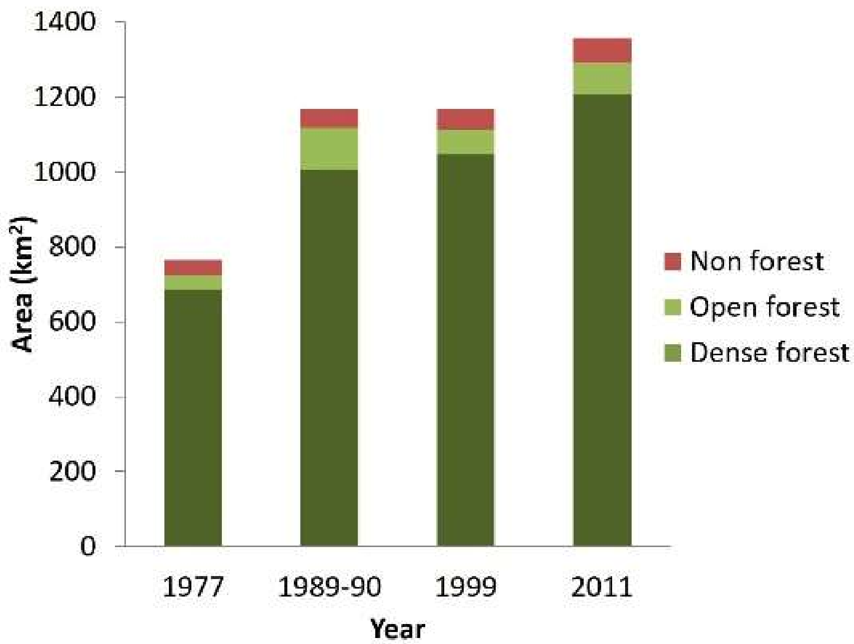
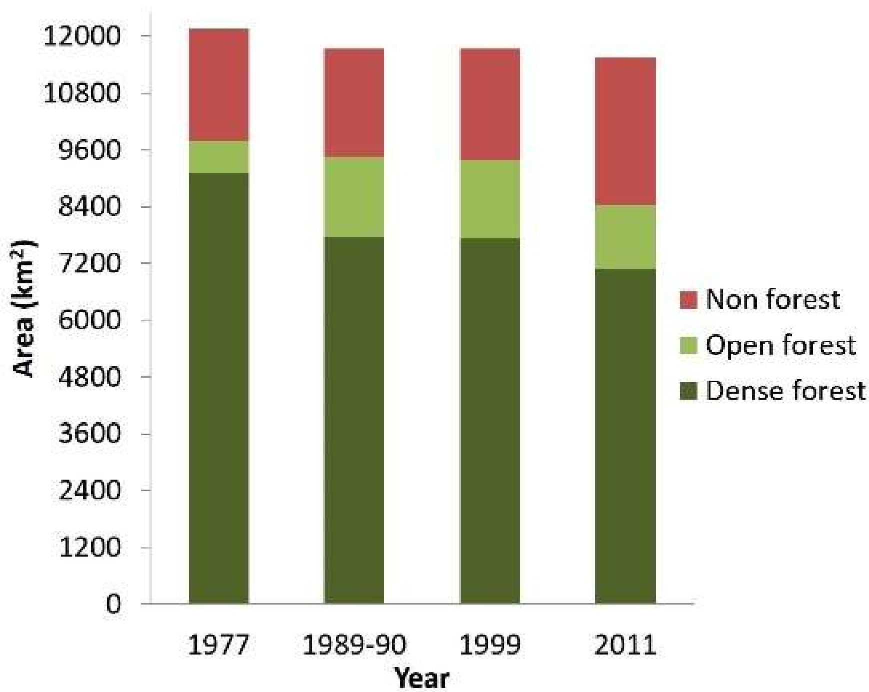


Figure 2.4.f. Change in area and land cover classes Protected Forest over time



(a)



(b)

Figure 2.5. Change in dense forest, open forest, and non-forest in the forests (a) inside categories of strict protection (TR, WLS, NP, and BZ) and (b) outside categories of strict protection (RF, PF, and FDCM)

81 land cover change trajectories were computed for the analysis of land cover change across four dates. 53.21% of the total area was occupied by stable non-forest (NF-NF-NF-NF) and 23.68% area by stable dense forest (DF-DF- DF-DF) categories. The remaining area of 23.11% shows a change in land cover over time. Of these, 6 change categories: NF-OF-NF-NF, DF-DF-DF-NF, DF-DF-OF-DF, DF-NF-NF-NF, DF-DF-DF-OF, and DF-OF-DF-DF occupy an area more than 1% (Table 2.5).

Table 2.5. Land cover change trajectory of classified images between 1977, 1989-90, 1999 and 2011

S.no.	1977	1989-90	1999	2011	Change in classes	Area percentage
1	NF	NF	NF	NF	NF NF NF NF	53.21
2	DF	DF	DF	DF	DF DF DF DF	23.68
3	DF	OF	DF	DF	DF OF DF DF	1.60
4	DF	DF	DF	OF	DF DF DF OF	1.59
5	DF	NF	NF	NF	DF NF NF NF	1.48
6	DF	DF	OF	DF	DF DF OF DF	1.36
7	DF	DF	DF	NF	DF DF DF NF	1.13
8	NF	OF	NF	NF	NF OF NF NF	1.05
9	NF	NF	OF	NF	NF NF OF NF	0.89
10	NF	DF	NF	NF	NF DF NF NF	0.72
11	OF	DF	DF	DF	OF DF DF DF	0.68
12	DF	OF	OF	DF	DF OF OF DF	0.64
13	NF	NF	NF	OF	NF NF NF OF	0.64
14	DF	DF	OF	NF	DF DF OF NF	0.57
15	DF	DF	OF	OF	DF DF OF OF	0.51
16	NF	NF	DF	NF	NF NF DF NF	0.49
17	DF	OF	OF	NF	DF OF OF NF	0.46
18	NF	OF	OF	NF	NF OF OF NF	0.43
19	DF	DF	NF	NF	DF DF NF NF	0.43
20	DF	OF	DF	OF	DF OF DF OF	0.41
21	OF	NF	NF	NF	OF NF NF NF	0.38
22	DF	OF	OF	OF	DF OF OF OF	0.38
23	DF	OF	NF	NF	DF OF NF NF	0.37
24	DF	OF	DF	NF	DF OF DF NF	0.31
25	NF	NF	NF	DF	NF NF NF DF	0.30
26	DF	NF	DF	DF	DF NF DF DF	0.30
27	NF	DF	OF	NF	NF DF OF NF	0.28
28	NF	DF	DF	DF	NF DF DF DF	0.27
29	DF	NF	OF	NF	DF NF OF NF	0.26
30	OF	DF	DF	OF	OF DF DF OF	0.24
31	NF	DF	DF	NF	NF DF DF NF	0.22
32	DF	NF	DF	NF	DF NF DF NF	0.21
33	DF	NF	NF	OF	DF NF NF OF	0.19
34	NF	OF	DF	NF	NF OF DF NF	0.19

S.no.	1977	1989-90	1999	2011	Change in classes	Area percentage
35	DF	DF	NF	DF	DF DF NF DF	0.17
36	OF	OF	DF	DF	OF OF DF DF	0.16
37	OF	OF	DF	OF	OF OF DF OF	0.15
38	NF	NF	OF	OF	NF NF OF OF	0.15
39	NF	OF	OF	OF	NF OF OF OF	0.15
40	DF	NF	OF	DF	DF NF OF DF	0.14
41	DF	DF	NF	OF	DF DF NF OF	0.13
42	DF	NF	OF	OF	DF NF OF OF	0.13
43	OF	OF	OF	OF	OF OF OF OF	0.13
44	DF	NF	NF	DF	DF NF NF DF	0.13
45	NF	OF	NF	OF	NF OF NF OF	0.12
46	DF	OF	NF	OF	DF OF NF OF	0.12
47	NF	DF	DF	OF	NF DF DF OF	0.12
48	DF	NF	DF	OF	DF NF DF OF	0.12
49	DF	OF	NF	DF	DF OF NF DF	0.10
50	OF	DF	DF	NF	OF DF DF NF	0.10
51	NF	OF	DF	DF	NF OF DF DF	0.10
52	NF	DF	OF	OF	NF DF OF OF	0.10
53	OF	OF	NF	NF	OF OF NF NF	0.10
54	NF	OF	DF	OF	NF OF DF OF	0.10
55	NF	NF	DF	OF	NF NF DF OF	0.10
56	NF	OF	OF	DF	NF OF OF DF	0.09
57	OF	OF	OF	NF	OF OF OF NF	0.09
58	OF	DF	OF	DF	OF DF OF DF	0.08
59	NF	NF	DF	DF	NF NF DF DF	0.08
60	NF	DF	OF	DF	NF DF OF DF	0.08
61	OF	OF	OF	DF	OF OF OF DF	0.08
62	OF	DF	OF	OF	OF DF OF OF	0.08
63	OF	DF	NF	NF	OF DF NF NF	0.08
64	NF	NF	OF	DF	NF NF OF DF	0.08
65	OF	NF	OF	NF	OF NF OF NF	0.08
66	OF	DF	OF	NF	OF DF OF NF	0.08
67	NF	DF	NF	OF	NF DF NF OF	0.07
68	OF	NF	NF	OF	OF NF NF OF	0.07
69	OF	OF	DF	NF	OF OF DF NF	0.06
70	OF	NF	DF	NF	OF NF DF NF	0.06
71	NF	OF	NF	DF	NF OF NF DF	0.06
72	OF	NF	DF	DF	OF NF DF DF	0.05
73	NF	DF	NF	DF	NF DF NF DF	0.04
74	OF	NF	OF	OF	OF NF OF OF	0.04
75	OF	OF	NF	OF	OF OF NF OF	0.04
76	OF	NF	DF	OF	OF NF DF OF	0.04
77	OF	DF	NF	OF	OF DF NF OF	0.03
78	OF	NF	NF	DF	OF NF NF DF	0.03
79	OF	NF	OF	DF	OF NF OF DF	0.02
80	OF	OF	NF	DF	OF OF NF DF	0.02
81	OF	DF	NF	DF	OF DF NF DF	0.02

Information about the Villages

Agriculture is the predominant occupation in the study landscape, with the majority of land owners being marginal or small farmers. Road access has improved the opportunities for youth to migrate to nearby towns and industrial centers in search of work. However, the lack of specific skills and the poor quality of education compels most people into taking up menial, low paying jobs that are typically seasonal in nature. Increasing population and limited income generating alternatives result in a continued dependence on the forests.

Although statutory provisions of RF have always restricted collection of fuelwood, non-timber forest products, and open grazing, the implementation has been lax, especially in well forested areas. However, with the stricter enforcement of these rules, as a consequence of the declaration of TRs, restrictions on extraction from the forest have become tightened, without providing feasible alternatives. Liquefied Petroleum Gas (LPG) stoves are made available by the FD in some villages, but many households cannot afford to refill the cylinders. Fodder for cattle, indispensable for predominantly agrarian communities, cannot be grown in farms due to small farm sizes, nor can the village residents afford to buy fodder.

Reasons for Forest Change

All forest patches in the 20 selected villages were under the RF category. Four out of ten village communities indicated that deforestation was due to the clearing of forest land for farming and the dependence of the villages on forest products. Two out of ten village communities said that the forest was clear felled by the FD as per working plans (i.e., five–ten years plan of forest division), mainly to create plantations of teak (*Tectona grandis*) and mixed species. Three out of ten village communities identified both causes. One village mentioned that deforestation took place because of illegal logging as the forest patch is situated close to the national highway. Interview data showed that deforestation was also due to unsuccessful plantation programs, conducted by the FD under their working plans, where trees were cut before the plantation process. Forests were also cleared for timber harvesting and for the construction and expansion of roads.

Eight out of ten forest patches were under the RF category, and the others were under the PF and FDCM category. Four out of ten village communities said that strict rules enforced by the FD and the plantation of teak are the main reasons for reforestation. People in the selected villages stated that they found forest plantations to be an advantage because they provide seasonal employment. Two out of ten village communities were actively involved in the regular monitoring/patrolling of the forest and also in developing the mixed plantations initiated under the JFM. In other villages, reforestation occurred as a result of plantation activities, and of strict enforcement of the limits on forest access by the Forest Department. Yet, village residents described a general disinclination to protect, monitor, and limit use once protection restrictions were imposed. Villagers indicated that given the lack of alternate sources that could be used to satisfy their requirements from the forest, they needed to resort to actions such as bribing of forest guards for forest access. Strict enforcement of rules has led to frequent conflicts. Rather than reducing their forest use, people moved elsewhere to less protected forests, where restrictions of use were reduced, and monitoring was less frequent or not as strict. People also said that the monoculture plantations raised by the FD (mostly teak) were not beneficial for them as they could not access non-timber products, and lacked other livelihood and subsistence support, except employment during the plantation process.

Discussion

This study examined the forest cover transformation and modification in a dry deciduous forest landscape within Maharashtra, India, connecting two important PAs, the Tadoba-Andhari TR and the Pench TR, between the years 1977 and 2011 (Figure 2.4). The findings show that while PAs are well conserved, the pressure on forests outside these areas is high. There has also been an increase in the percentage of DF cover within the PAs and a decrease in the percentage of DF cover outside the PAs. Additionally, outside the PAs, the percentage of area in OF and NF categories has increased.

This study demonstrates the importance of the long time series provided by the Landsat satellite images for understanding the long term trends of forest change in India, and of examining the impact of PAs on forest protection at a landscape scale. In doing so, this research builds on previous research studies on forest change in the Pench and Tadoba-Andhari TRs (Mondal and Southworth 2010; Nagendra et al. 2006; Nagendra et al. 2010) that examine deforestation and regrowth in these PAs, as well as the region in the immediate periphery. Extending the study to the landscape level, this study demonstrate the importance of combining RS using GIS maps of management boundaries and interviews with the local communities, to better understand the impact of PAs on forest change at a landscape scale: a matter of increasing global concern.

Linking satellite data with community interviews across twenty villages, representative of different categories of population density as well as different trajectories of forest change, this study find that the increased level of strict conservation has led to forest protection within PAs. Yet this has also resulted in a pressure shift outside PAs boundaries to other types of forests, which are now under even more severe threat than before. Surveys show the continued dependence of local communities living in this landscape on the forests for livelihood, as well as for non-economic uses.

In 1977 only four PAs had been established, while five additional PAs were created after 2010 (Table 2.2). Yet, even in the less protected RF, PF, and FDCM forests outside the PAs (TRs, WLSs, and NPs), forests have been subject to higher degrees of protection, with greater patrolling, a larger number of forest staff, and greater enforcement of restrictions on access to the forest. Despite this, forest cover in RF and PF is declining.

Forest degradation is frequently attributed to population increase, and to the high dependency of local communities on the forests (Karanth and DeFries 2010). However, deforestation could occur because of other causes as well. PAs are embedded within a larger multifunctional landscape, where community interviews indicate that village residents have not reduced their dependence on forests, but rather, transferred their dependence to less protected forests. Forests also continue to face threats due to the growing market demand for forest products, which also encourages the growth of monoculture teak plantations by the FD (Dewi et al. 2013). Thus, central Indian forests form a landscape of contrast, where there are several usage and control mechanisms existing in a single region which acts as a forest corridor for wildlife. The approach employed by the state has been to restrict people from using the forest via the creation of new PAs, expansion of established areas, and strengthening of rules limiting forest entry and use. This appears to be working within parks, but with the consequence of increasing forest degradation outside the parks. Interviews with villagers also indicate that deforestation is not only an outcome of increased forest use and high population demand with no alternate opportunities, but also that it takes place in RF areas due to clear felling under the FD working plans. Furthermore, reforestation frequently fails as a consequence of unsuccessful plantation programs, or results in the creation of monoculture teak plantations with little biodiversity or local-use value.

The FD typically manages the forest in a bureaucratic manner, justified for enhancing ecological services and biodiversity conservation, but with the challenges of rent seeking, driven by institutionalized incentives (Fleischman 2014). The FD gains revenue through the regular felling of trees in selected beats/coupes, and via plantations, usually of eucalyptus and teak. Despite claims of ecological services being enhanced by forest plantation, other research has demonstrated the problems of forest degradation and ecological damage resulting from such activities (Afreen et al. 2011; Chaturvedi et al. 2011; Das 2010). Thus, market-driven plantation based projects are problematic, and more attention should be given to plantations to meet local conditions (Vatn and Vedeld 2013). Teak plantations may provide short term economic benefits through wage labour earnings, but monocultures adversely affect the livelihood of communities dependent on a range of non-timber forest products that do not grow in such plantations. Teak plantations also impact the ecology of the landscape, converting a biodiverse dry forest into an area where tree cover is protected, but with low ecological value in terms of their overall support of wildlife, bird, and insect diversity (Mondal and Southworth 2010).

There is need to better understand the complexities of landscape change before embarking on continued declarations of new and expanded PAs. The boundaries created by the FD seem to provide increased forest protection within TRs, WLSs, and NPs. However, ironically, they seem to exacerbate forest conditions in forests with lower levels of protection, where a pressure shift plays a dominant role in deforestation and forest fragmentation at the landscape scale, in the backdrop of increased conflicts between forest residents and forest management authorities.

This research can help address larger questions of how different forested patches, governed by a variety of management approaches ranging from strict conservation to more open areas, need to be integrated within regional landscape planning across a large spatial extent in order to facilitate conservation processes over the long term. Incorporating a variety of institutions including strict PAs as well as community institutions, could strengthen the resilience of forests outside the PAs (Schwartzman et al. 2010; Wikramanayake et al. 2011). Such planning has been implemented in Nepal, for instance, where despite the almost complete cessation of park monitoring and a spike in poaching between 2002 and 2006 because of civil violence, tiger and rhino populations were able to persist—most likely because of landscape level connectivity to Indian parks (Wikramanayake et al. 2011). Similarly in Indonesia, research indicates that poaching-related depletions in specific PAs can be offset by migration from other landscapes if the connectivity between reserves is maintained (Linkie et al. 2006). In this landscape mosaic of different protection categories, broader approaches, that involve local communities with forest protection and in decision-making about the nature of forest management outside the strict PAs, need to be strengthened and enabled via a strong policy focus.

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Chapter 3:

Protected area expansion and institutional enclosure increases forest fragmentation

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Chapter 3:

Protected area expansion and institutional enclosure increases forest fragmentation

Introduction

Large scale transformations of the earth's land surface have taken place due to human activity, leading to severe forest degradation and fragmentation (Foley et al. 2005). Globally, 70% of forest cover is within 1 km of the forest's edge, leaving it highly susceptible to degradation (Haddad et al. 2015). Forest fragmentation can lead to reduced biodiversity and severely impact ecosystem services (Fahrig 2003). Hence, forest landscape connectivity is very important for viable wildlife populations. For instance, species extinction rates are higher in fragmented forest patches (Gibson et al. 2013) as fragmentation constraints animal movement and habitat selection (van Langevelde 2015). So far, most conservation efforts have beenfocused on protecting forest cover, with an emphasis on protected areas (PAs). However, there is an equally important need to conserve forests outside PAs to maintain forest connectivity (DeFries et al. 2005). Yet, forests outside PAs are comparatively neglected in terms of forest policy and management, despite being under greater threat from human activity (Karanth and DeFries 2010; Nagendra et al. 2010).

Forest protection is challengingespecially in human-dominated landscapes, such as most of the present day tropical forests. India contains some of the most biodiverse forests in the world, but has faced substantial forest loss in recent decades. The total loss of forest area in India was around 0.25 million km^2 between 1930 and 2013 (Reddy et al. 2016), while globally between 2000 and 2012, the loss of forest area was 1.71 million km^2 (Riitters et al. 2016). This forest loss is accompanied by extensive forest fragmentation. While there has been substantial remote sensing research on the impacts of PAs on forest protection (Nagendra et al. 2015), there has been limited attention towards understanding the social-ecological processes and policies that lead to forest fragmentation. This calls for the coupling of remote-sensing based studies of patterns of forest change with social and institutional research on the driving processes – i.e. establishing the link between process and pattern (Nagendra et al. 2003).

In India, forests are managed by the Forest Department (FD) (Guha 1983)which functions in a hierarchical manner that is typical of most bureaucratic agencies of the State (Fleischman 2015; Guha and Gadgil 1989). Conservation efforts in India have been largely PA-centric and presently there are 733 PAs in India (http://www.wiienvis.nic.in/Database/Protected_Area_854.aspx). Around 275 million people in India are dependent on forests within and outside the PAs for their livelihoods (Fisher et al. 1997).

There is a need to understand the role of forest management on forest fragmentation at a regional scale, looking at the larger landscape connecting forest PAs with forest patches outside PAs. A forest corridor connecting two important Tiger Reserves (TRs) – Pench and Tadoba-Andhari TRs in central India was selected, located in the Indian state of Maharashtra. Through an interdisciplinary approach combining satellite remote sensing and institutional interviews in selected villages, two research questions were addressed to link ecological (forest fragmentation) pattern with institutional (forest management) process:

1) What kinds of forest fragmentation are observed within and outside PAs?
2) How does increasing forest enclosure impact local communities?

Institutional enclosure

In the selected site, there are nine PAs: two TRs, six Wildlife Sanctuaries (WLSs), and one National Park (NP) (Figure 1.2). Four PAs, namely, Pench TR, Nagzira WLS, Navegaon NP and Tadoba-Andhari TR have existed since 1970s (some have changed management designations and boundaries over years), whereas Mansinghdeo, Koka, Umred-Kandarla, New-Nagzia and Navegaon WLSs were established after 2010 (Figure 1.2). A rise in their numbers has led to an increase in restrictions on forest use within PAs and around their periphery. Outside PAs, the number of forest administrative sub-units - forest ranges, rounds, and beats have increased steadily over time. Thus, a larger number of FD staff now monitors smaller areas of forests (Agarwal et al. 2016). Both within and outside PAs, the entire forested landscape in this region has experienced an increase in institutional enclosures. This has led to greater control of the forests by the FD with increased restrictions on forest access and use by local communities.

The establishment of five new PAs increased the spatial extent of PAs in the landscape by 746.5 km^2. this forest area came from forest patches under Reserve Forest (RF), Protected Forest (PF), and Forest Development Corporation of Maharashtra (FDCM) categories (Table 3.1). Forest area of 1585.76 $km^2$was also added to buffer zones established around TRs. Local communities living in buffer zone areas faced an increase in forest restrictions imposed by Tiger Task Force officials. However, establishment of buffer zones led to eco-development programs that provided employment opportunities to the local community.

Table 3.1. Area transferred from various forest management categories to PAs

Area	Year	RF (km^2)	PF (km^2)	FDCM (km^2)	Other govt. land (km^2)
Koka WLS	2013	--	2.51	97.62	--
Navegaon WLS	2012	109.44	--	13.32	--
New Nagzira WLS	2012	25.48	--	125.86	--
Umred-Karhandla WLS	2012	61.86	116.42	--	0.09
Mansinghdeo WLS	2010	172.95	9.64	--	11.31
Pench TR buffer zone	2010	342.27	45.15	--	96.54
Tadoba-Andhari TR buffer zone	2010	587.24	113.04	--	401.49

Materials and Methods

Forest fragmentation analysis

Landsat images from 1977, 1990, 1999, and 2011 were classified into dense forest, open forest and non-forest category using supervised classification performed in ERDAS Imagine™ (9.2, ERDAS Inc., Norcross, GA, United States) software with average accuracy of 91.88%. The details of the classification are available in Chapter 2.

The images were reclassified into forest and non-forest classes for fragmentation analysis using Riitters fragmentation model. The modelhas been widely used to understand global, regional, and local fragmentation patterns (Chakraborty et al. 2017; Riitters et al. 2002; Wade et al.

2003). The model is based on the following equations, that are applied in 3x3 moving pixel window (Riitters et al. 2002; Wade et al. 2003).

Forest Density (FDens) = Nf / Nw

Where, Nf is number of forest pixels and Nw is total number of pixel. FDens is the proportion of forest pixel within the selected window size. A lower value of FDens indicates poor local forest density, and is one indicator of fragmentation.

Forest Connectivity (FConn) = (F-F) / (F-F)+(F-NF)

Where, F-F is the number of forest pixels paired with another forest pixel and F-NF is the number of forest pixels paired with a non-forest pixel. Lower values of FConn indicate lesser connectivity between forest pixels, and provides a second indicator of forest fragmentation. Both FDens and FConn range from 0 to 1.

Based on FDens and FConn values, the Riitters index divides the forest category into core, perforated, edge and patch classes (Riitters et al. 2002). A forest class is termed as core when the FDens value is more than 0.9; perforated when FDens is more than 0.6 and greater than the FConn value; edge when FDens is more than 0.6 and less than the FConn value; and patch when FDens is less than 0.6 (Riitters et al. 2000). Next, subsumed areas are classified as edge into the patch class, as the percentage of edge was negligible in this landscape, less than 1%.
Riitters forest fragmentation model was compared across different forest management institutions found in the landscape: PA, FDCM, RF and PF. There were exchanges of areas among these institutions over time, which makes an exhaustive cross-temporal comparison difficult. In order to understand the fragmentation process within each of the management category, the analysis was restricted to patches that have not undergone changes in designation (among these four categories) and boundary (since 1975). This subset constitutes around 80% of the studied landscape (Figure 3.1).

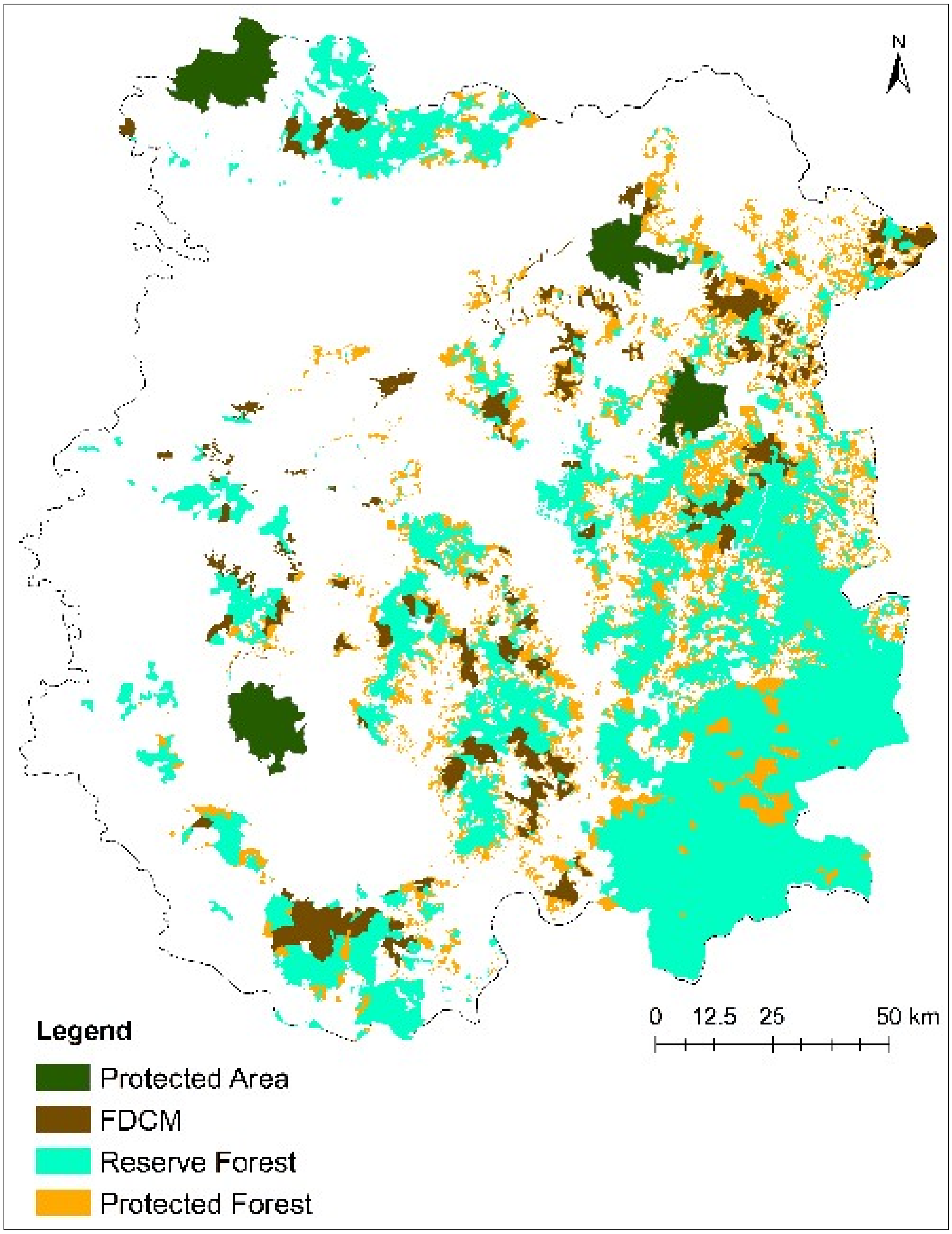


Figure 3.1. Boundaries of forest management institutions that have remained constant since 1975

(Note: Forest Department of Maharashtra has provided the spatial layers in shapefile format, which have been used to create these maps).

Impact of forest management strategies on local communities

In order to understand the impact of forest management strategies on local use of forest, semi-structured focus group discussions of 3–5 hours were conducted in 20 randomly selected villages from areas that were forested in 1975, but which later experienced deforestation (10 villages) and reforestation (10 villages). These were further stratified to represent the existing gradient of population size. Details about random selection of the villages are discussed in Chapter 2. In group discussions, people representing different groups, typically a mix of elderly men (aged 70–80 years) and young to middle aged men (25–50 years old) were present. Women were interviewed separately to ensure adequate representation. Questions focused on the rules and norms of forest resource uses, and of formal as well as informal institutions of forest management. Along with that, questions relating to changes in forest access over time, and changes in peoples' strategies of forest use due to changes in the level of restrictions were also asked.

Results

Fragmentation Analysis

In PAs, FDens and FConn values are close to 1, which shows that forest pixels are high in proportion and also well connected. There was an increase in the percentage of the perforated class between 1970 and 1990, which reduced in the subsequent years; while percentages of core and non-forest remained constant over time (Figure 3.2, 3.3, 3.4.a, 3.4.b, and 3.4.c).

Outside PAs, in FDCM areas (details in Chapter 1), the FDens value mostly ranged between 1-0.8 over time depending on the status of plantation (i.e. whether trees were standing, or logged). In 2011 the FDens value went down from 0.9 to 0.8 but the FConn value remained constant between 1999 and 2011. This is because of an increase in percentage of non-forest in 2011, while connectivity remained similar among the forested areas. However, overall, the density of forested areas decreased, due to some conversion of forest to non-forest in 2011 (Figure 3.2, 3.3, 3.4.d, 3.4.e, and 3.4.f).

In RFs, the FDens value is approximately 0.9 in all the images studied, except in 1977 where the FDens is 1. The value of FConn remained constant at 1 from 1977 to 1999, and reduced to

0.8 in 2011. The connectivity value remained constant till 1999 even though there was decrease in FDens from 1 to 0.9. This is because there was increase in the percentage of non-forest and its effect is visible in 2011, where the connectivity reduced to 0.8 with increase in percentage of non-forest (Figure 3.2, 3.3, 3.4.g, 3.4.h, and 3.4.i).

In case of PF, substantial variations were found in proportion of forest pixel over time, which decreased from 0.6 in 1977 to 0.1 in 2011. FDens of 0.1 denotes poor condition of forest and shows that the deforestation was high in PF during 2011. Similarly, the value of FConn also decreased from 0.8 to 0.5 between 1977 and 1990 after which it remained constant till 1999. In 2011 the FConn value increased to 0.6 even though the FDens was reduced to 0.1. This is because percentage of non-forest increased in 2011 as patchy forest got completely converted into non-forest and remaining pixels are connected with an index value of 0.5 in 2011 with reduction in core area in PF (Figure 3.2, 3.3, 3.4.j, 3.4.k, and 3.4.l).

Changes in FD management outside PAs

In RF, statutory provisions restrict collection of fuelwood and open grazing. However, in the past (around 1970s) this was not strictly followed, especially in areas with high forest cover. Villagersdepended on resources like grass, timber, and fuelwood for subsistence along with a number of Non-timber Forest Products (NTFPs) like Mahua (*Madhuca longifolia*) flowers and Tendu (*Diospyros melanoxylon*) leaves, largely for livelihood supplementation via sale in the market.Other NTFPs such as resins and fruits of Amla (*Phyllanthus emblica*), Bael (*Aegle marmelos)*, and Tendu are used for subsistence consumption. During the focus group discussions and interviews, villagers revealed a steady increase in restrictions on forest resource use since past 2 decades: they were not allowed to take bullock carts, axes, and bicycles inside the forest. They were also not allowed to take logs from the forest, while fuelwood and NTFPs could be taken only as headloads.

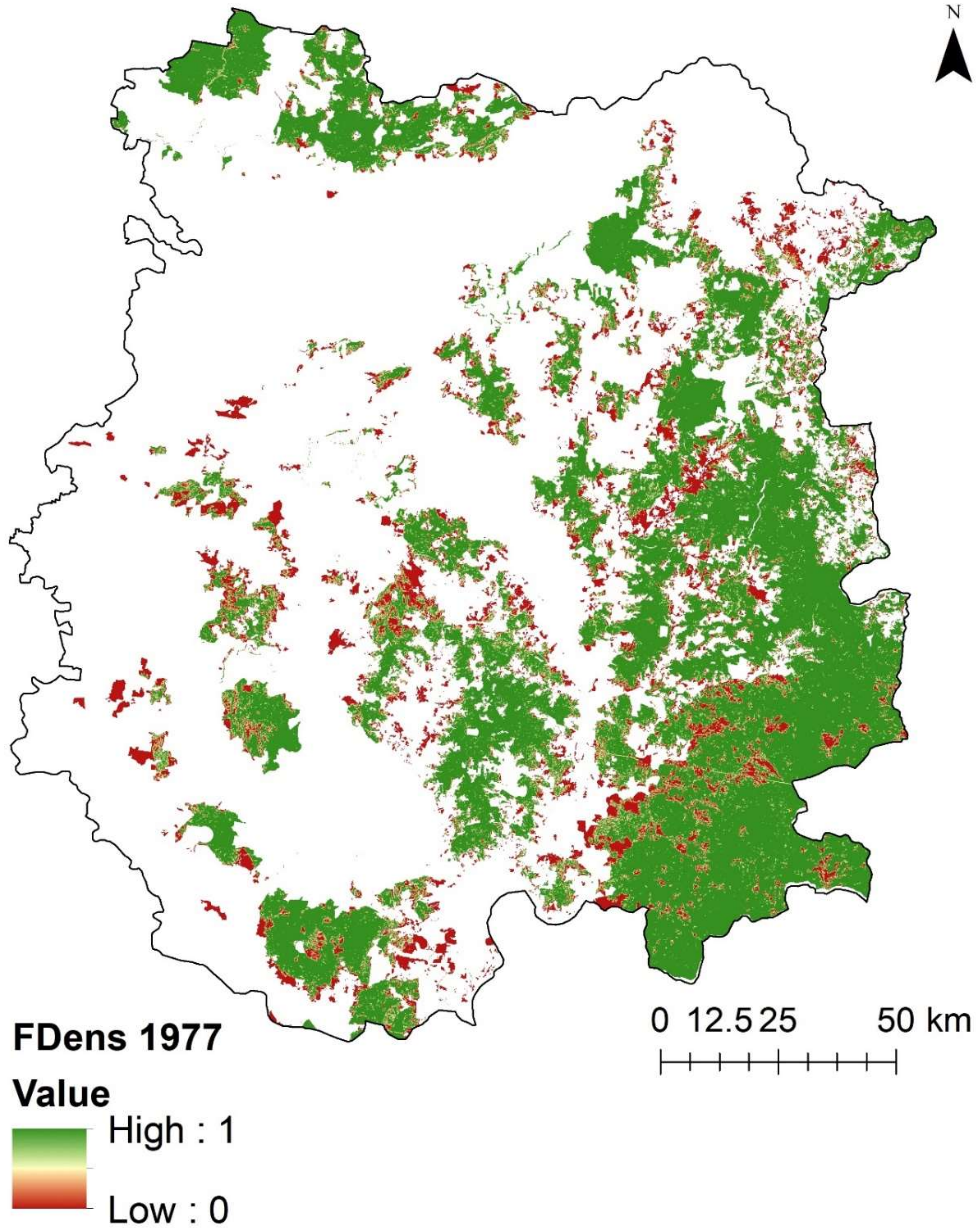


Figure 3.2.a. Forest Density map of 1977

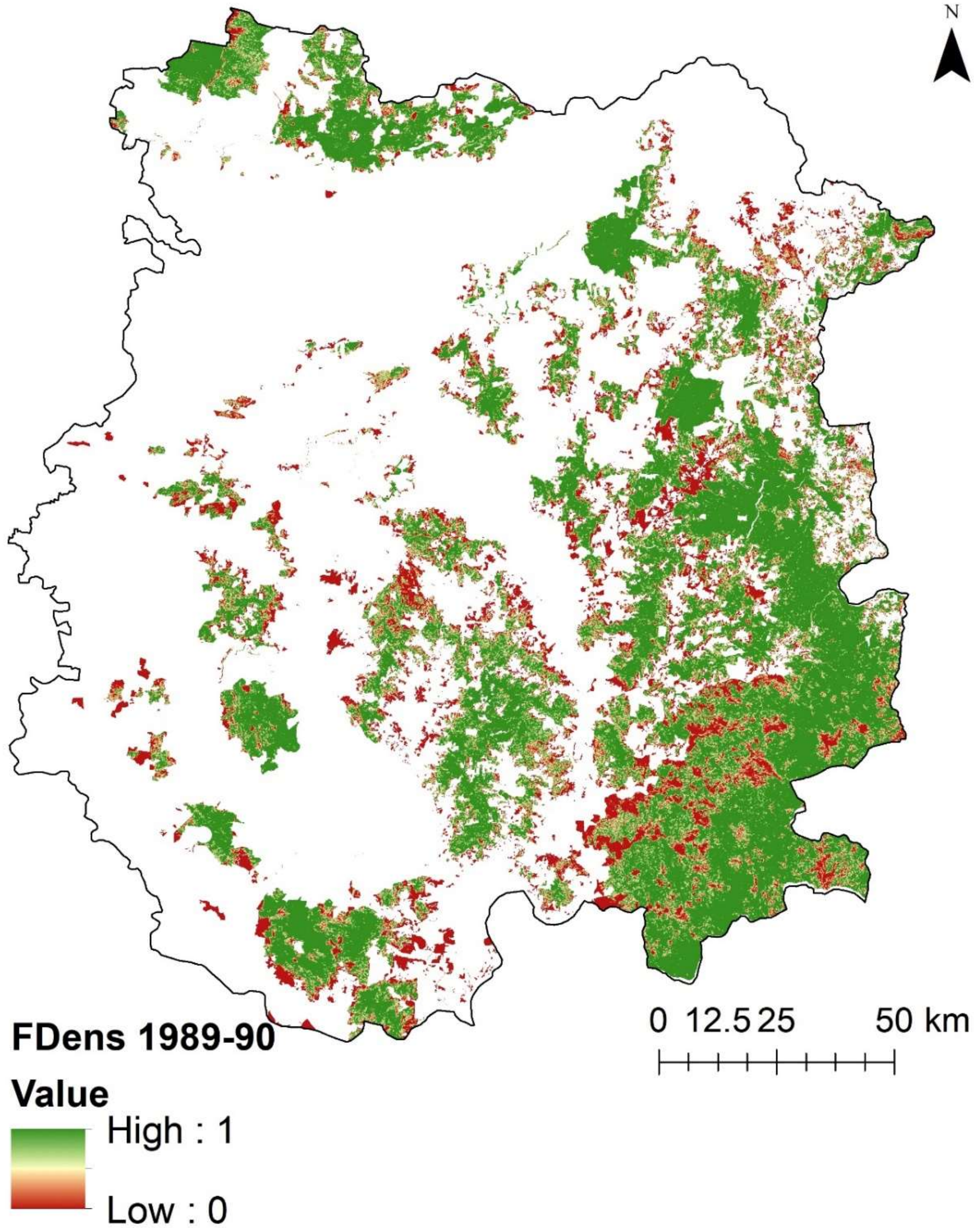


Figure 3.2.b. Forest Density map of 1989-90

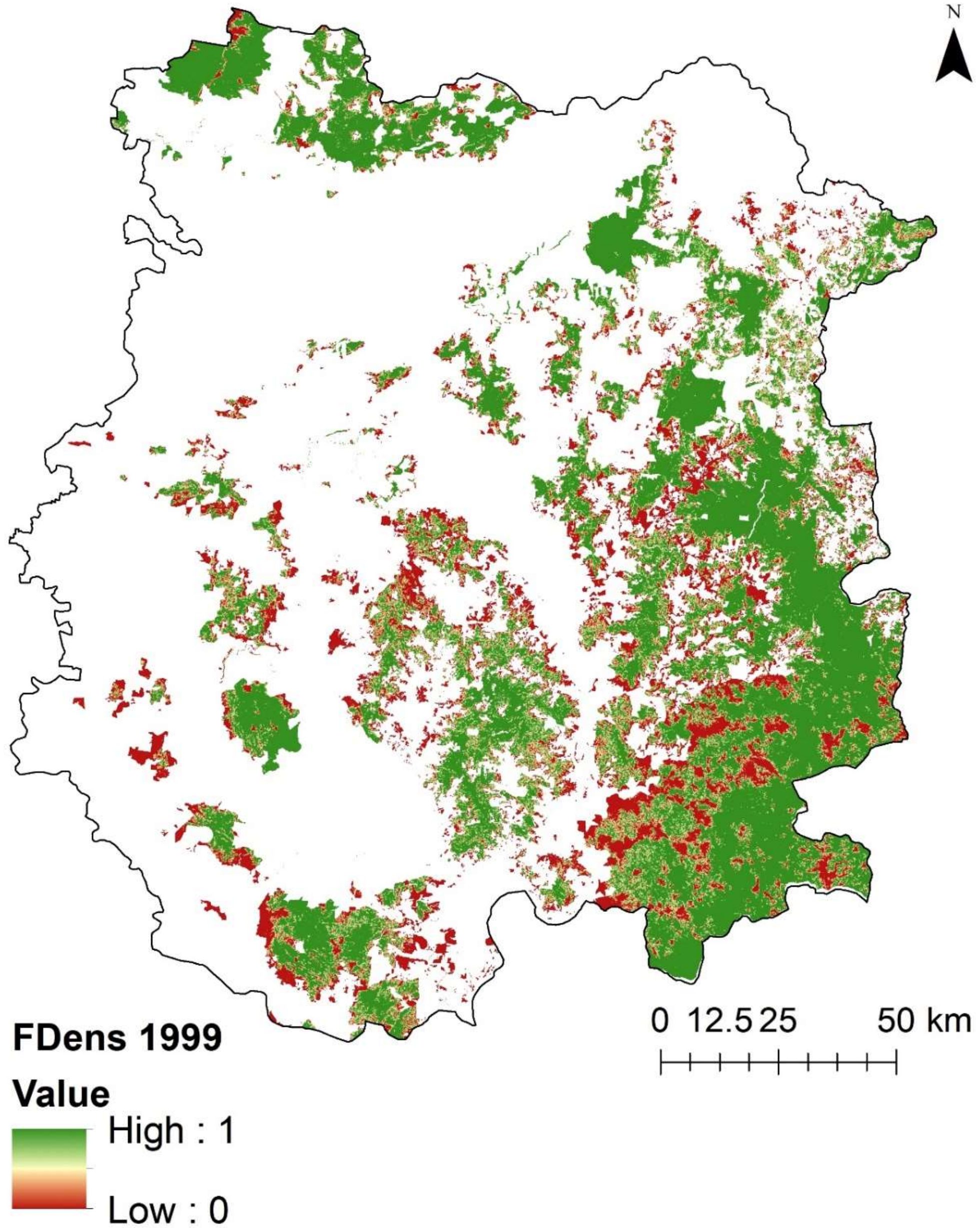


Figure 3.2.c. Forest Density map of 1999

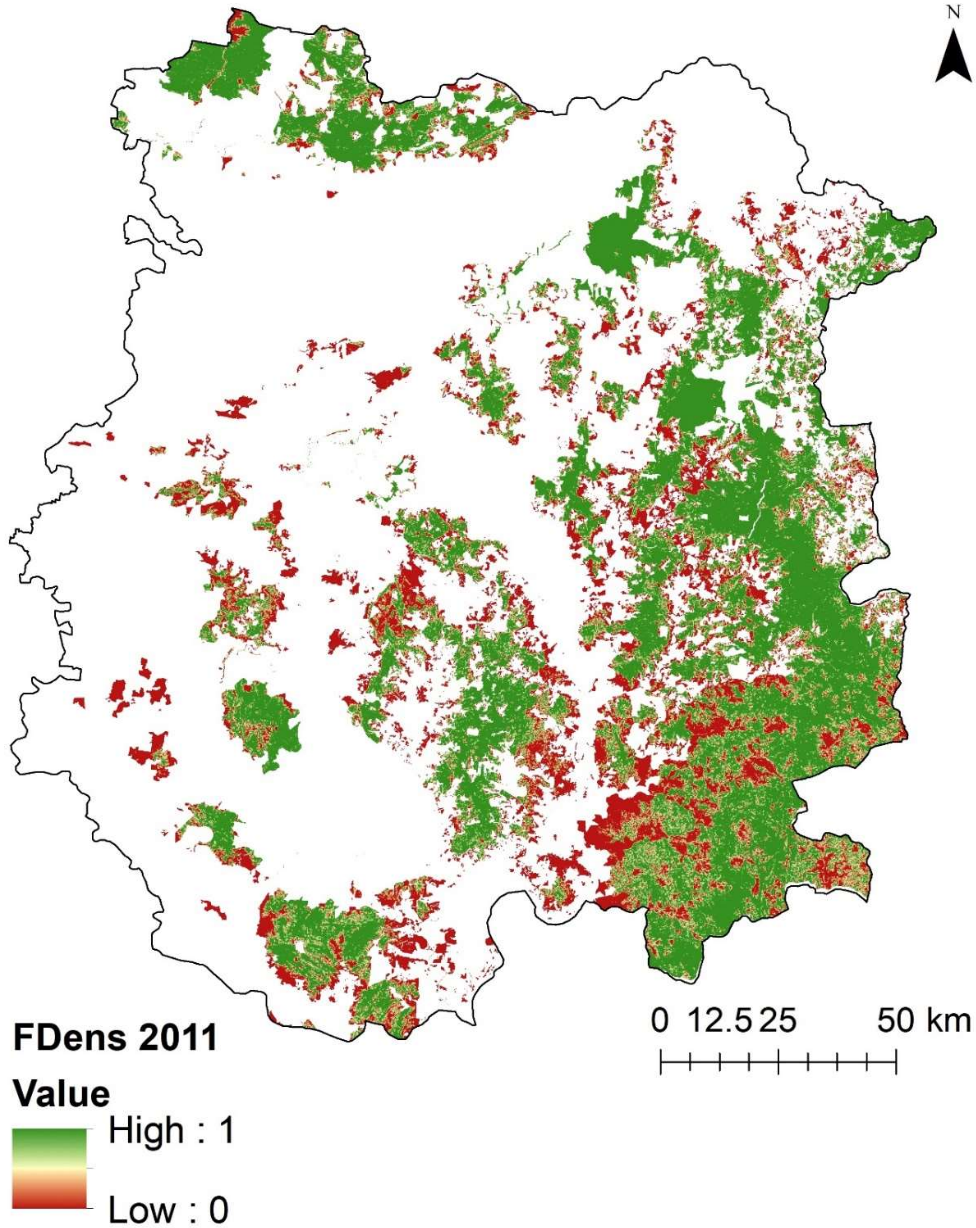


Figure 3.2.d. Forest Density map of 2011

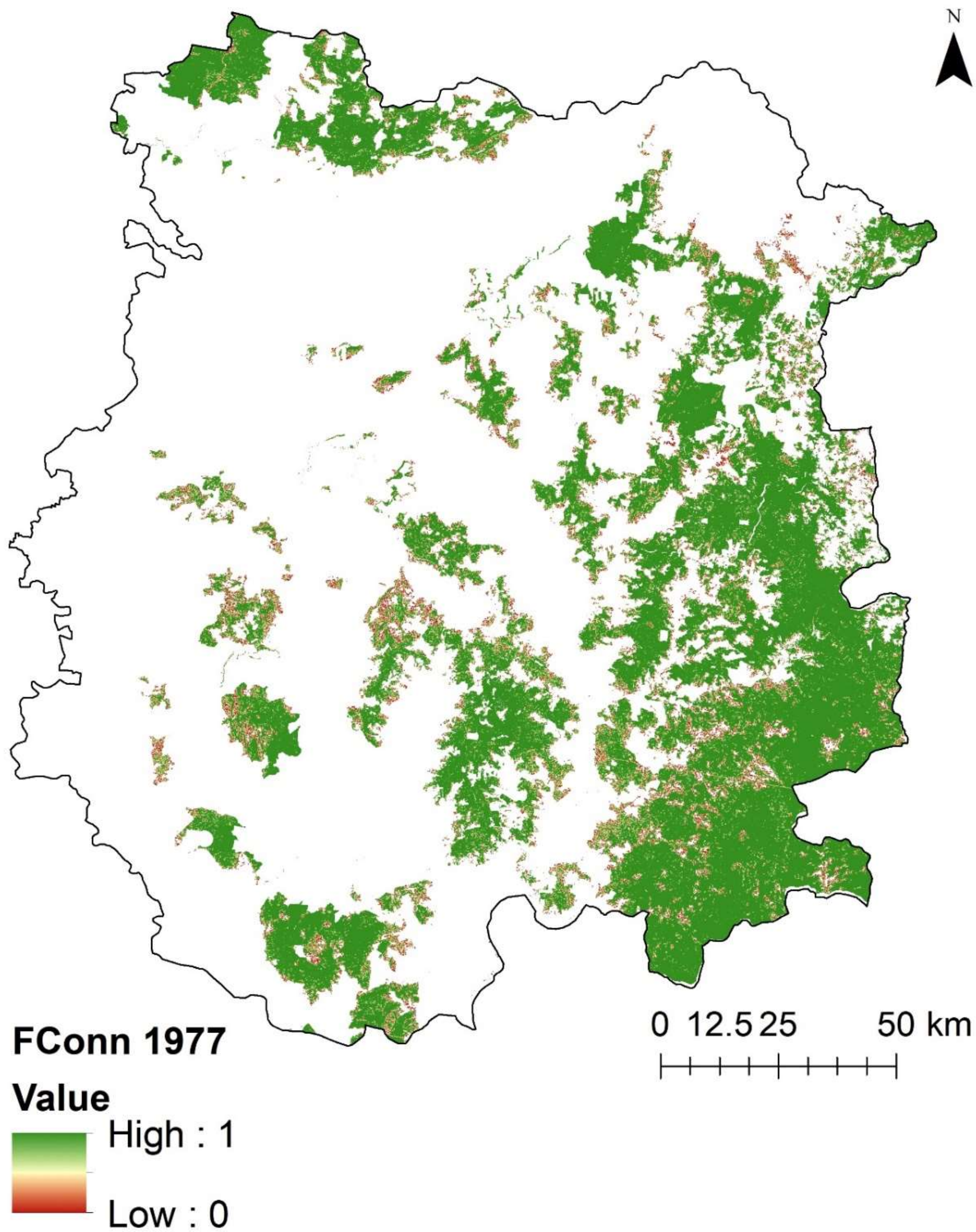


Figure 3.3.a. Forest Connectivity map of 1977

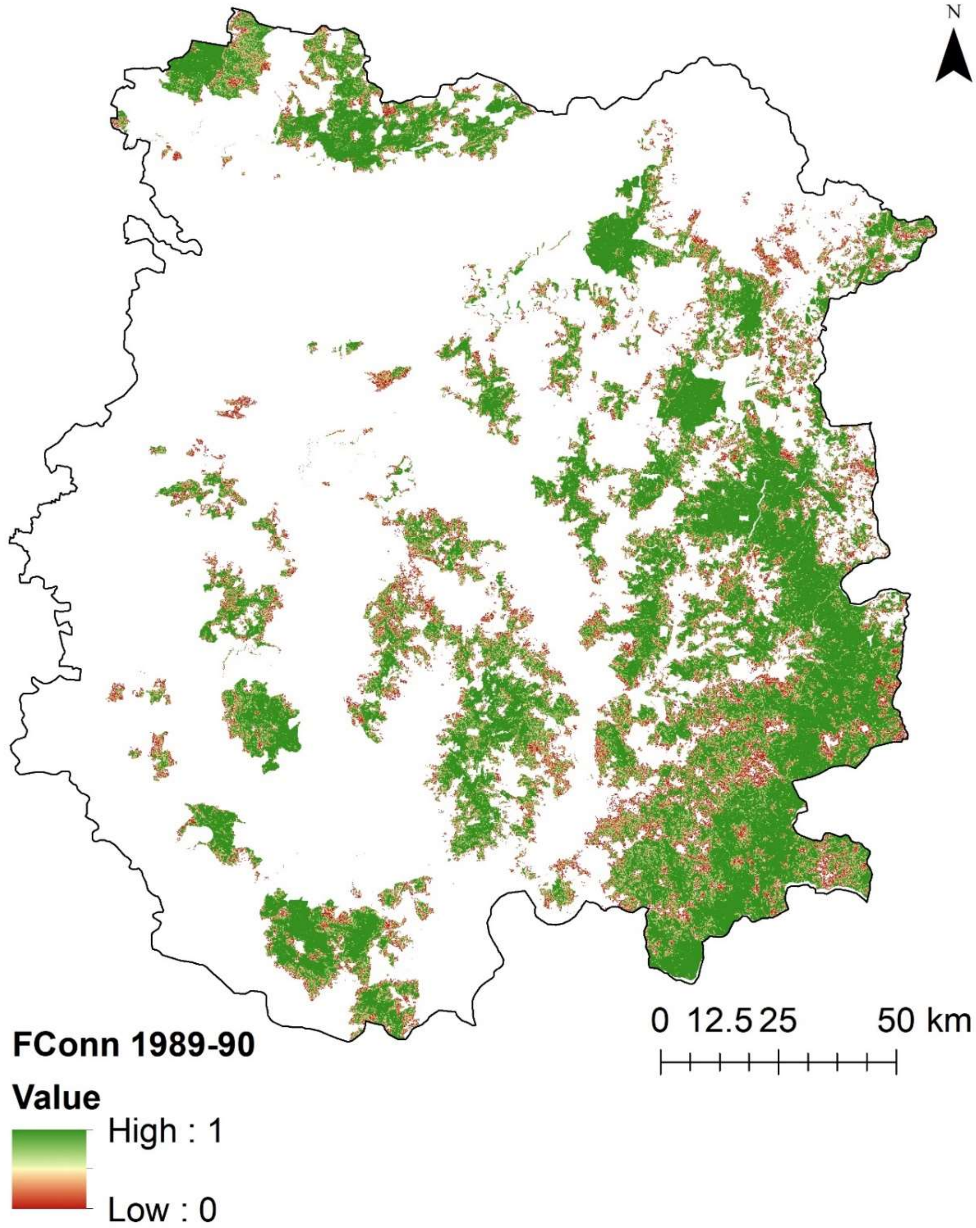


Figure 3.3.b. Forest Connectivity map of 1989-90

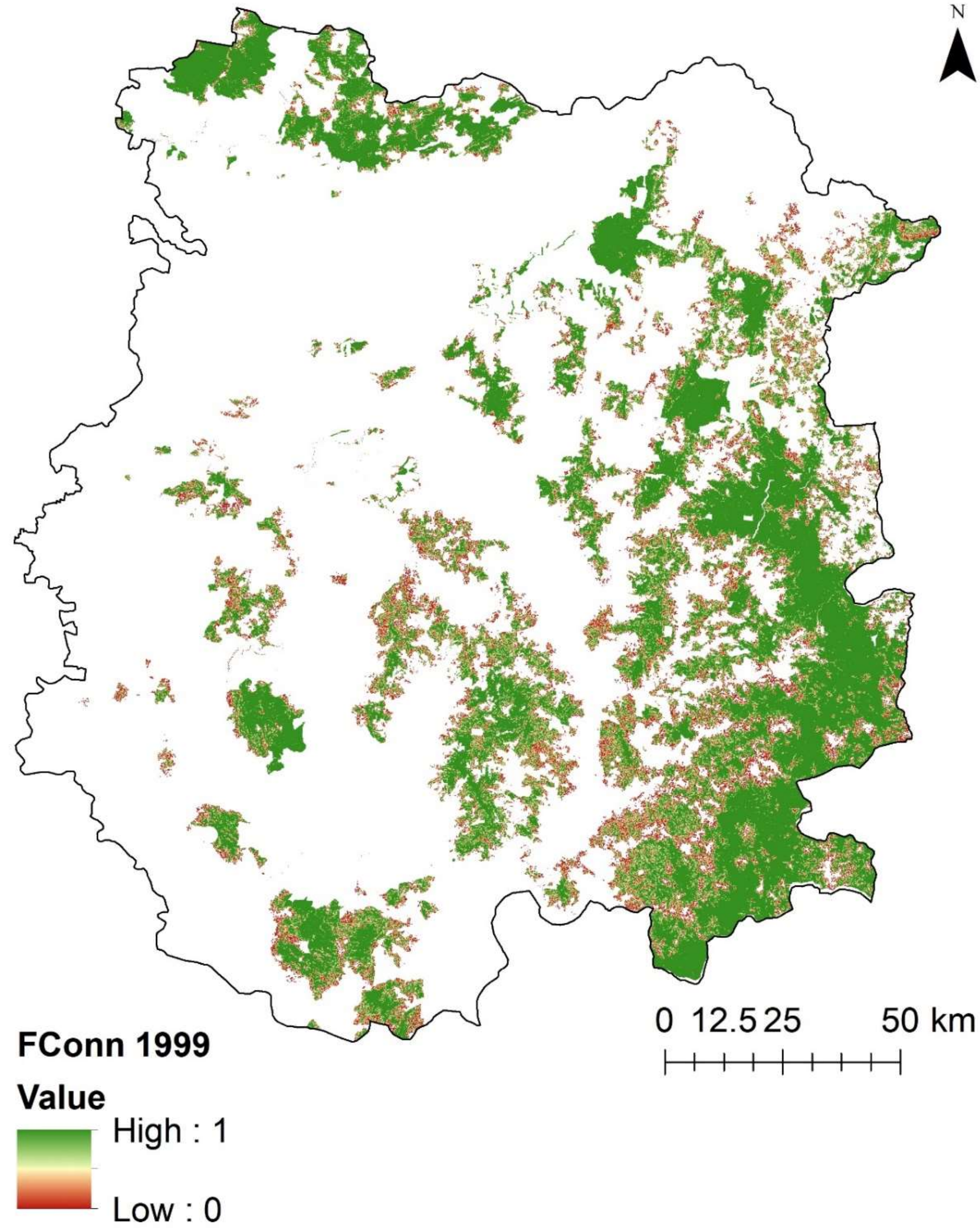


Figure 3.3.c. Forest Connectivity map of 1999

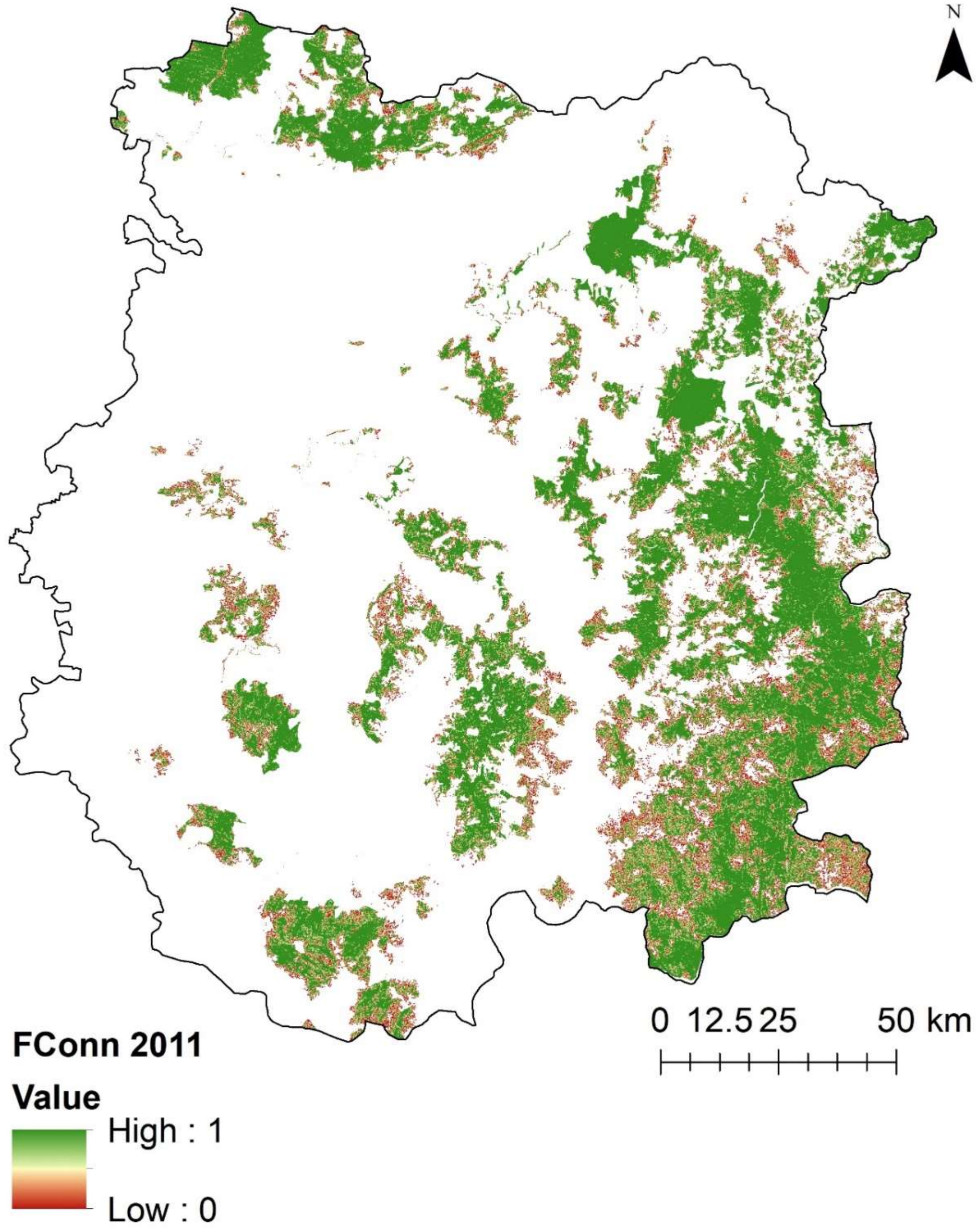
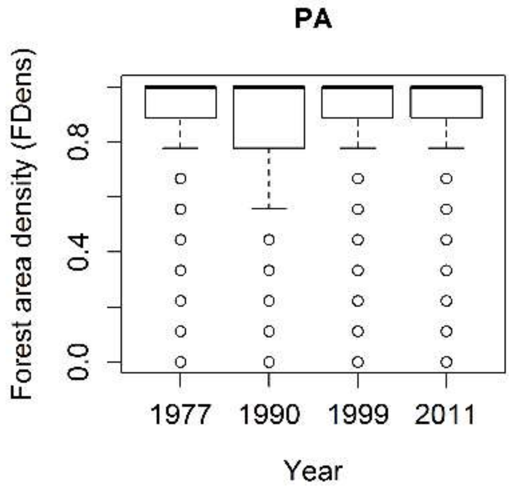
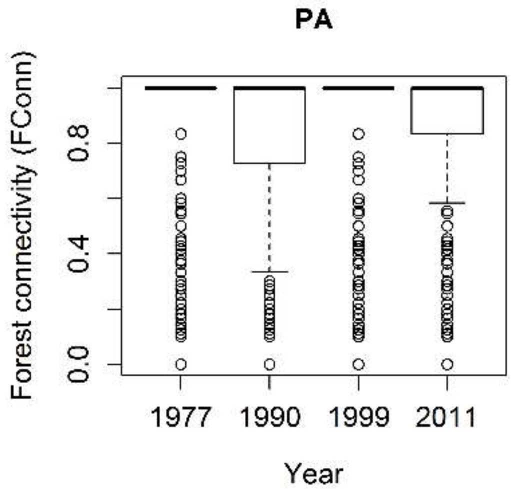


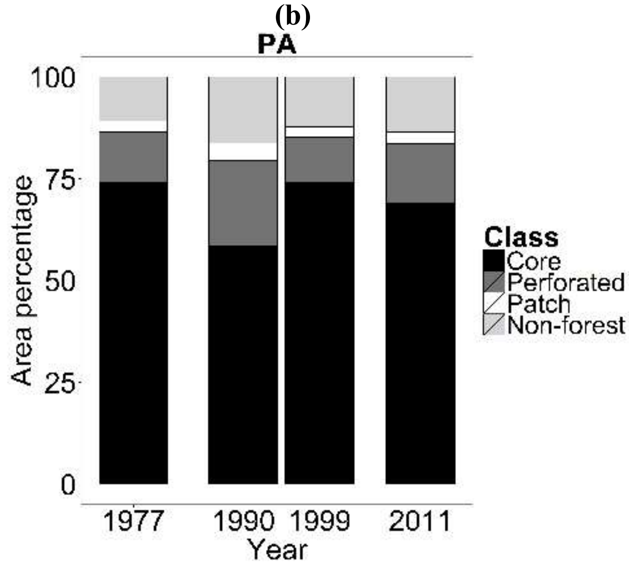
Figure 3.3.d. Forest Connectivity map of 2011



(a)

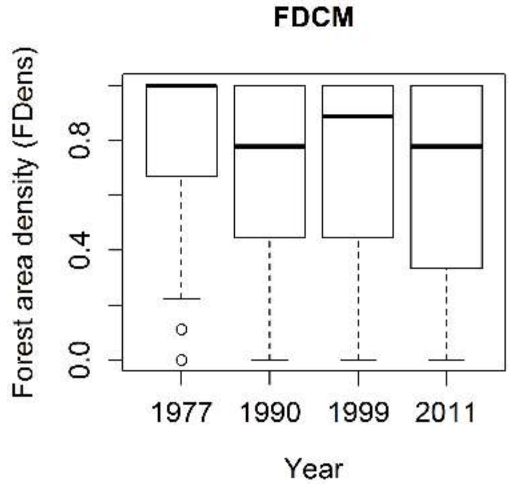


(b)

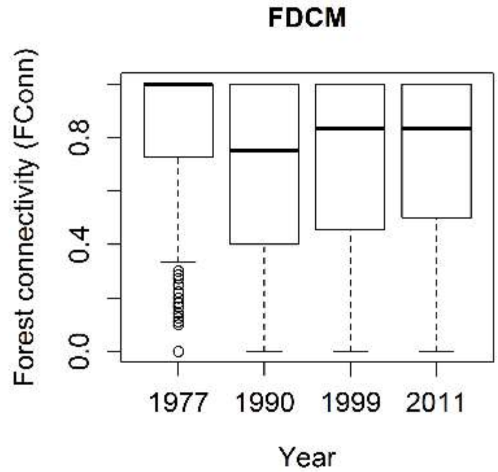


(c)

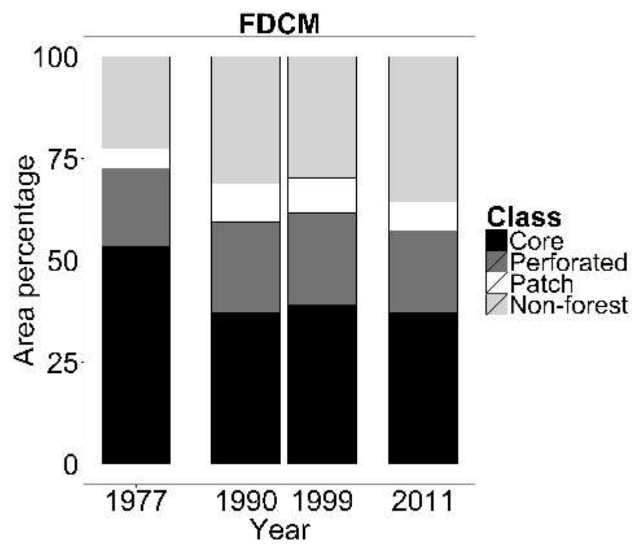
Figure 3.4. (a) Forest area density (FDens), (b) forest connectivity (FConn), and (c) area percentage under Riitters forest fragmentation classes in Protected Areas



(d)

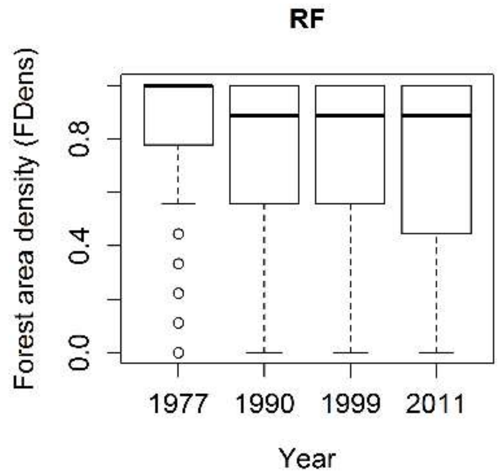


(e)

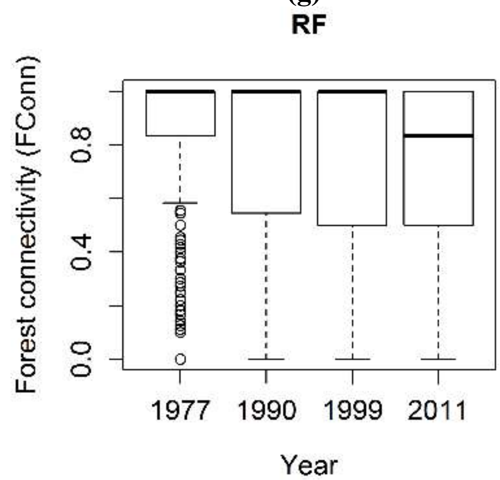


(f)

Figure 3.4. (d) Forest area density (FDens), (e) forest connectivity (FConn), and (f) area percentage under Riitters forest fragmentation classes in FDCM



(g)



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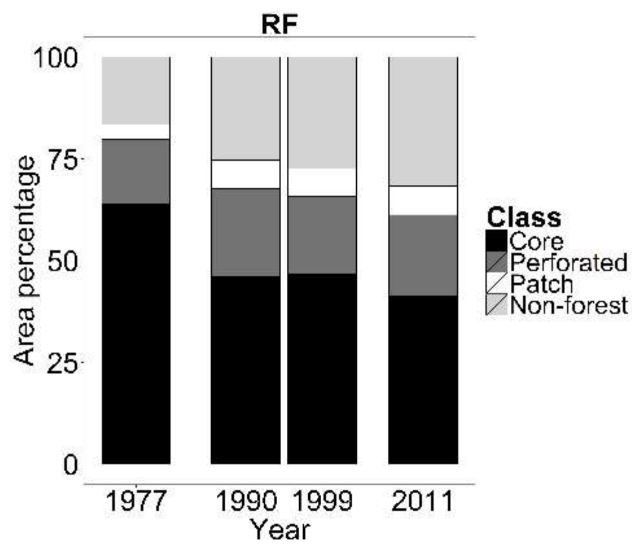
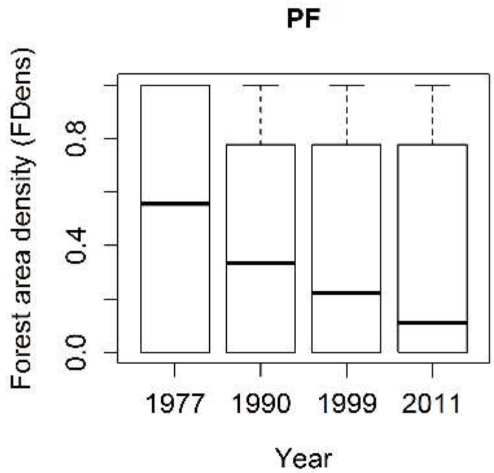


(i)

Figure 3.4. (g) Forest area density (FDens), (h) forest connectivity (FConn), and (i) area percentage under Riitters forest fragmentation classes in Reserve Forest



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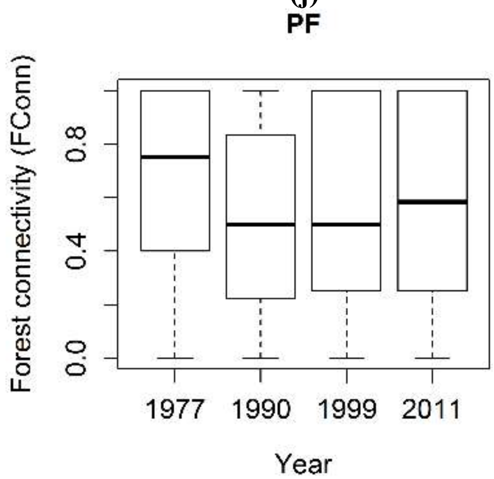
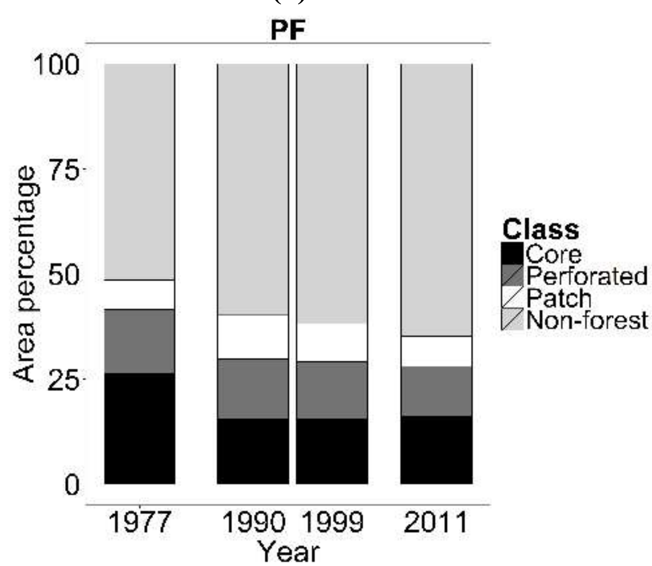


(k)



(l)

Figure 3.4. (j) Forest area density (FDens), (k) forest connectivity (FConn), and (l) area percentage under Riitters forest fragmentation classes in Protected Forest

The villagers also experienced difficulties in adapting alternatives such as, Liquefied Petroleum Gas (LPG) stoves that are made available by the FD. Many households cannot afford to refuel the cylinders. Most households cannot grow sufficient fodder for cattle because of small farm sizes or purchase it as they find it expensive. Forest patches were monitored by forest guards, and villagers indicated the widespread incidence of corruption and bribery to access forest products.

In a few villages, plantations were initiated as a result of Joint Forest Management (JFM) activities, but most were largely unsuccessful. Although local people benefited from employment during the plantation process, the villagers were not interested in monitoring and managing the forest due to the dominant presence of FD. Local respondents said that the condition of the forest has deteriorated tremendously from 1970s to the present day, and that almost all the villages have considerably less forest cover than in the 1970s. Although teak was planted in some areas, both from an ecological perspective as well as for their livelihood, these plantations were not helpful, except for a few months of transient employment that the villagers received from the FD during the time of plantation.

Changing strategies of forest access as a consequence of increased restriction

Discussion with older residents indicated that in the decades from 1970s to the 1980s, although rules were made by the FD, operational rules considered local needs and norms of use. Earlier, there was greater support by local communities in protecting the forest, but this support has waned in recent years due to increasing restrictions as well as increased enforcement of the restrictions, leading to conflict with the FD. Residents could only collect deadwood by headloads, and were not permitted to take timber from the forest. If caught violating rules, they had to pay fines. Occasionally, they also had to deal with cases registered against them by the FD. To avoid fines, many reported resorting to offering bribes to junior forest employees. By and large, people indicated that hunting of large wild animals had ceased, but trapping and hunting of small animals like hare and squirrels continues.

In 18 out of 20 villages surveyed, people said they need to travel longer distances to collect fuelwood, timber and NTFPs than they did in the 1980s (Figure 3.5). A number of reasons were cited – including increase in restrictions on forest use, forest fragmentation leading to greater distance to travel between forest patches, and the degraded condition of forest patches. Most travel is done by bullock cart or bicycle. However, according to RF rules, the use of the bullock cart and bicycle is not allowed inside the forest. People dealt with this by bribery, or by accessing those locations where monitoring was lower, and the chances of getting caught in the act of violation were therefore reduced.

People were aware of the FD rules, but did not necessarily follow them. They covered larger distances for collection of forest resource based on their convenience and restrictions, while balancing the chance of getting caught or the need to pay a bribe. This led to expressed distrust of the FD, with people speaking of their loss of sense of belonging with the forest, and hence their unwillingness to protect the forest or use resources sustainably. In nine villages, communities expressed a desire to regain control over their forests, and said that given a chance they would be able to manage the forest better if they could operate independently.

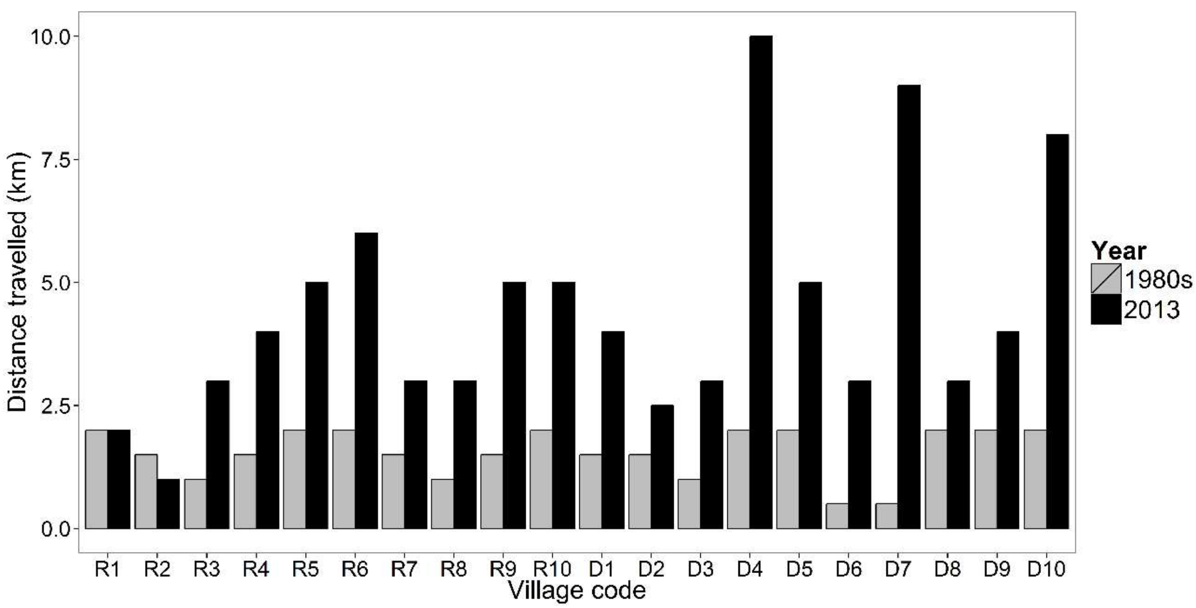


Figure 3.5. Distance travelled by villagers for fuelwood, timber and NTFPs collection in 1980s and 2013

Discussion

Dry Tropical forests represent some of the most endangered, yet biodiverse forest categories, with 97% of the world's remaining tropical dry forest at risk from human activity (Miles et al. 2006). The dominant approach of forest conservation has been the expansion of the PA system

(Davidar et al. 2010). Yet, many tropical dry forests are located in areas with high levels of human population (Karanth and DeFries 2010), often dominated by indigenous communities with a long history of co-existence with forests (Carter et al. 2012). Indefinite expansion of PA network would increase conflict between the FD and indigenous communities, making achievement of conservation goals difficult. Thus, forest conservation must be approached at a regional scale, involving a combination of PAs with stricter levels of protection, and community conservation in areas outside PAs, in order to deal with the reality of balancing conservation with social justice in human-dominated landscapes (Shahabuddin 2010).

This chapter examines the impact of forest conservation using a PA-centric State dominated approach on a central Indian forest landscape connecting two important TRs. The landscape has faced significant institutional enclosure over the past four decades, with increase in the number of PAs and strictness of protection, as well as increase in administrative subdivisions outside PAs. This has led to increase in monitoring, patrolling, and sanctioning which puts restrictions on forest use even outside the PAs. In 1970, there were only four PAs, while currently, there are nine, of which five WLSs were formed after 2010 (Figure 1.2). Large regions of the study area have been transferred from the less intensively managed categories of RF, PF and FDCM to formnew PAs (Table 3.1). There were also changes in designation of the PAs, towards increasing restrictions on forest access and use, which led to the resettlement of several villages from PAs. The number of forest administrative sub-units – ranges, rounds, and beats – outside PAs have increased over time (Agarwal et al. 2016), with an increase in forest staff – viz. range officers, round officers, beat offices, and forest guards. Thus, a larger number of FD staff now monitors smaller areas of forests.

While this strategy led to increase in forest cover within PAs, it also increased fragmentation and forest loss outside the PAs (DeFries et al. 2005). In response to increased forest restrictions and monitoring, local communities resorted to less protected forests located at a greater distance, leading to continued impact at a regional-scale. Thus, restriction on access helped maintain the forest cover and prevented fragmentation inside the PA. However, replicating similar controls outside the PA has led toloss of many unconnected forest patches particularly between 1999 and 2011 and increased fragmentation in forest corridorsbetween the PAs.

The results of Riitters fragmentation model showed that the FDense and FConn is maintained inside the PAs since 1977. There is not much change in the core area inside the PAs, whereas forest outside PA has undergone significant change, most of which are found in PF category. The FDens values kept decreasing from 1977 to 2011 in PF. PF is the least protected among outside PAs categories and has undergone maximum forest fragmentation. In case of RF and FDCM, the FDense values decreased from 1977 to 1990. The FDens value between 1990 and 1999 and then again decreased between 1999 and 2011 in FDCM. This could be because of the plantation and timber extractions projects under FDCM. There were fluctuations in FDense and FConn values in case of FDCM but they never regained the original state that existed in 1977. In case of RF the extent of core area pixels decreased between 1999 and 2011. The results support the fact that the forest inside the PA is protected and have not undergone fragmentation. Whereas, forest outside PA is getting fragmented over time. As discussed earlier restrictions from FD has intensified over time with the objective of protecting the forest outside protected areas, but this has proved ineffective in limiting forest degradation.

One way to protect forests outside PAs from fragmentation and degradation is through strengthening of local community based institutions (Ghate et al. 2013; Hayes and Ostrom 2005). There is a vast body of literature that shows participation by local communities through informal institutions can help forest protection and regrowth (Agrawal and Ostrom 2001; Ostrom and Nagendra 2006). Such studies argue that common pool resources could be efficiently managed by local communities through practices such as rights of making rules, ownership over resource and equitable sharing of benefits (Brondizio et al. 2009; Cox et al. 2010).

Yet the strategies used for forest conservation in this region are quite the opposite. Using fines and other sanctions such as confiscation of implements, the FD is imposing a 'command and control' form of management. In some cases, the department may also register legal cases against violators. Over the last three decades the area under strict control of FD has increased, through increase in the number of PAs and buffer zones, teak plantation projects, and in some cases though formation of name sake JFM committees (Sarin et al. 2003). These interventions have imposed restrictions on forest use (Agarwal et al. 2016). The focus group discussions revealed a perceptible resentment towards these institutional enclosures.

Ironically, many of these forests were once governed by traditional norms that restricted forest harvest in certain seasons, regulated excessive use, and were effective in maintaining forests for centuries (Ghate and Nagendra 2005). Taking over of forest management by the State has led to deterioration in indigenous norms and local institutions as policy makers have neglected the intrinsic motivation and traditional norms of communities (Vollan 2008).

Conclusions

This research demonstrates how landscape change, detectable from remote sensing coupled with fragmentation analysis, can be linked to social surveys to understand the underlying social consequences, thereby establishing a clearer understanding of the pattern-process linkage. Forest density and connectivity is maintained inside PAs, but has deteriorated in the area outside PAs over a period of 35 years. Despite the increasing State control over forests, this approach has not led to a greater balance between forest conservation and people's needs in this human-dominated landscape. In fact, the top-down approach of forest management has created conflict between the FD and local communities, alienating them from the forest and weakening their motivation to protect the forest.

This research demonstrates the importance of going beyond PA-focused studies to a regional approach in order to understand forest fragmentation and change at a regional-scale, in landscapes that contain a mix of forests within and outside PAs. Such interdisciplinary research helps develop a better understanding of the human factors shaping deforestation at a regional-scale. This can help design solutions that go beyond the dominant PA-centric approach, to address the reality of balancing social needs with conservation in the human-dominated and contested landscapes of the tropics.

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Chapter 4:

Exploring the relationship between remotely-sensed spectral variables and attributes of tropical forest under the influence of local forest institutions

Publication

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Chapter 4:

Exploring the relationship between remotely-sensed spectral variables and attributes of tropical forest under the influence of local forest institutions

Introduction

Ecological research is vital for establishing effective management and conservation policies for the proper governance of natural resources (Groom et al. 2006). In particular, evidence-based data on the effectiveness of conservation management typically requires a solid foundation of in-depth fieldwork. Although this is very important, field data collection is a time-consuming and expensive process (Kerr and Ostrovsky 2003). It can often be very difficult to acquire field data in remote and inaccessible places, in areas with challenging terrain, or in areas of ongoing conflict and turmoil that may be of high ecological importance.

Remote Sensing (RS) can be a valuable aid in such contexts. RS studies are conducted with the aid of satellite images whereas ecological studies involve in-depth field work, which may or may not cover large spatial regions (Kerr and Ostrovsky 2003). Predictions based solely on ecological field studies are hence spatially bounded, and often need to be complemented with broad-scale geographic data for extrapolation to the landscape or regional-scale (Chambers et al. 2007). A combination of RS and field-based ecology research has contributed immensely towards understanding ecological processes, since they facilitate research at moderate to large spatial extents in a cost-effective manner (Nagendra 2001; Newton et al. 2009). Although ecological field based research is not replaceable by RS methods, the two methods complement each other for better understanding of ecological processes. This can further be incorporated in conservation and management plans (Horning et al. 2010).

Ecological variability (heterogeneity and biodiversity) forms an important indicator of ecosystem function and ecosystem health (Gaston and Spicer 2004). Several studies have been carried out to find the relationship between remotely sensed spectral heterogeneity and ecological variability (Oldeland et al. 2010; Rocchini 2007). The Normalized Difference Vegetation Index (NDVI) and other vegetation indices have frequently been used as proxies for vegetation health and structure (Pettorelli et al. 2011; Pettorelli et al. 2005; Tucker et al. 2005). Recent studies have also demonstrated the potential for spectral heterogeneity to be used as a proxy for alpha and beta-diversity of an area, helping in the characterization of biodiversity at larger spatial scales (Rocchini 2007; Rocchini et al. 2009). However, ecological processes are complex and the relationship with spectral data may not be very straightforward. For example, it is very difficult to assess understory vegetation variability through optical RS, as such images typically capture information largely from the upper canopy. Active RS such as Light Detection And Ranging (LiDAR) technology could provide solutions to this challenge (Morsdorf et al. 2009) but typically, such images are expensive and often difficult to acquire, particularly in many biodiverse tropical environments (Nagendra and Rocchini 2008). Thus, so far, most studies have been based on moderate resolution images such as the Landsat data archive, which is freely available (Wulder et al. 2012).

Vegetation structure and variability arises not only as a consequence of ecological and bio-physical processes but is also shaped by social, economic and institutional processes (Brechin et al. 2002; Holling 2001; Ostrom and Nagendra 2006). Studies from Europe have shown that the species richness, number of dead logs, and soil nitrogen are higher in unmanaged forest patches as compared to managed forest patches, and that the forest patches differ in forest structural stages such as understory growth (Paillet et al. 2010; Sitzia et al. 2012). Institutional processes play an important role in impacting vegetation structure and variability, such as management of forest patches within as well as outside Protected Areas (PAs) (Ghate and Nagendra 2005; Nagendra et al. 2006). In this context, most research addressing the impact of institutions on forest biodiversity and variability has focused on state-administered PAs (Hayes 2006; Karanth and DeFries 2010; Naughton-Treves et al. 2005). Globally, a large extent of forests lies outside PAs and is managed by various institutional structures. Local community institutions play an important role in maintaining these forest patches (Coleman and Fleischman 2012).

India harbours large, connected forest areas with high plant and animal diversity. A large proportion of India's forest land is located outside the country's PA network (DeFries et al. 2010; Karanth and DeFries 2010). Legally, forest patches outside PAs belong to the state. These forest patches are under the formal control of the Indian Forest Department (FD), but at smaller scales may be managed by local communities through informal institutions such as sacred groves, as well as by traditional norms of local communities that relate to hunting and harvesting of forest resources (Fleischman 2015). Recently, through Joint Forest Management and the Indian Forest Rights Act, 2006, local communities have also received some *de jure* (formal) rights to access and maintain forest patches (Ghate and Nagendra 2005; Sarin et al. 2003). However, forests outside PAs are undergoing rapid changes, given their location in densely populated landscapes and face economic and political pressure (DeFries et al. 2010; Karanth and DeFries 2010; Shahabuddin and Rangarajan 2007). Conservation of these forest patches is very important for social reasons such as livelihood dependence of local communities, as well as ecological reasons including wildlife protection.

So far, remotely sensed data has been widely used to classify different types of forest and to assess changes in the forest density, diversity and distribution (Cohen and Goward 2004; Nagendra 2001). However, understanding the role of local institutions with the aid of RS is comparatively less explored. This study attempts to develop a better understanding of the relationship between spectral and ecological variability under the influence of local institutions. This can help in extrapolating the relationship between institution and vegetation to the regional level so as to provide policy inputs.

The location of this research is in a forest corridor that connects important PAs such as the Pench Tiger Reserve (TR) and the Tadoba-Andhari TR, among several others, within the eastern Maharashtra region. The focus on the forest outside the TRs that are potential corridors for biodiversity (Joshi et al. 2013). In this landscape, forest patches are managed by diverse institutional settings that range from active involvement of local communities in forest management, to co-management by local communities and the FD, and management entirely by the FD, without any participation from local communities. Several common pool resource studies have shown that there is a need for local participation in order to achieve larger conservation goals (Ghate et al. 2013; Hayes and Ostrom 2005; Ostrom 2003; Pretty and Smith 2004). Previous research in this region has argued that community institutions are important for protection outside PAs (Ghate et al. 2013). However, there has been limited assessment of this hypothesis.

In this study, Landsat imagery was used to understand the relationship between spectral heterogeneity and vegetation variability in the presence or absence of local institutions. The specific objectives are:

1. To explore the relationship between remotely-sensed spectral variables such as NDVI, and attributes of forest vegetation, in particular those of species richness, tree density, and biomass.
2. To investigate how management by local (community) institutions influences vegetation diversity.
3. To examine whether the relationship between remotely-sensed spectral variables and attributes of forest vegetation diversity differ in forests managed with and without the participation of local communities.

Materials and Methods

Field Data Collection

Fieldwork was carried out from October 2013 to February 2014 (during winter), in eight forest divisions (administrative categories) namely Nagpur, Bhandara, Gondia, Brahmapuri, Wadsa, Gadchiroli, Chandrapur buffer and Chandrapur non-buffer (Figure 4.1). In order to separately manage some forests within the buffer region of Tadoba-Andhari TR under the eco-development policy, the Chandrapur forest division was recently divided into buffer and non-buffer forest divisions.

Two villages were selected in each of the eight forest divisions. The snowball sampling method was used to gather information from FD officials, local NGOs and other key informants regarding local forest institutions. In order to focus on institutional effects, the villages were purposefully selected in such a way that they were similar in terms of population, distance to forest, proximity to market and town, and other facilities. In villages where there was active participation of local residents in forest management or where there was joint action by local residents and the FD in monitoring or managing the forest resource, institutions were categorized as 'Present'. In villages where peoples' participation was lacking, either due to the dominance of management by the FD or with no management of forest resources either by people or by the FD, institutions were categorized as 'Absent'. As the Chandrapur Buffer Forest Division has no village without local forest institutions, 15 villages were selected for this study. Involvement of local people in forest management was subjective and needed thorough information. Therefore, snowball and purposive sampling methods were used to identify the villages.

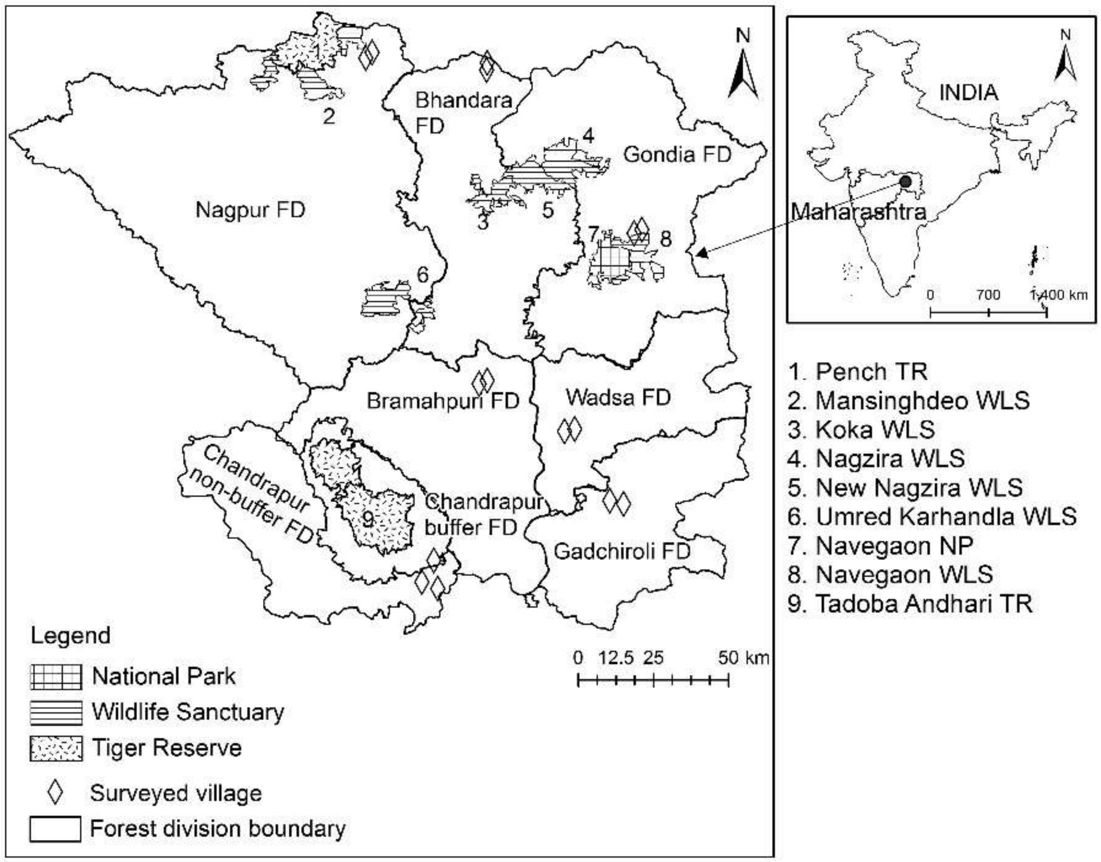


Figure 4.1. Distribution of the locations of 15 surveyed villages

Within each of the selected 15 villages, tree density, species richness and tree biomass were estimated using 30 circular forest plots (i.e., a total of 450 plots across the study area) of 10m radius, within which smaller nested circular plots of 3m and 1m radii were used to assess sapling and seedling density and diversity (Figure 4.2). To select the location of the circular plots, the forest boundaries of each village were mapped and divided into 60m × 60m grids, so that the plots were at least be 60m or two pixels (in case of Landsat image) apart from each other. Then, 30 grids were randomly selected using the vector tool operation of QGIS (Team 2015). Each plot in the field was located by tracking the centroid of each selected grid using a GPS device (GARMIN eTrex Vista, Olathe, Kansas, United States). Circular plots were laid by measuring 10m radii around the centroid. The projection used was the geographic latitude/longitude World Geodetic System 1984 (WGS84).

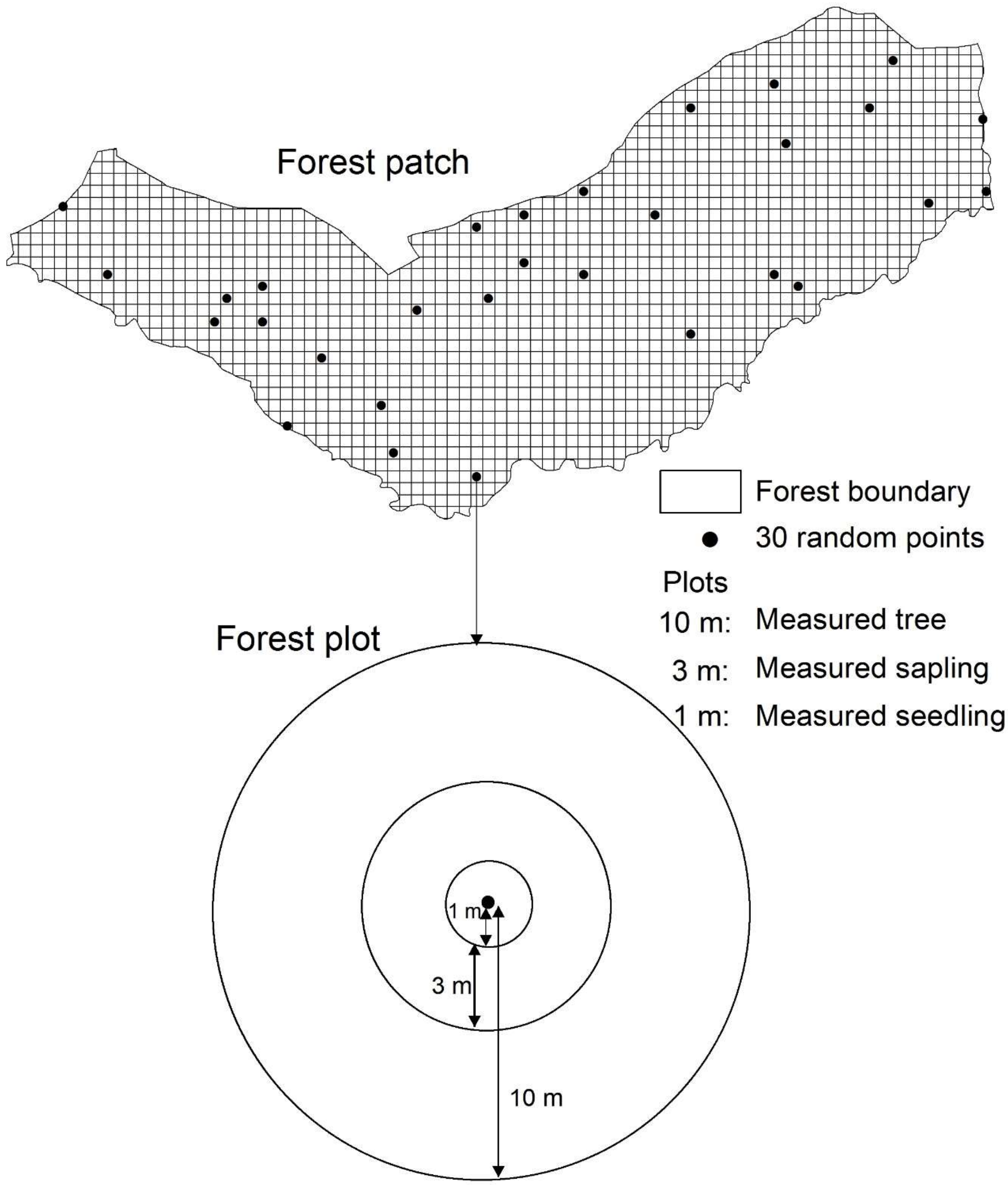


Figure 4.2. Circular plot method for sampling tree, sapling and seedling in each surveyed village

In 10m circular plots, the GBH (Girth at Breast Height) and height of all trees, shrubs and climber species were recorded for all individuals with GBH of more than 10cm. In 3m circular plots, the GBH and height of all trees, shrubs, and climber species were recorded for all individuals with GBH less than 10cm and height more than 1m. In 1m circular plots, species identity was recorded for all trees, shrubs, climber species, and herb individuals with height less than 1m. Later, DBH (Diameter at Breast height) was calculated using GBH. In order to avoid seasonal variation that mostly affects shrub and herb species composition, the data was collected in winter across all villages.

Tree density, species richness and biomass was calculated for each plot. The biomass was calculated using the formula provided by Chave et al. (2005), which accounts for tree taper and in which wood density is multiplied by the volume of the cylinder. Wood density data was obtained from Zanne et al. (2009) and the Ecosystems Ecology laboratory of the National Centre for Biological Sciences (NCBS), Bangalore, India.

Remotely Sensed Data

Landsat 8 surface reflectance imagery with a spatial resolution of 30m, of 14th December 2013 acquisition date was downloaded from the USGS website, to assess the relationship between spectral value and vegetation variability across different sites. This time frame corresponds with the same time frame (October–February) during which field data was collected. The size of each plot i.e., 10m radius circular plot is less than the pixel size of 30m resolution of Landsat 8 images. In order to account for the positional error of around 5–8m radius, a 3 × 3 pixel window around the central pixel of plot, location was used to calculate the mean and standard deviation of selected indices and bands. This method was used to extract value for Tasseled Cap indices for wetness (Baig et al. 2014), NDVI and standard deviation of NDVI (SD–NDVI). NDVI is derived from red and infrared bands. NDVI values range between −1 to +1, where high values indicate greener vegetation. Image processing software, ERDAS Imagine™ (9.2, ERDAS Inc., Norcross, Georgia, United States) was used to calculate NDVI and SD–NDVI; and GRASS GIS 7.0.0RC2 (GRASS Development Team, Michele all'Adige, Italy) was used for Tasseled Cap indices for Wetness.

Data Analysis

Quantile regression was used at very high quantile values (tau = 0.95) to describe the relationship between NDVI and tree density at plots. NDVI, which is a measure of greenness (or absorption of solar radiation by chlorophyll), is an indicator of the health of vegetation and is positively correlated with the live vegetation cover. This may include any form of vegetation such as grasses, shrubs, or tree, and its value of NDVI is not limited by tree density alone. Therefore, ordinary least squares regression that describes the relationship between mean of tree density and NDVI is not appropriate. By fitting regression exclusively to higher quantiles of the data, the prediction was restricted to the slice of the data where most NDVI is contributed by standing tree vegetation, which is a positive co-relation. Quantile regression is extensively used in various ecological studies, as it helps in estimating the functional relationship between the variables at different quantile values (Cade and Noon 2003; Koenker and Bassett Jr 1978; Rocchini et al. 2010; Rocchini et al. 2009). In ecological studies, it is very difficult to measure all the variables causing an effect, and threshold values are often better described than total variation. Therefore, estimating multiple regression slopes at different quantiles provides greater understanding as compared to ordinary least squares regression (Cade and Noon 2003). The eight forest divisions within which the villages were present had identical modes of operation and did not have any specific differences in the policies they were implementing. Therefore, while the villages were nested within forest divisions, this did not have an effect in addition to local conditions. To confirm this assumption, tree density, species richness and tree biomass of between villages were compared within each forest division using Mann–Whitney U test (Appendix 4.1).

The relationship between spectral and plant community data between villages with and without institutions were also compared using regression at a high quantile (0.95). As spectral heterogeneity is a good proxy for beta diversity (Rocchini et al. 2010), the relationship between spectral dissimilarity and beta-diversity was also compared in the institution and non-institution villages. The analysis was performed in R 3.2.2 (R Core Team, Vienna, Austria) using package "quantreg version 5.11" for quantile regression (Koenker 2015) and package "vegan version 2.3-1" (Oksanen et al. 2015) for dissimilarity indices.

Results

Relationship between Plant Species and Spectral Diversity

Tree density and richness showed clear positive relationships with spectral indices such as NDVI and wetness and negative relationship with SD-NDVI index, while the relationship between biomass and the spectral indices was much weaker in both cases. Variance of the response variables also increased with the spectral indices. This is most likely due to the nature of the relationship between spectral indices and tree vegetation (Figure 4.3).

Tree density, species richness, and biomass were significantly related to spectral values in both quantile and linear regression. Estimates of intercept took more extreme values (positive and negative), and slopes were steeper in quantile regression compared to linear regression. Thus, the relationship between attributes of vegetation and spectral indices varies with the quantile value, and the higher quantiles have a stronger effect than the mean (Figure 4.3 and Table 4.1).

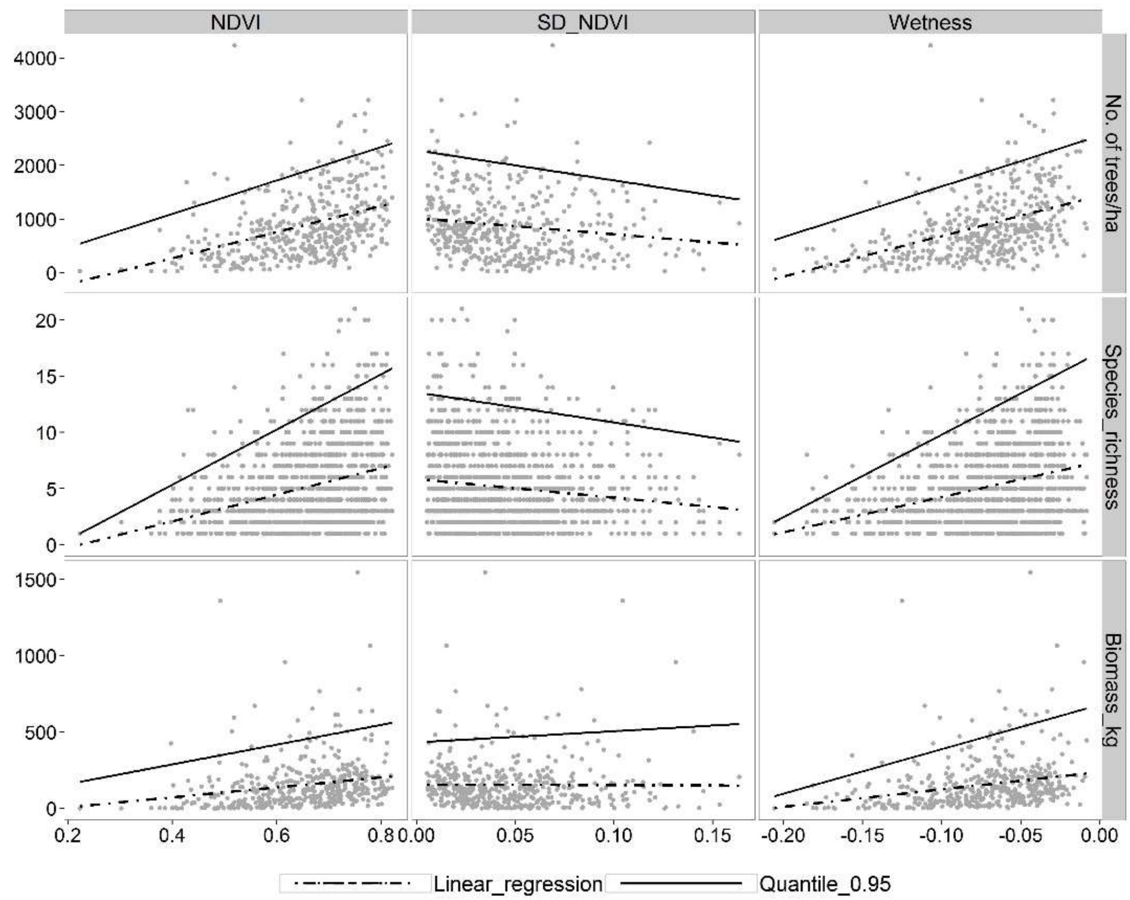


Figure 4.3. Relationship between tree density (no. of trees/ha), species richness and biomass (kg) with NDVI, SD–NDVIand wetness using quantile regression (0.95 tau) and linear regression. The dashed line is for linear regression and solid line is for quantile regression (0.95 tau)

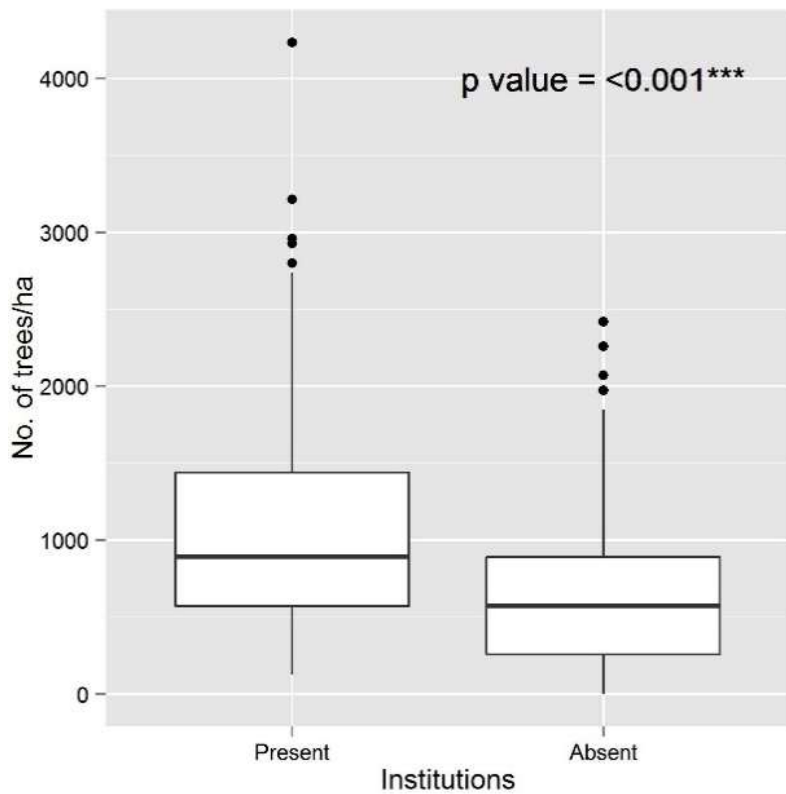
Table 4.1. Comparison of the results of quantile regression (0.95 tau) and linear regression for the relationship of tree density, species richness and biomass with NDVI, SD–NDVIand wetness

Variable	Parameter	Quantile Regression (tau = 0.95)		Linear Regression	
		Estimate	***p* Value**	**Estimate**	***p* Value**
Tree density	Intercept: NDVI	−4.68 (±7.9)	0.55	−21.9 (±3.0)	<0.001***
	Slope: NDVI	97.97 (±11.29)	<0.001	76.5 (±4.6)	<0.001***
	Intercept: SD–NDVI	71.67 (± 2.5)	<0.001	32.07 (±0.9)	<0.001***
	Slope: SD–NDVI	−175.81 (±46.6)	<0.001	−94.6 (±17.5)	<0.001***
	Intercept: Wetness	80.22 (±4.0)	<0.001	45.29 (±1.0)	<0.001***
	Slope: Wetness	296.36 (±36.7)	<0.001	236.9 (±12.9)	<0.001***
Species richness	Intercept: NDVI	−4.47 (±1.5)	<0.001	−2.65 (±0.6)	<0.001***
	Slope: NDVI	24.57 (±2.4)	<0.001	11.85 (±0.9)	<0.001***
	Intercept: SD–NDVI	13.57 (±0.7)	<0.001	5.86 (±0.1)	<0.001***
	Slope: SD–NDVI	−26.89 (±10.6)	0.01	−16.65 (±3.4)	<0.001***
	Intercept: Wetness	17.14 (±0.6)	<0.001	7.39 (±0.2)	<0.001***
	Slope: Wetness	73.41 (±7.1)	<0.001	31.42 (±2.7)	<0.001***
Tree biomass	Intercept: NDVI	29.5 (±176.0)	0.80	−57.82 (±28.7)	<0.001***
	Slope: NDVI	647.52 (±268.5)	0.01	326.11 (±43.7)	<0.001***
	Intercept: SD–NDVI	432.06 (±44.3)	<0.001	155.87 (±8.5)	<0.001***
	Slope: SD–NDVI	735.88 (±988.7)	0.45	−40.02 (±154.6)	0.79
	Intercept: Wetness	679.04 (±31.5)	<0.001	238.7 (±10.1)	<0.001***
	Slope: Wetness	2911.19 (±196.1)	<0.001	1141.29 (±121.9)	<0.001***

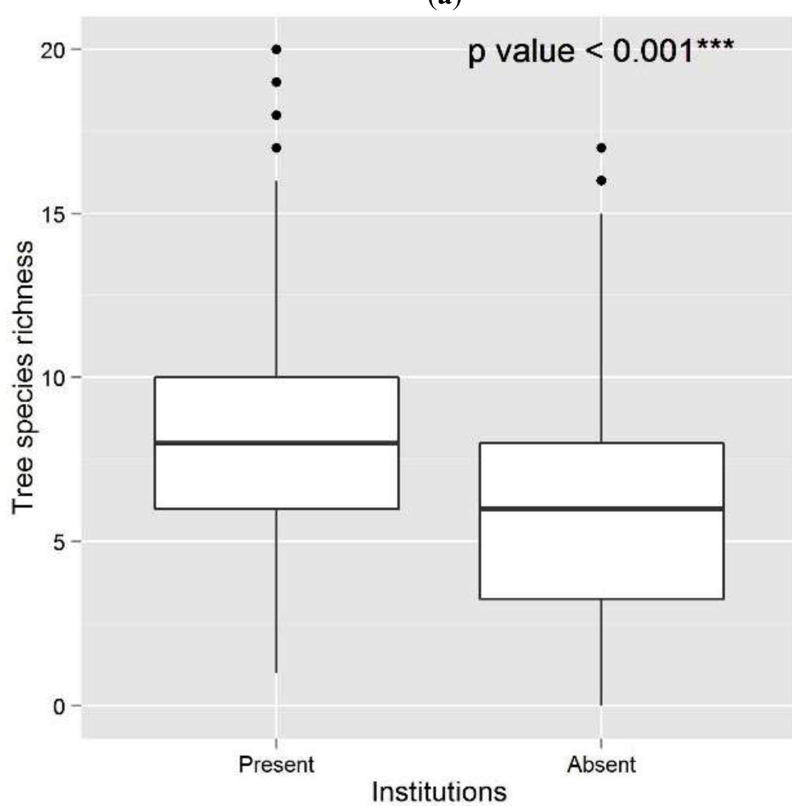
Significance codes: *** 0.001, ** 0.01, * 0.05, · 0.1, 1.

Impact of Institutions on Plant Species Diversity

Species richness and tree density were higher in villages with institutions as compared to villages without institutions (Figure 4.4 a and b). However, the biomass was the same in different institution settings (Figure 4.4 c). On the other hand, regeneration was high in villages with institutions as compared to villages without institutions (Figure 4.4 d).

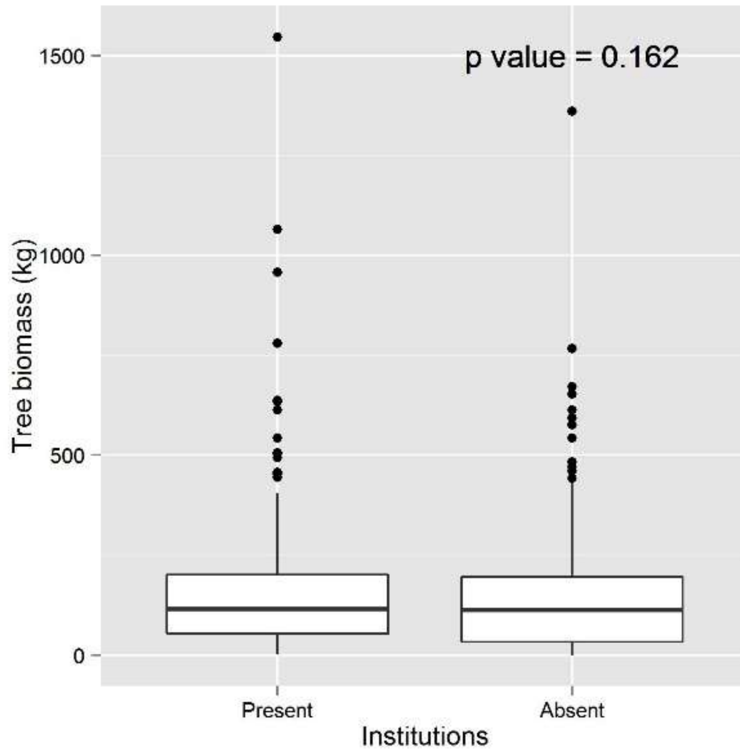


(a)

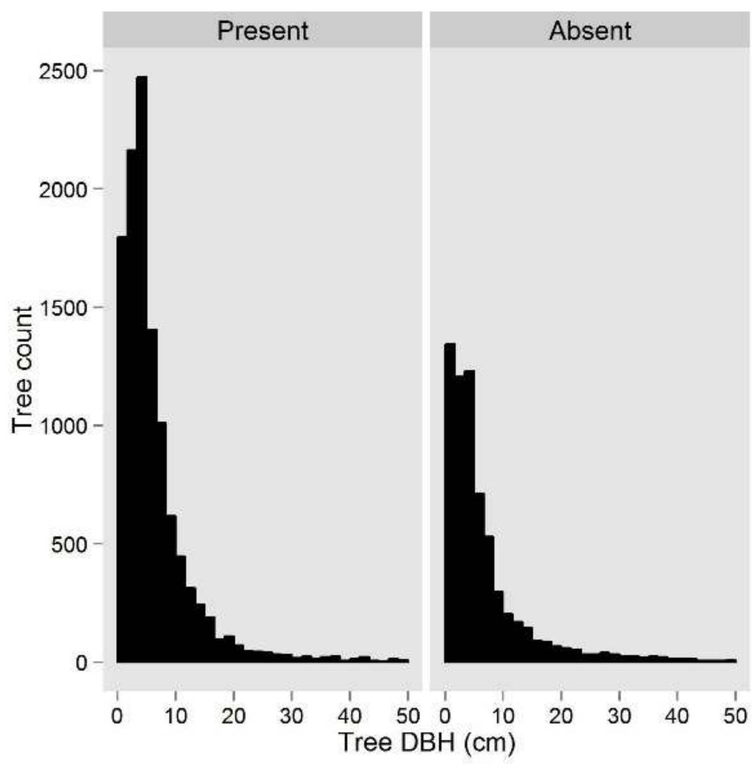


(b)

Figure 4.4. (a) tree density (no. of trees/ha) (b) tree species richness in the forest patch of villages present and absent local forest institution



(c)



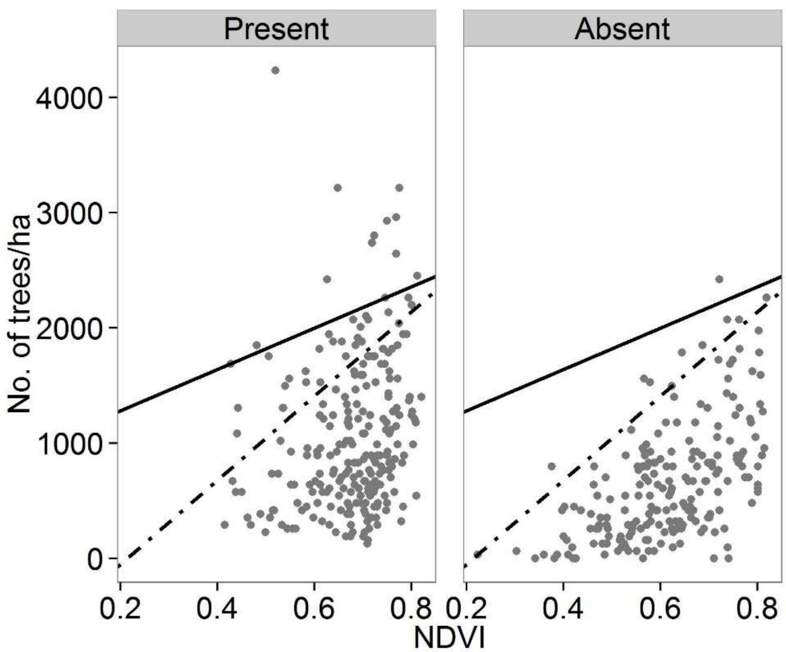
(d)

Figure 4.4. (c) tree biomass and (d) frequency of tree DBH in the forest patch of villages present and absent local forest institutions

Relationship between Vegetation Diversity and Spectral Values in Presence and Absence of Forest Institutions

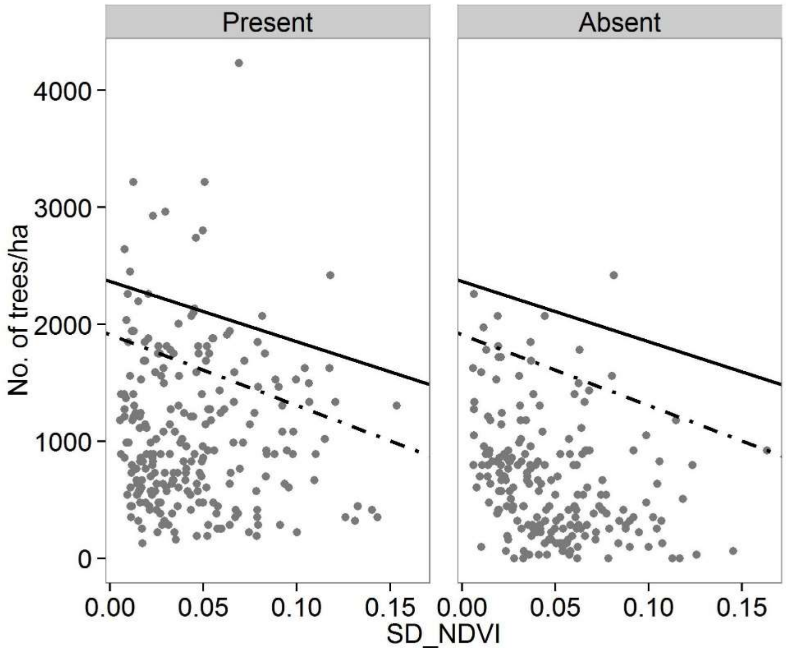
In villages with institutions, the slope of relationship between NDVI and tree density was flatter, and the intercept was higher (Figure 4.5 a); none of the plots recorded an NDVI below 0.4. In contrast, the intercept for villages without institutions was significantly lower as compared to that with institutions (Table 4.2) and there were some plots that had NDVI below 0.4 (Figure 4.5 a).

The relationship between tree density and SD–NDVI was significantly different in villages with and without forest management institutions (Table 4.2 and Figure 4.5 b). The relationship between tree density and wetness was not significantly different in villages and without institutions (Table 4.2 and Figure 4.5 c).

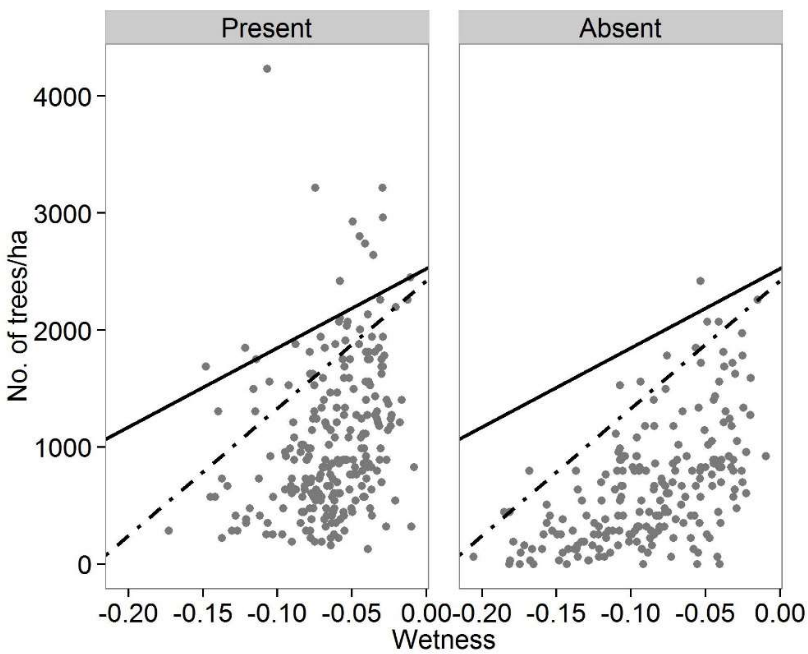


(**a**)

Figure 4.5. Results of quantile regression (tau = 0.95) for tree density (no. of trees/ha) with (a) NDVI under presence or absence of local institutions. The dashed line represents fitted values in villages without local institutions and the solid line is for villages with local institutions



(**b**)



(**c**)

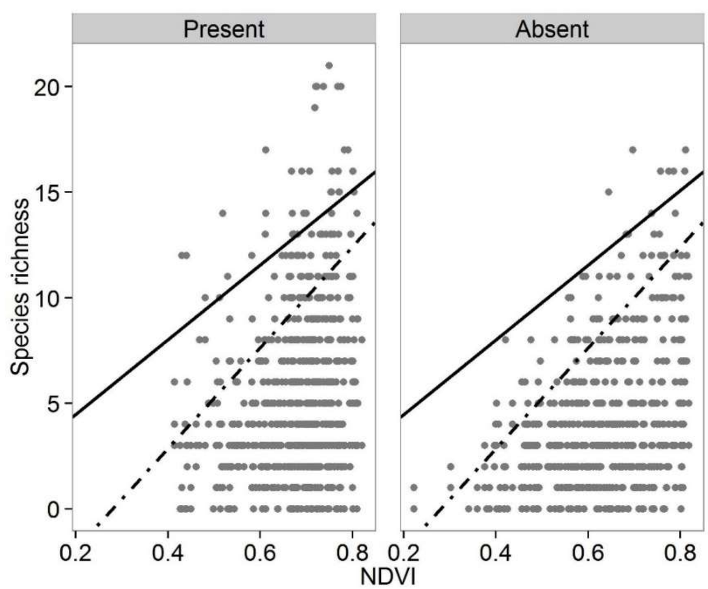
Figure 4.5. Results of quantile regression (tau = 0.95) for tree density (no. of trees/ha) with (b) SD-NDVI (c) wetness index under presence or absence of local institutions. The dashed line represents fitted values in villages without local institutions and the solid line is for villages with local institutions

Table 4.2. Results of quantile regression for tree density (tau = 0.95) in the villages with presence and absence of the local forest institutions

Predictor Variable	Parameter	Estimate	*p* Value
NDVI	Institutions present	28.93 (±12.44)	0.02*
	Institutions absent	−53.51 (±16.0)	<0.001***
	Institutions present: NDVI	56.35 (±22.3)	0.01**
	Institutions absent: NDVI	58.41 (±27.5)	0.03*
SD–NDVI	Institutions present	74.31 (±7.8)	<0.001***
	Institutions absent	−14.27 (±8.3)	0.08·
	Institutions present: SD–NDVI	−161.17 (±155.8)	0.30
	Institutions absent: SD–NDVI	−28.73 (±162.3)	0.85
Wetness	Institutions present	79.31 (±7.2)	<0.001***
	Institutions absent	−3.21 (±8.2)	0.69
	Institutions present: Wetness	212.71 (±80.3)	<0.001***
	Institutions absent: Wetness	129.53 (±89.9)	0.15

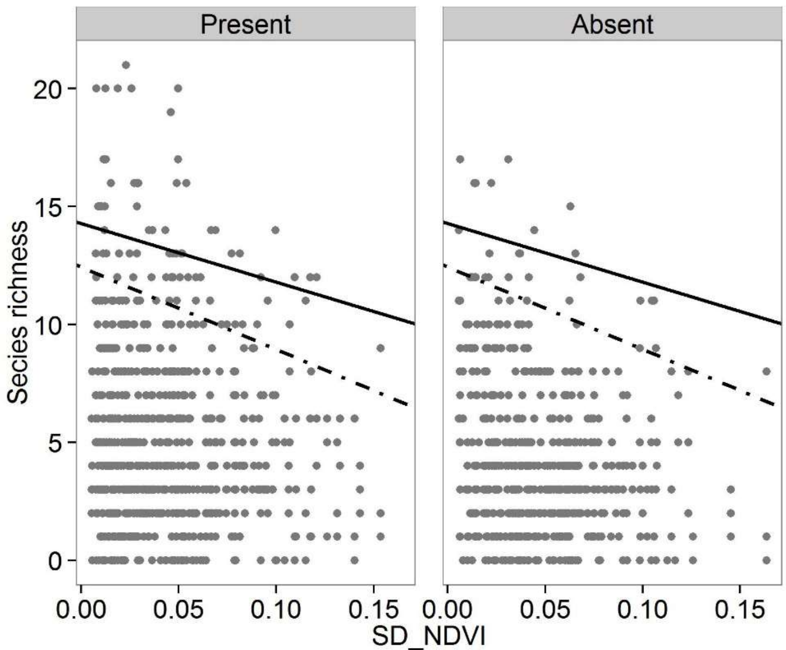
Significance codes: *** 0.001, ** 0.01, * 0.05, · 0.1, 1.

The relationship between species richness and NDVI, SD–NDVI and wetness did not significantly differ between villages with and without institutions (Figure 4.6 and Table 4.3). Thus it appears that Landsat RS is more sensitive to tree density, and less able to discern differences in species richness.

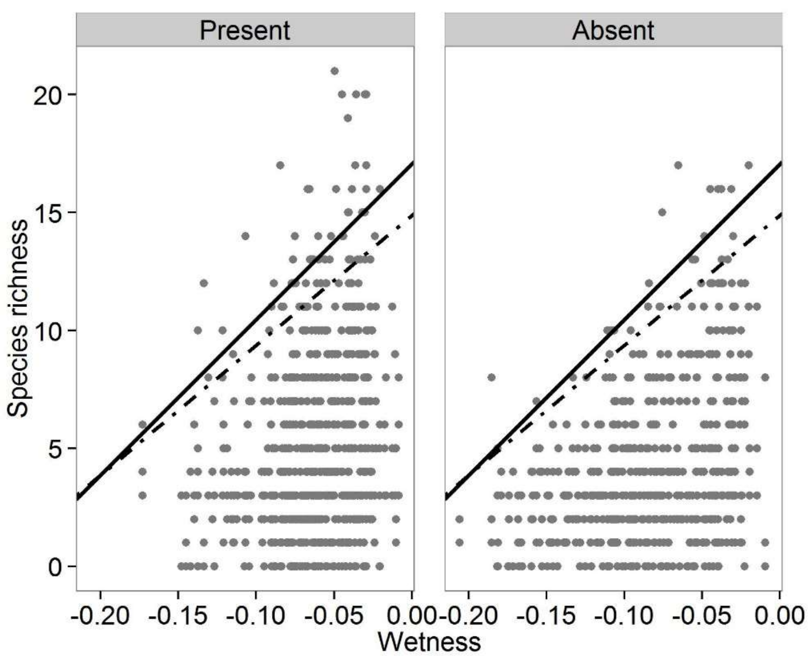


(a)

Figure 4.6. Quantile regression (tau = 0.95) for species richness with (a) NDVI under presence or absence of local institutions. The dashed line represents fitted values in villages without local institutions and the solid line is for villages with local institutions



(**b**)



(**c**)

Figure 4.6. Quantile regression (tau = 0.95) for species richness with (b) SD-NDVI (c) wetness index under presence or absence of local institutions. The dashed line represents fitted values in villages without local institutions and the solid line is for villages with local institutions

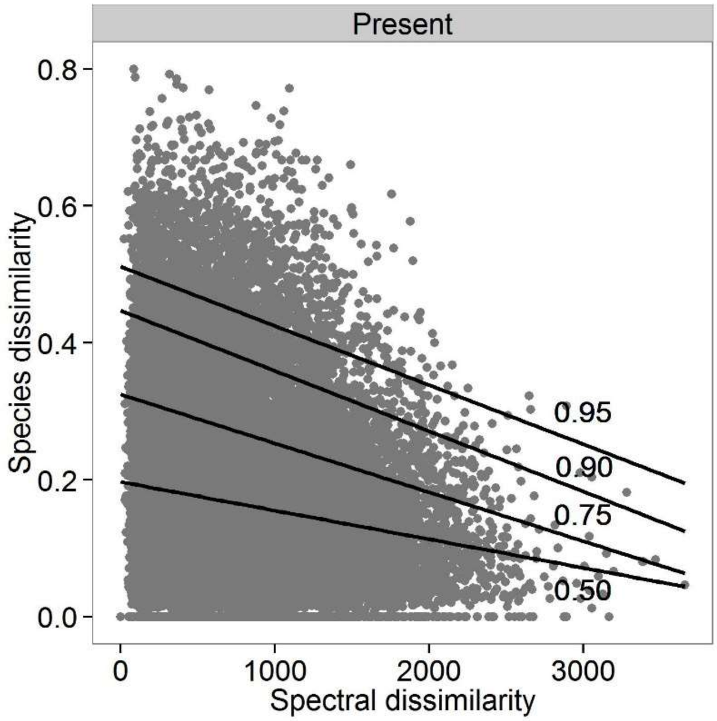
Table 4.3. Results of the quantile regression for species richness (tau = 0.95) in the villages with presence and absence of the local forest institutions

Predictor Variable	Parameter	Estimate	*p* Value
NDVI	Institutions present	0.92 (±4.1)	0.82
	Institutions absent	−5.8 (±4.4)	0.18
	Institutions present: NDVI	17.72 (±5.9)	<0.001***
	Institutions absent: NDVI	6.19 (±6.6)	0.35
SD–NDVI	Institutions present	14.29 (±0.9)	<0.001***
	Institutions absent	−1.85 (±1.3)	0.18
	Institutions present: SD–NDVI	−24.92 (±11.6)	0.03*
	Institutions absent: SD–NDVI	-9.98 (±22.8)	0.66
Wetness	Institutions present	17.03 (±0.9)	<0.001***
	Institutions absent	−2.17 (±1.3)	0.11
	Institutions present: Wetness	66.01 (±12.2)	<0.001***
	Institutions absent: Wetness	−10.94 (±15.0)	0.46

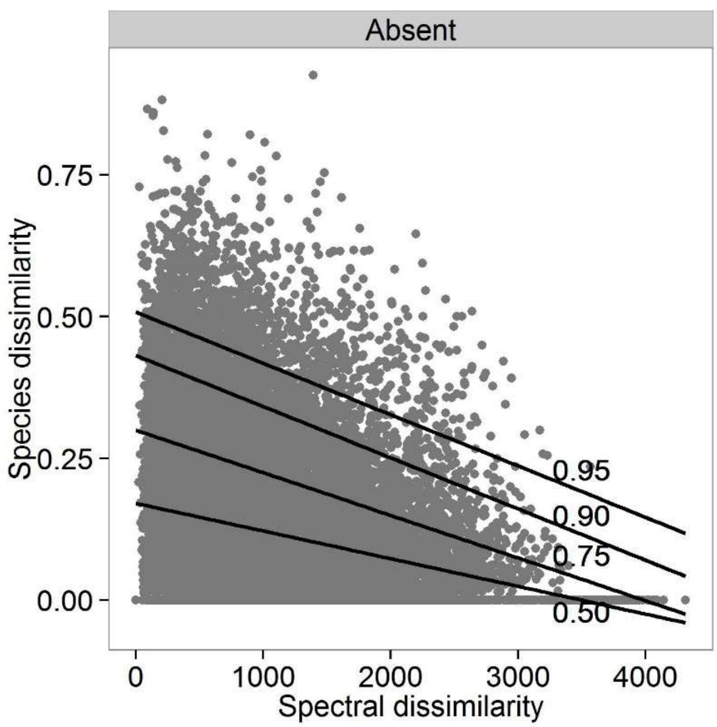
Significance codes: *** 0.001, ** 0.01, * 0.05, · 0.1, 1.

Relationship between Species Dissimilarity and Spectral Dissimilarity

As the dissimilarity (beta diversity) between species sampled at different locations increases, the spectral distance also increased. A fitted quantile regression line at different quantiles (0.95, 0.90, 0.75, and 0.50) was used to help in describing the heterogeneity in tree composition. There was a weak relationship between species similarity and spectral distance. No difference was found in terms of species dissimilarity and spectral dissimilarity in villages with and without institutions (Figure 4.7 and Table 4.4).



(**a**)



(**b**)

Figure 4.7. Quantile regression for species dissimilarity against spectral dissimilarity at 0.95, 0.90, 0.75 and 0.50 quantile in villages (a) with and (b) without forest institutions

Table 4.4. Quantile regression for species dissimilarity against spectral dissimilarity at 0.95, 0.90, 0.75, and 0.50 quantiles in villages with and without forest institutions

Parameter	Institutions Present		Institutions Absent	
	Estimate	*p* Value	Estimate	*p* Value
Intercept: tau 0.95	0.51 (±0.003)	<0.001***	0.51(±0.005)	<0.001***
Slope: tau 0.95	−0.00009 (0)	<0.001***	−0.00009 (0)	<0.001***
Intercept: tau 0.90	0.45 (±0.003)	<0.001***	0.43 (±0.004)	<0.001***
Slope: tau 0.90	−0.00009 (0)	<0.001***	−0.00009 (0)	<0.001***
Intercept: tau 0.75	0.33 (±0.002)	<0.001***	0.30 (±0.002)	<0.001***
Slope: tau 0.75	−0.0007 (0)	<0.001***	−0.00008 (0)	<0.001***
Intercept: tau 0.50	0.20 (±0.001)	<0.001***	0.17 (±0.001)	<0.001***
Slope: tau 0.50	−0.00004 (0)	<0.001***	−0.00005 (0)	<0.001***

Significance codes: *** 0.001, ** 0.01, * 0.05, · 0.1, 1.

Discussion

Remotely sensed indices such as NDVI, SAVI, SD–NDVI, greenness, and wetness have been previously demonstrated to be useful for the study of vegetation structure, composition and quantification of tree density (Krishnaswamy et al. 2009; Oldeland et al. 2010; Pettorelli et al. 2005). Previous research has utilized remotely sensed data to estimate species richness, diversity, tree density and forest heterogeneity (He et al. 2009; Nagendra et al. 2010). However, dry tropical forests remain relatively less studied as compared to moist tropical forests. In this study of a dry tropical forest in central India, dominated by deciduous species with relatively open canopy and low-relief topography, I demonstrated relationships between variables of tree composition and density (tree density, species richness and biomass) and spectral values. Specifically, I found that tree density, species richness, and biomass are positively related to NDVI and wetness, and negatively related to SD–NDVI.

Quantile regression approach was adopted to investigate the relationship between spectral indices and forest vegetation. Previous research had demonstrated the use of quantile regression techniques to better capture aspects of ecological variability, as compared to conventional regression approaches (Rocchini et al. 2010; Rocchini et al. 2009). Quantile regression was used to set the threshold for tree density, species richness and biomass at a high (0.95 tau) quantile. Setting the relationship to a higher quantile helped in building a relationship with spectral values and the variation contributed by standing trees.

The sampled 450 plots had 12,277 number of tree individuals representing 105 tree species which contained 6,8237.46 kg biomass. *Terminalia alata* was the most abundant species in both types of villages, with (20%) and without (15%) institutions and contributed to the maximum biomass. Other abundant species in the villages with institutions were *Cleistanthus collinus* (16%), *Diospyros melanoxylon* (9%)*, Tectona grandis* (8%), *Chloroxylon swietenia* (8%), *Woodfordia fruticosa* (7%)*, Maytenus emarginata* (7%), *Lagerstroemia parviflora* (7%), *Holarrhena antidysenterica* (7%), and *Anogeissus latifolia* (6%) (Appendix 4.2). The abundant species in villages without institutions were *Diospyros melanoxylon* (13%), *Lagerstroemia parviflora* (13%), *Chloroxylon swietenia* (11%), *Cleistanthus collinus* (10%), *Woodfordi fruticosa* (7%), *Maytenus emarginata* (7%), *Anogeissus latifolia* (6%), *Tectona grandis* (6%), and *Holarrhena antidysenterica* (6%) (Appendix 4.2).

The abundant species may or may not contribute most of the biomass, as it depends on the DBH, height, and wood density of the individual trees. Therefore, the species contributed most of the biomass in the villages with institutions were *Tectona grandis* (14%), *Madhuca longifolia* (11%), *Pterocarpus marsupium* (8%), *Anogeissus latifolia* (8%), *Dalbergia paniculata* (7%), *Schleichera oleosa* (7%), *Soymida febrifuga* (6%), *Chloroxylon swietenia* (5%), and *Lannea coromandelica* (5%) (Appendix 4.3). The species contributed most of the biomass in the villages without institutions were *Madhuca longifolia* (15%), *Tectona grandis* (10%), *Chloroxylon swietenia* (8%), *Anogeissus latifolia* (7%), *Diospyros melanoxylon* (7%), *Soymida febrifuga* (7%), *Butea monosperma* (6%), *Lannea coromandelica* (5%), and *Cleistanthus collinus* (5%) (Appendix 4.3). There is limited research that assesses above ground biomass in Indian tropical forests (see Behera et al. 2017, for an exception).

V3 village had the maximum abundance (2,613) as the forest was regenerating, whereas, V10 village contributed to the maximum biomass (7,710.47 kg). V9 village had the maximum tree species richness (66) (Appendix 4.4 and 4.5). Significant differences were found in tree density and species richness between villages with and without forest management institutions, but there was no difference in biomass. Forest patches where local people were involved in management had larger numbers of small trees with DBH less than 15 cm that contributed to the density but did not contribute substantially to woody biomass (Figure 4.4 d). The local institutions in the villages studied were constituted not more than 10–15 years ago. Therefore, the most evident effect of management on vegetation was in terms of increasing the numbers of young trees. If the institutions persist, the biomass in these forests is likely to increase in the future. Given better spatial or spectral resolution data, it may be possible to detect some of these differences even at early stage.

Given the low rainfall in this climatic zone, trees in these dry deciduous forest areas tended to be slow growing as compared to their moist tropical counterparts where there was a relatively rapid increase in biomass. Studies have shown that the time elapsed since human interventions (including management, past condition of the forest, and intensity of management) has an effect on forest structure and species composition (Paillet et al. 2010; Sitzia et al. 2012). The observed differences could be a function of the relative time because of management and the use of forests in different management regimes. Trees in dry tropical forests can take as long as 20 years to regrow (Murphy and Lugo 1986). These forest patches could even take longer because of the sustained levels of human use. The density of trees with small DBH can also explain relative differences in the relationship between vegetation attributes and spectral values among villages with and without local institutions. There were a greater number of small trees in the forest patches with institutions as compared to those without institutions. As these small trees are under the canopy, they did not contribute to an increased NDVI value. Therefore, the intercept of the tree density relationship was higher in villages with institutions as compared to those without institutions. However, the relationship between species richness and indices was not significantly different across institutions. The villages shared a large number of similar tree species. Therefore, the difference in species richness across institutions was not clearly captured by remotely sensed data. The relationship between tree density and wetness was also not significantly different across institutions. This could be because the habitat is a dry deciduous forest. Villages with institutions had a greater number of small trees below the upper canopy. Indices of wetness were not able to capture this variation across villages with and without institutions.

Recent studies have shown that as species dissimilarity increases, spectral dissimilarity also increases. This study also found a similar relationship between beta diversity and spectral heterogeneity (Rocchini et al. 2010; Rocchini et al. 2009). However, there was no difference in beta diversity in the villages with and without institutions. This could be because the focus of the institutions is not on maintenance of species diversity, in particular of beta diversity. The main focus of these institutions is on protecting their forest patch from excessive tree felling, and on tree plantation. The major difference found in villages with institutions is in terms of regeneration (natural as well as via plantation), which leads to high tree density (Shahabuddin and Rao 2010).

Local institutions are known to play an important role in managing common pool resources such as forests (Agrawal and Ostrom 2001; Hayes and Ostrom 2005; Ostrom 2000). Understanding functionality of local institutions is very important for conserving forests outside the PAs (Agrawal and Ostrom 2001; Poteete and Ostrom 2004). This study demonstrates that remotely sensed data has the potential to monitor forest outcomes under different management regimes, and to assess the effectivenessof local institutions on different parameters of forest quality such as tree density, biomass, species richness and beta diversity. Such research that integrates ecology, RS and institutional research on forest management is useful for assessing the impact of forest protection outside PAs—an area that has been insufficiently studied despite its importance. This study demonstrated that tree density and species richness could be assessed in tropical forests by using information provided by vegetation indices. Determining a relationship with remotely sensed data can help in developing a better understanding of the role of institutions in forest management, so as to provide better insights for policy. This is particularly relevant in this dry deciduous forest landscape, which is a very important corridor for wildlife, and one that supports local livelihoods. Here, RS methods could serve as an important tool to understand complex socio-ecological processes.

Conclusions

This research has demonstrated a significant potential of RS for monitoring ecological consequences of forest management institutions. However, a direct relationship with the presence or absence of institutions was difficult to establish, mainly because of scale issues and complexities associated with the functionality of institutions. This may be solved by higher spatial and spectral resolution sensors in future studies. Specifically, the availability of high temporal resolution data e.g., from the Sentinel-2 constellation will make it possible to use seasonal data for evaluation of forests, while the availability of LiDAR and very high spatial resolution data e.g., Worldview 2/3 will enable the testing of other, less explored proxies such as tree height, canopy structural diversity and texture, all of which can provide important insights in future studies (Nagendra et al. 2015).

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Chapter 5:

Forest protection in Central India: Do differences in monitoring by state and local institutions result in diverse social and ecological impacts?

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Chapter 5:

Forest protection in Central India: Do differences in monitoring by state and local institutions result in diverse social and ecological impacts?

Introduction

Protected Areas (PAs) have been the cornerstone of Indian and global conservation efforts. There were over 2,09,000 marine and terrestrial PAs worldwide in 2014 that cover more than 30 million km² (https://protectedplanet.net/c/united-nations-list-of-protected-areas/united-nations-list-of-pro tected-areas-2014). In India there are 733 PAs as of 2016 that cover 4.89% of the country's land area (http://www.wiienvis.nic.in/Database/Protected_Area_854.aspx). However, effectiveness of conservation and protection by the state Forest Department (FD) varies considerably across these PAs. Furthermore, these PAs have become increasingly isolated as pressure on forests has shifted towards the portion of forests falling outside these PAs (DeFries et al. 2010; Ravindranath et al. 2012). Studies have shown that these forest patches are under great threat and getting degraded due to various reasons such as monoculture tree plantations (teak, eucalyptus), and plantations of coffee and tea, extraction of biomass by local communities, encroachment for agriculture land, demand for timber, among other reasons (Heltberg et al. 2000; Lugo 1997). This impacts the ecological processes such as connectivity among wildlife populations and dispersal that are important for long term species survival and persistence (DeFries et al. 2005; Karanth and DeFries 2010). Since effective implementation of any PA program involves high economic as well as social costs, connectivity across vast landscapes cannot be provided solely by expansion of the PA network; the forest outside the PAs are as important as the PAs themselves (Agrawal and Ostrom 2001; Nagendra et al. 2008).

In India, forests are legally under the FD (Guha 1983) that functions in a hierarchical and top-down manner typical of most bureaucratic agencies of the state (Fleischman 2015; Guha and Gadgil 1989). The department is divided into the following divisions in decreasing order of hierarchy: circle, division, range, round, and beat. Historically, the British colonialists introduced a system of scientific management of forests through centralized approaches to forest management and development. These forest management strategies were markedly biased towards commercial and industrial exploitation (Guha 1983). After adoption of the PA model, in post-colonial era, the FD's mandate became protection of the forests. However, outside the PAs the department performs a range of revenue generating functions such as plantation, harvest and sale of timber and non-timber products; and also monitors forest patches (Fleischman 2015). In recent years, the functionality of the FD is always justified for enhancing ecological security and biodiversity conservation (Fleischman 2014). However, Fleischman (2014) has argued that there are several reasons and motivation behind the FD functionality at the local-scale such as rent seeking, discursive power, and institutionalized incentives. There are two main functions of the FD: one being beat or coupe cutting (cutting trees in selected beat) and the other of promoting plantation, usually of eucalyptus and teak, which generate revenue for the FD. Many afforestation programs such as the CAMPA (Compensatory Afforestation Fund Management and Planning Authority) were based on this process. Promoting monoculture through plantation results in problems such as biodiversity loss, adverse impacts on soil (Bonell et al. 2010) and hydrological processes (Krishnaswamy et al. 2012). Thus, ecological services are not enhanced by adopting monoculture plantation as other studies have also suggested (Afreen et al. 2011; Chaturvedi et al. 2011; Das 2010).

Another complexity behind managing forests situated outside PAs in India is the high population density and livestock density living in close proximity to forests with a high dependency on biomass for livelihood. When compared to other countries, a large part of India's population live in and around the forest (DeFries et al. 2010). Historically and traditionally local communities were dependent on forests for livelihood and cultural services. Such dependence promoted practices for monitoring and managing forests. Studies on common pool resources (Agrawal and Ostrom 2001; Nagendra et al. 2008) show how participation by local people through informal institutions can effectively manage common pool resources (Agrawal and Ostrom 2001; Ostrom 2000). Such studies argue that common pool resources could be efficiently managed by local communities through practices such as rights of making rules, ownership over resource and equitable sharing of benefits (Cox et al. 2010). This is often seen coherent with the larger objective of conserving biodiversity (Ghate et al. 2013a). However, such narratives to achieve conservation goals are disconnected with motivation of the local people behind the common resource management. In return for managing and monitoring the forest, local communities seekbenefits, such as rights over resource, transparent and equitable sharing of the forest resource, and rights to form and change rules, that are often denied as the decision making power lies with the FD (Cox et al. 2010). Therefore, on many occasions local communities and the FD find themselves in conflict with each other because, of differences in understanding of ownership over resources (Sarin et al. 2003) and lack of adequate dialogue (Castro and Nielsen 2001).

Before promoting or rejecting either form of management, it is important to understand its ecological as well as social consequences. This chapter studies the effects of such disparate management approaches on vegetation in the central Indian dry forests, using a range of institutional settings present in the area. Here the forests are managed by (a) strong participation of local people, (b) joint management by people and the FD, and (c) FD only, without any participation from local community. These institutions mainly help in monitoring the forest patch, which in turn help in maintaining forest density and diversity effectively (Fleischman 2009). Therefore, to achieve regional and landscape-level conservation goals, such as the maintenance of forest corridors outside PAs, one needs to understand the social and ecological impact of local institutions. This study addresses the following questions:

1. Is there any difference in the vegetation (tree species richness, abundance and biomass) across the institutional settings?
2. How do the local forest institutions function on ground in terms of rulemaking, monitoring and regulation?
3. What are the perceptions and motives of different actors, namely, the local community and FD behind forest management? And how do the two interact with each other?

Materials and Methods

Field method

Information on the Joint Forest Management (JFM) committees as well as the villages where local informal institutions were present was collected from FD officials, local non-governmental organizations (NGOs) and other key informants. The villages identified were under eight forest divisions that include Nagpur, Bhandara, Gondia, Brahmapuri, Wadsa, Gadchiroli, Chandrapur buffer and Chandrapur non-buffer forest divisions. Using this information and adopting a purposive sampling approach, two villages in each forest division were identified, one with a local informal or formal institution and another without. The two villages within each forest division were comparable in terms of population, distance to forest, proximity to market and town, and other facilities (refer chapter 4 for more details on village selection).

Data on vegetation

Forest patches from which the villages were extracting resources were identified. In each of these forest patches, 30 random circular plots of 10m radius were established. At each plot species identity, Girth at Breast Height (GBH), and height of all individuals greater than 10cm GBH were recorded. Within each 10m plot, two nested concentric plots of 3m and 1m radius was established. In the 3m plots GBH and height of all trees, shrubs, and climbers with GBH less than 10cm and height greater than or equal to 1m were recorded. In the 1m plots all trees, shrubs, climbers and herbs with height less than 1m were recorded. Later, Diameter at Breast height (DBH) was calculated using GBH. Out of 16 selected villages, vegetation data was collected for 15 villages. This was because in one buffer zone forest division, viz. Chandrapur, there were no villages with local forest institutions (Refer Chapter 4 for more details on vegetation sampling).

Data on institutions

At each village, semi-structured focused group discussions were conducted each lasting about 3-5 hours at public meeting places. People representing different groups, typically a mix of elderly men, and young to middle aged men were present. Additional information was gathered through open ended questions, from key informers and forest officials in each division. Questions with the objective of gaining insights about the three main components namely, constitution, functionality, and motivation were considered for understanding the forest management institutions. The questions included how the forest committee was constituted, who took initiative to constitute the committee, and how members were elected. In order to understand the functionality, Questions related to rules and norms, who made these rules, whether the rules were based on the consideration of equity or not were asked. Questions relating to imposition of fines were also asked. Apart from this, questions such as why members of the committee were interested in the management and what motivated them to constitute the committee were also discussed.

The effectiveness of the local or state institutions will depend on ability to monitor and moderate, resource use from the forest. Therefore, this chapter particularly focused on monitoring practices by the different institutions. The hypothesis was that these would have most direct impact on vegetation. Definition of monitoring was borrowed from Ghate and Nagendra (2005) that defines monitoring as the process of restricting outsiders from the use of forest resource along with mechanisms to ensure rule compliance and dealing with infraction.

Analytical methods

Analysis of vegetation data: Generalized Linear Mixed Models (GLMM) (Bates et al. 2012) were used to compare observed tree species richness and tree abundance between categories of institutions identified using interview data. Vegetation biomass was not considered for the regression since it did not vary across monitoring categories. The institution type along with other landscape variables were used as fixed effects and village code as random effect of intercept (Table 5.1). The landscape variables were divided into 3 levels viz., plot, forest patch and village. Two generalized linear mixed models were compared, one with only institutions categories, and the other with institutions categories and one variable from each of the landscape-level, which was highly correlated with tree abundance and species richness. The villages selected were only a small subset of all the possible villages that can have similar institutions. Therefore, village identifier was included as random effect. Regression for species richness had poisson error structure while for abundance and biomass had negative-binomial distributions (He and Gaston 2000; Smith and van Belle 1984; Ver Hoef and Boveng 2007). The lme4 package (Bates et al. 2012) in R 3.2.2 (R Core Team, Vienna, Austria) software was used to perform the GLMM.

Spatial autocorrelation was checked using 'Moran's I' and also compared strength of spatial autocorrelation in observed values of species richness and abundance with residuals of regression with institutional categories, which was the main variable of interest. The autocorrelation in regression residuals was not significant. Therefore non-spatial regression models were used for the rest of the analysis. The package spdep version 0.6-6 (Bivand et al.

2013) in R 3.2.2 (R Core Team, Vienna, Austria) software was used to estimate spatial autocorrelation.

Table 5.1. Description of the variables used as fixed effect

Levels	Variables for fixed effect	Description
Forest	Area of forest patch	Area of forest patch from digitized polygon of each village
	Surrounding village population	Total population from 2011 census data of villages within 1km buffer around each surveyed village
	Adjoining forest area	Area of forest in 2km buffer around each nearest village, as people from each village could travel a minimum distance of 2km
Plot	Slope	Calculated using ASTER DEM data of 30m resolution
	Distance to village	Distance from each plot to the respective village
	Distance to non-forest edge	Distance from each plot to non-forest edge such as road, agricultural field, water body
Village	Population	From 2011 census data
	Increase in population	Difference in population from 1991 to 2011 using census data
	Distance to market	Distance from each village to nearest market

Results

Based on the focused group discussions, this study found that monitoring is an integral component of the local forest institutions. Effectiveness of these institutions was based on effective monitoring. With the help of monitoring and forest management, one community restricts the use or overuse of the forest resource by other villages, and also controls the use within the community. Most forest patches are under Reserve Forest (RF) category; hence the forest patches are also monitored by forest guards. The sampled villages were broadly falling under three different categories of monitoring (Table 5.2).

1) Monitoring by forest guards (FD)

2) Local people participation in monitoring (People)

3) No involvement of FD and local community in monitoring (None)

Table 5.2. Information on local institutions and monitoring status

Village code	Local institutions	Year of JFM formation	Monitoring
V1	JFM	2006	FD
V2	-	NA	FD
V3	Community managed and JFM	1994	People
V4	-	NA	None
V5	Community managed and JFM	1998	People
V6	-	NA	None
V7	JFM	2000	None
V8	-	NA	None
V9	Community managed and JFM	1998	People
V10	-	NA	None
V11	JFM	2000	People
V12	-	NA	FD
V13	JFM	2003	FD
V14	-	NA	FD
V15	JFM	2002	People
V16	-	NA	FD

Estimating spatial auto-correlation

Observed species richness and abundance were spatially autocorelated. However, the magnitude of spatial auto-correlation in residuals of generalised linear mixed model for abundance and species richness with institutional categories, was much weaker and not significant (Table 5.3).

Table 5.3. Spatial auto-correlation

Variable	Moran I statistic	Variance	Standard deviation	p value
Tree abundance	0.3009	0.00013	25.97	< 2.2e-16
Residual of GLMM model for abundance	0.00319	0.000136	0.464	0.32
Species richness	0.2860	0.00013	24.65	< 2.2e-16
Residual of GLMM model for species richness	-0.0109	0.000136	-0.745	0.77

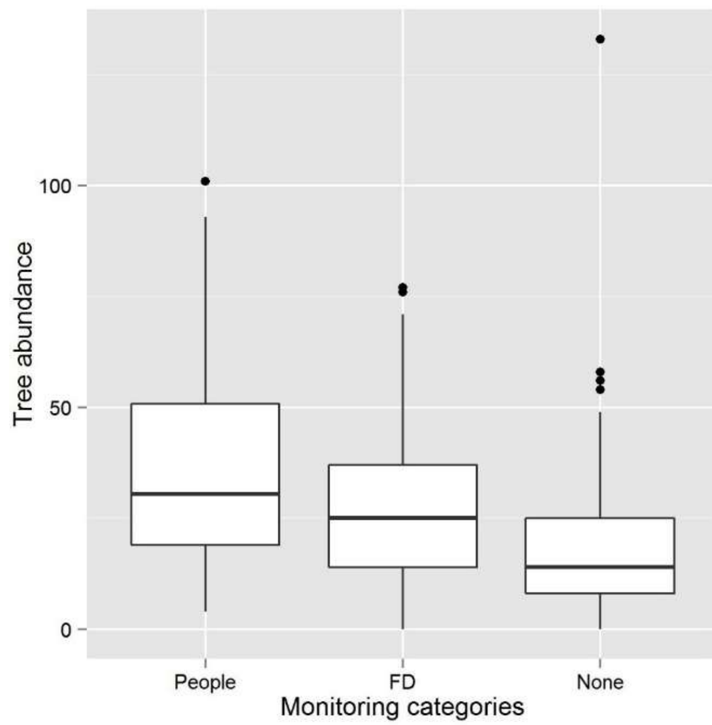
Effect of institutions on vegetation using generalized linear mixed model

There was variation in the abundance and species richness across villages. To account for these differences GLMM with random intercepts term for village was used. Forest patches that were not monitored had consistently lower abundance and species richness than forests that were monitored by either people or FD (Figure 5.1 a and b). However, which institution was carrying out monitoring was of little importance. The magnitude of difference between monitoring by people and FD was always much less than that between monitored and unmonitored forest patches (Figure 5.1 a and b). The relative ranking of the three categories was consistent even after including other potential predictor variables. When comparing abundance of stems with different DBH, abundances of small stems were most different between forest patches with and without monitoring (Figure 5.1 c and d). On the contrary, tree biomass of the forest plots was not different across the three categories (Figure 5.1 c and d).

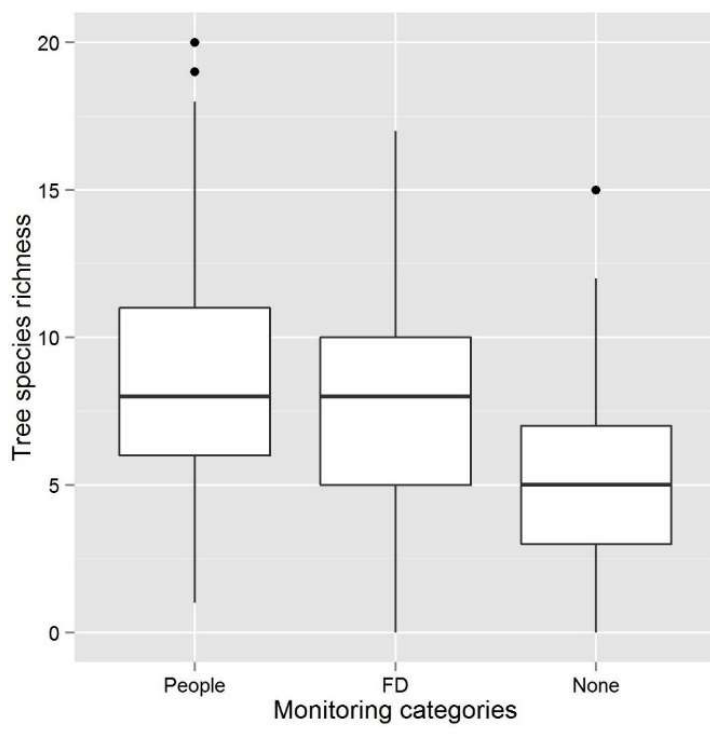
Null model was performed in order to compare with different other models. The AIC value of null model was highest as compared to other models implying that adding covariates would be useful to understand the relation with tree abundance and species richness. In all the models, variance explained by the random effect term was very small. Therefore, most of the unexplained variance was either random or due to unmeasured process.

In case of abundance, landscape variables had very little effect on the model. The pseudo-R^2 as well as AIC values of models with only institutional categories and more complex model with landscape variables were almost identical (Table 5.4). While in case of species richness, the explanatory power of any model was very poor, therefore it is difficult to draw inference on relative importance of variables (Table 5.5). The two models, other than null model, show that tree abundance in unmonitored forest patches was significantly lower as compared to monitored forest patches. The tree abundance in forest patches with FD monitoring was lower as compared to forest patches with people's participation in monitoring by -0.2 (Table 5.4).

Similarly, in the case of species richness, both the models show that species richness in unmonitored forest patches was significantly lower as compared to monitored forest patches. The species richness in forest patches with FD monitoring was lower as compared to forest patches where there was people's participation in monitoring (Table 5.5).

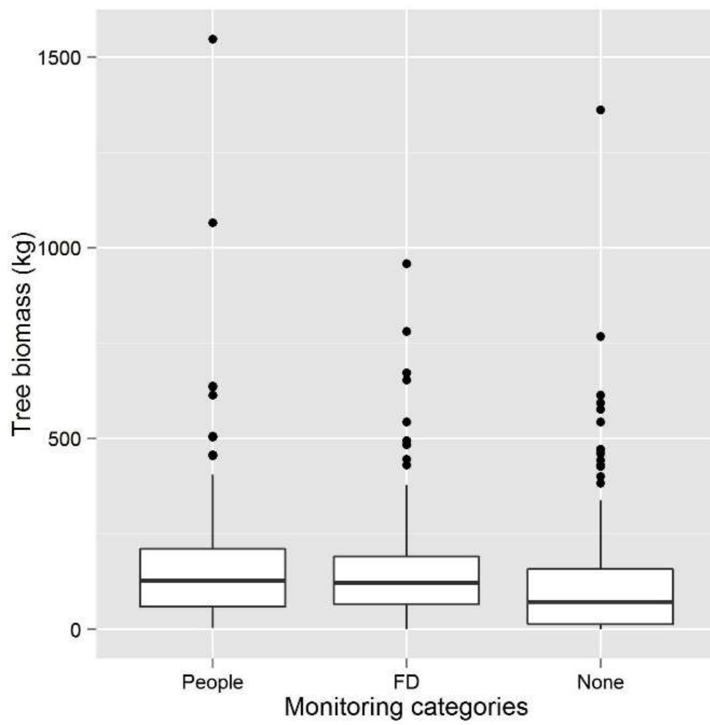


(a)

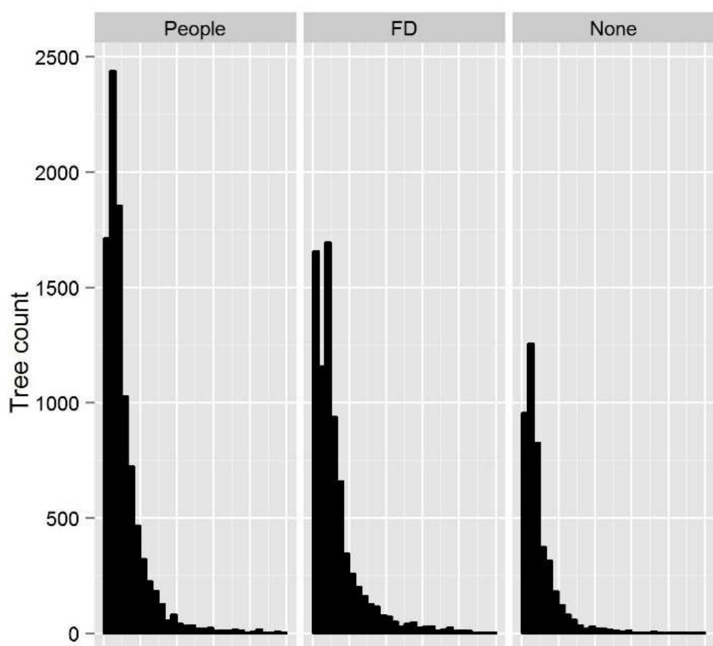


(b)

Figure 5.1. (a) Tree abundance (b) tree species richness in the forest patch of villages in different monitoring categories



(c)



(d)

Figure 5.1. (c) tree biomass and (d) frequency of tree DBH in the forest patch of villages in different monitoring categories

Table 5.4 GLMM for tree abundance

GLMM for tree abundance (family: negative binomial)	Variables for fixed effect	Estimates of fixed effects	Estimates of village random effect	AIC	Log likelihood	Pseudo R^2
Null	1	4.86 (±0.17) ***	0.4248	5334.8	-2664.4	
Monitoring	People	3.50 (±0.14) ***	0.091	3714.9	-1852.4	0.30
	FD	-0.27 (±0.20)				
	None	-0.66 (±0.22) **				
Monitoring, area of forest patch, population increase, distance to village	People	3.47 (±0.14) ***	0.091	3715.6	-1849.8	0.30
	FD	-0.28 (±0.21)				
	None	-0.54 (±0.24) *				
	Distance to village	0.10 (±0.05) *				
	Increase in population	0.09 (±0.10)				
	Area of forest patch	0.006 (±0.11)				

Table 5.5 GLMM for tree species richness

GLMM for tree species richness (family: poisson)	Variables for fixed effect	Estimates of fixed effects	Estimates of village random effect	AIC	Log likelihood	Pseudo R^2
Null	1	1.93 (±0.08) ***	0.095	2313.2	-1154.6	
Monitoring	People	2.13 (±0.09) ***	0.039	2305.3	-1148.6	0.005
	FD	-0.13 (±0.13)				
	None	-0.58 (±0.14) ***				
Monitoring, area of forest patch, population increase, distance to village	People	2.10 (±0.08) ***	0.033	2297.9	-1142.0	0.01
	FD	-0.12 (±0.12)				
	None	-0.47 (±0.14) **				
	Distance to village	0.07 (±0.02) **				
	Increase in population	0.02 (±0.06)				
	Area of forest patch	0.05 (±0.06)				

Focus group discussion in different monitoring categories

Constitution

All the selected villages with participation by local communities had JFM committees, which were almost 15 years old (Appendix 5.1). These villages had a longer history of informal management of the forest since the 1980s, and the formal JFM committees were constituted later, after the introduction of the JFM programme in this region. The JFM committee was constituted by the community and the members selected by the villagers in the village assembly (*gram sabha*). All the households had one or two members from the committee. In the past 15 years, the committee were re-elected at least twice and recently, the composition of female members had also increased.

In contrast, only two villages had JFM committees in the villages where the forest was monitored by the FD. These committees had been functioning for the last 10 years (Appendix 5.1). The FD initiated the JFM committees and the forest officials elected members. The selected members were also found to be members of the village committee (*gram panchayat*). In the past 10 years, the original JFM executive committee members had not changed. Only the number of executive members had increased due to recent changes in the rules of the JFM committee.

Functionality

In the villages where the local community participated in forest management and monitoring, the people had a good understanding of their forest boundary, rules and norms, and were also involved in rule making through village meetings or JFM committee meetings (Appendix 5.2). In most of the villages, local people were directly involved in monitoring the forest, in groups that were formed by involving each household on a rotational basis. Village V3 appointed two guards from the village for monitoring the forest, who were paid collectively by the villagers. Harvest of fuelwood, timber and other non-timber forest products (NTFPs) was regulated by the committee with complete restriction on any resource use by outsiders. The committee imposed fines if anyone violated the rules. These villages have a good relationship with FD, were beneficiaries of plantation projects, and had a share in timber proceeds and received a yearly JFM prize from the state government.

In contrast, in the villages where FD officials monitored the forest patch, the forest guard and other department staff had a clear idea about the forest boundary but villagers were less sure about theirs (Appendix 5.2). Even though villagers were aware of the forest boundary, they did not strictly adhere to these limits and used to extend collection of forest resource in a 2-3 km radius around the village based on their convenience and restrictions on collection. Everyone in the village knew the rules of RF, such as the ban on carrying an axe into the forest and prohibition on taking a bullock cart and bicycle inside the forest for any collection. They were allowed to collect fuelwood and NTFPs from the forest, but cutting live trees as taking logs was completely prohibited. The violators were fined by the forest guard based on the number and size of the logs illegally extracted.

Motivation

From group discussions and informal interactions, in the villages, where people were participating in forest monitoring, the feeling of belonging towards their forest was found to be strong. The local leaders and NGOs also influenced the villagers. The interview data indicated that in these villages the motivation was resource based as these villages are highly dependent on forest resource for their livelihood (Appendix 5.3). The ownership over the forest patch led to decreased struggle over resources and more equitable and fair sharing of the resources. Self-governance nature of the resource use had enabled them to restrict outsiders and maintain the patch in such a way that the resource would be available in the long term. Villagers had the right to make rules and modify them with consensus if needed. In many instances, local rules and norms of forest management pre-dated the formation of JFM committees. These existing formal or informal committees were renamed as JFM committees and showcased as JFM success stories. Villagers felt that the presence of the FD was helpful in regard to reducing the incidence of violent interactions with outsider villages. They also took pride in stating that the forest density had increased over time.

In contrast, in the villages where the forest patch was monitored, there was a lack of motivation towards forest management among villagers. Four out of six villagers had responded that they would like to manage the forest patch without any intervention from the department (Appendix 5.3). The FD focused on managing forest patches via plantation projects. They selected villages for creation of JFM committees based on the availability of areas for plantation. Forest officials mentioned that they had been given targets from higher authorities to create JFM committees in each range, which was the reason to form JFM committee. They were tasked with demonstrating a high success rate of plantation, and preferred planting teak because this species grows in this region relatively easily as compared to mixed species plantation.

In all the villages, people had strong cultural dependencies on the forest, with traditions of worship of *Madhuca longifolia* and *Ficus* trees. Although there were no sacred patches conserved, villagers refrained from cutting sacred trees. They believed that the forest was important for maintaining the biodiversity, soil, air and rain, and wanted to protect forests even though they faced problems such as crop depredation by wild animals.

Unmonitored forest patch

In unmonitored forest patches, there was no defined boundary for forest resource use (Appendix 5.4). The forest patch of the village had degraded over time. The people of this village had recently encroached upon forest land for agricultural purposes. The FD was also not paying attention in these forest patches owing to the degraded condition of the forest patch and absence of any plantation project. In two locations, the villagers were aware of the forest boundary and interested in the protection of the forest. However, there was high pressure from outside villages. The population of the two villages was low, while the villages outside had a higher population (Appendix 5.4). As a result of the influence of local politics, the FD was unable to prevent over-use of the forest by outsiders. Villagers did try to prevent forest use by outsiders, and this had resulted in a few incidences of violence. However, the violators had political support, and the villagers progressively lost interest in protecting the forest.

In these villages, the local people were distrustful of the FD. There was a lack of interest in protecting the forest patch among both villagers and forest officials. This was stated to be due to various reasons in different locations such as local political support, the influence of local militancy and violence, degraded condition of forest, and absence of plantation projects.

Discussion

The study found that monitored forests were performing better when compared to unmonitored forest in terms of both tree abundance as well as species richness. Previous research has shown that monitoring of common pool resources and sanctioning of violators had a positive relationship with effective community based natural resource management (Ghate et al. 2013b; Ghate and Nagendra 2005). Similarly, in this study as well, monitoring has emerged as an important component that is associated with reduced degradation. Even though the difference in abundance and species richness was not very high in people-monitored verses FD-monitored forest patches, there was positive social implication in the villages with active participation in forest management. It was found that participation from local people is important, especially from the point of view of rule-making and equitable management of resource use. Research has demonstrated that local participation in forest management has led to better forest management (Cox et al. 2010; Ghate et al. 2013a) as this provides rights to make and modify rules for the use of common pool resources.

This study found that the villages that had local participation of people in forest management had a clearer understanding of forest boundaries—a finding supported by previous research on community management of resources (Cox et al. 2010). Studies have demonstrated the importance of vertical and horizontal interplay between community and state institutions (Berkes 2007; Brondizio et al. 2009). Thus, the FD should provide increased support to community based institutions for better functionality.

Many studies have found that the bureaucratic and hierarchical nature of the FD was a major reason for the failure of JFM programs (Fleischman 2014). Previous research has suggested that the FD seeks monetary benefits through plantation and JFM projects. They seek power and control over the forest resources including timber and NTFPs to restrict the local communities. They also do not want to delegate the power of making rules and control over resources to the local community (Fleischman 2015). This research corroborates this. Traditional 'Nistar Rights' under which the villagers are permitted to use the forest resources for their subsistence without any restriction, were no longer available to the villagers. Instead, fines were imposed, villagers were forced to surrender their axe, bullock cart or bicycle to the FD. Such instances had led to distrust and conflict between villagers and FD, alienating the villagers from the forest, and reducing their sense of belonging.

The status of the forest patches under FD is known to be dynamic as the functioning of the institutions depend on the quality, competence and attitude of the forest staff. The FD staff keep changing every 2-3 years (Fleischman 2015). During interviews, people said that the changes in guards led to changes in implementation. Forest guards, who are in the lower rank of the FD, usually communicate with the villagers regarding policies. Responses of the local people and outlook towards the forest and the FD depend a great deal on the interaction between forest guards and other officials (Vasan 2002). However, the status of the FD officials was very dynamic and vary based on their individual backgrounds and training imparted before they join the department. In contrast, the forest patches under the management of local communities was found to be more resilient to these crucial micro-level changes, as the functionality was dependent on the local people, and their interest and motivation was long-term and less dynamic (Ghate et al. 2013b). For instance in village V9, people mentioned that they had some differences with the range officer in the past, because of which the process of monitoring was affected, but later due to good leadership of committee members from the village, people started monitoring the forest patch again (Appendix 5.2). Hence, the forest patch is more resilient to such external changes.

The mosaic of PAs linked to forests outside PAs is needed to achieve larger conservation goals, as this provides better connectivity across PAs for wildlife movement and supports livelihoods of the local community (Nagendra et al. 2008). There is a need to find a balance between conservation goals, socio-ecological stability, and sustainable use of forest resource. The literature on common pool resources broadly discusses the role of local people, and rules and norms in managing the resources (Agrawal and Ostrom 2001; Ghate et al. 2013a; Ghate and Nagendra 2005; Hayes and Ostrom 2005). The state policies also play a major role in facilitating support to the local community (Berkes 2007). However, these polices neglect the motivation of the local community behind participation in forest management. Studies show that local people need rights over resource management, instead of externally enforced rules (Torri 2011; Vollan 2008). In many cases JFM committees are not successful because of the hierarchical nature of the committee (Fleischman 2014). The villages where active participation of the local people in management are heterogeneous (Poteete and Ostrom 2004). The core reasons behind better functionality may differ from case to case but by and large they had equitable sharing of resources, the rights to formulate the rules, and support from the FD (Cox et al. 2010). Whereas, where top down approach is practiced by the department and rules were externally enforced on the community, people seem to be alienated from the forest and lacked interest in monitoring and managing the forest (Gautam et al. 2004; Sarin et al. 2003). This further makes the forest corridor more fragile and in danger of degradation, rendering forests less sustainable for both people and wildlife.

Conclusions

In order to achieve conservation goals, protection of forests outside PAs is important to ensure forest connectivity across larger landscapes at the regional-scale. This study found that forest patches that are monitored have improved vegetation quality (tree density and species richness) when compared to unmonitored forests. In the monitored forests, those with active monitoring by local people performed better as compared to FD managed forests, in terms of forest management institutions. Analysis of the interviews point out that when forests were managed entirely by the FD, lack of access to the forest led to mistrust, alienated local communities from the forest and weakened their motivation to protect and nurture the forest. Hence, to achieve conservation goals, the state should facilitate more local participation in forest management policies by providing community rights for decentralized forest governance. The findings of such region-specific experiments would better help design collaborative conservation planning between the FD and local communities. This will also help provide effective mechanisms for protection of biodiversity outside PAs with the participation of incentivized and empowered local communities.

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Chapter 6:
Conclusions

This research has examined the social and ecological impact of forest institutions on land use land cover change and forest fragmentation within and outside Protected Areas (PAs). The research has employed an interdisciplinary approach, combining methods including Remote Sensing (RS), Geographical Information Systems (GIS), landscape fragmentation analysis, tree diversity data from forest plot sampling, and social-institutional analysis based on interviews of different actors involved in forest management.

The study focuses on the connecting forest patches between Pench and Tadoba-Andhari Tiger Reserves (TRs), in the eastern part of Maharashtra, India. There are nine PAs in this region. Among PAs, there are different categories of management regimes, ranging in intensity from TRs - most strict, banning harvest of all forest products, to Wildlife Sanctuaries (WLSs) and National Parks (NPs) - least intensively managed. Forests outside PAs are managed under categories of Reserve Forest (RF), Protected Forest (PF), and Forest Development Corporation of Maharashtra (FDCM). In the forests outside PAs, the Forest Department (FD) performs a range of revenue generating functions including plantation and revenue from timber and non-timber production. In order to perform these functions the department is divided into the following administrative units in descending order of hierarchy: circle, division, range, round, and beat. The FD also monitors or patrols forest patches from getting overexploited from nearby villagers. Other than the FD, the forest is also managed by local communities through informal institutions such as sacred groves, as well as by traditional norms of local communities that are associated with limitations on hunting and harvesting of forest resources. This research tries to understand the impact of these different forest management institutions, both state and local community based, on forest landscape change.

The study was carried out at regional and local levels. At the regional level, forest change and forest fragmentation were mapped and analyzed in different categories of PA and non-PA forests. Later, to understand the drivers of forest change and social impacts of these institutions, 20 stratified random villages were selected. Semi-structured interviews and focus group discussions were conducted in these villages to understand the reasons behind the spatial pattern of land use land cover change and forest fragmentation. At the local level, in order to understand the functionalities of these forest management institutions on ground and their impacts on tree diversity, 15 villages were selected using purposive sampling method. Chapters 2 and 3 describe the findings of the regional level study and the subsequent two chapters (4 and 5) explain the results of the local level study.

The study found that forests of this landscape have been subjected to "institutional enclosure", with strict rules on access and extraction, and an increase in the number of PAs as well as forest administrative units and forest staff involved in management. The number of PAs has increased, from four in 1975 to nine at present. Five Wildlife Sanctuaries (WLSs): Mansinghdeo, Umred-Karhandl, Koka, New-Nagzira, and Navegaon; were formed between 2010 and 2013. There is also a transition of some PAs to stricter management categories. Tadoba-Andhari WLS became a TR in 1993, and Pench NP was declared a TR in 1999. Similarly, there has been an increase in the numbers of forest administrative sub-units—forest ranges, rounds, and beats—outside PAs. Ranges have increased from 45 to 70, rounds from 235 to 304, and beats from 1060 to 1243 in the past four decades. Each range, round, and beat has an associated range officer, round officer, and beat office, with a proportional number of forest guards. Thus, a larger number of FD staff now monitors smaller areas of forests. The restrictions have also increased through various plantation projects, regular monitoring by forest guards, buffer zone establishment, rise in number of administrative sub-units, and also through policies of the Joint Forest Management (JFM).

Despite increase in restriction on forest use by the FD, the forest fragmentation and loss of dense forest outside PAs was found to have increased. At the regional level, RS methods were used to map and analyse forest cover change and forest fragmentation in the landscape between 1977 and 2011. Landsat satellite images from 1977, 1990, 1999, and 2011 were used to perform supervised classification to classify the images into dense forest, open forest and non-forest categories. The change analysis showed that the landscape has lost 1478km^2 of dense forest cover between 1977 and 2011, with a maximum loss of 1002km^2 of dense forest occurring between 1977 and 1990. The loss of dense forest was greater in the forest outside PAs, whereas forests inside PAs have been relatively maintained over time. Forest fragmentation was also mapped using the Ritters fragmentation model. This analysis demonstrated that the forest outside PAs was more fragmented, especially in the PF category, which has less protection, whereas forest inside PAs was found to be relatively intact over time.

Interviews with residents of 20 randomly selected villages indicate that in the absence of alternatives, rather than lowering their dependence on forests, communities appear to shift their use to other, less protected patches of forest. Pressure shifts seem to be taking place as a consequence of increasing protection, from within PAs to forests outside, leading to the creation of protected but isolated forest islands within a matrix of overall deforestation and increased conflict between local residents and the FD. Villagers were aware of the FD rules, but nobody followed them. They covered increased distances for collection of forest resource based on their convenience and restrictions while balancing the likelihood of getting caught or the need to pay a bribe. This led to expressed distrust of the FD, with people speaking of their loss of sense of belonging with the forest, and hence their unwillingness to protect the forest or use resources sustainably.

However, the study also found that at local level some village communities are protecting and managing the forest. Therefore, at local level, this study also looks at the functionalities of these institutions on ground and their impacts on the tree diversity. In Chapter 4, I used Landsat data to explore the relationship between vegetation structure and forest management institutions, in order to assess the efficacy of local institutions in the management of forests outside PAs. Forest condition was assessed using 450 randomly placed 10 m radius circular plots in forest patches of 15 villages, selected using purposive sampling based on with and without local institutions, to understand the impact of these institutions on forest vegetation. This analysis found that tree density and species richness were significantly different between villages with and without local forest institutions, but there was no difference in tree biomass. Higher quantiles were used to compare the relationship across villages with and without institutions because the Normalized Difference Vegetation Index (NDVI) values are not limited by trees since other grass and shrub species also contribute to the NDVI values. Therefore setting the limits to the higher quantile will help in building the relation with standing tree biomass. However, the study also found that in villages with institutions there are high numbers of trees at lower NDVI. This is because these trees in villages with institutions are in regenerating stage, mostly under canopy and hence not contributing to higher NDVI values. However, the difference may be visible over time, depending on persistence of these institutions.

In order to understand what institutional mechanism generate these differences, and how these institutions function on ground in terms of rulemaking, monitoring and regulation, and motivations, focus group discussions were conducted in the selected 15 villages. The two main forest management institutions were the FD and local communities managing forest resources. Based on focused group discussions, this study found that monitoring is an integral component of the local forest institutions. The sampled villages broadly fell under three different categories of monitoring: 1) Monitoring by forest guards, 2) Local community participation in monitoring, and 3) No involvement of FD or the local community in monitoring. In this chapter, I found that forests with monitoring had significantly higher tree density and vegetation species richness compared to forests without monitoring.

Even though the difference in abundance and species richness were only slightly higher in people-monitored forests as compared to the FD-monitored forest patches, there were high and positive social impacts in the villages with active community participation in forest management. Participation from local people was important, especially from the point of view of rule-making and equitable management of resource use. Research has demonstrated that local participation in forest management has led to better forest management as this provides rights to make and modify rules for the use of common pool resources. In forests monitored by the FD, local communities indicated a feeling of alienation from the forest that weakened their motivation to protect the forest and wildlife. Recognition of local community rights is essential to achieve conservation goals and reduce social conflicts outside PAs, requiring collaboration between state and local institutions.

This research supports the argument that the Indian PAs have become increasingly isolated as pressure on forests has shifted towards the portion of forests falling outside these PAs (DeFries et al. 2010). The study found that while PAs are relatively well protected, at a regional level increasing restrictions on local people have ironically led to greater fragmentation in the broader landscape, as local communities have shifted their forest access to less protected forests. Since the effective implementation of any PA program involves high economic as well as social costs, connectivity across vast landscapes cannot be provided solely by the expansion of the PA network (DeFries et al. 2007). Conservation of forest patches outside PA is crucial for social reasons such as livelihood dependence of local communities, as well as for ecological reasons including wildlife protection.

However, extension of conservation efforts outside the existing PA has resulted in restrictions on local forest resource use. Such situations arise due to differences in understanding of forest as a resource for communities and as a conservation space for endangered species. This research also addresses the need for a clearer focus on the functionality and socio-ecological outcomes of different forest management institutions to address such issues. This research can help address larger questions of how different forested patches, governed by a variety of management approaches ranging from strict conservation to more open areas, need to be integrated within regional landscape planning across a large spatial extent in order to facilitate conservation processes over the long term.

Recently, through JFM (1990s) and the Indian Forest Rights Act, 2006 (FRA, 2006), local communities have also received some *de jure* (formal) rights to access and maintain forest patches (Bose 2010; Ghate and Nagendra 2005; Sarin et al. 2003). After a long struggle, FRA, 2006 has come into effect under which villages through the village committee could apply for Community Forest Rights (CFR). Under this act, villagers will have the rights over the forest resources. However, only 3% of the total potential of CFRs has been achieved in India (CFR-LA, 2016). Among other states, Maharashtra is performing better and has achieved 18% of the total potential of the CFR (CFR-LA, 2016). However, implementation of the CFR is still problematic mainly due to lack of FD and political support (Kothari 2011). In order to facilitate implementation of CFR rights and ensure communities manage the forest sustainably, the Ministry of Tribal Affairs (MoTA) and the Ministry of Environment, Forest and Climate Change (MoEFCC) have established a joint committee to prepare the guideline for CFR (http://fracommittee.icfre.org/). This research has not looked the functionality of CFR in particular due to lack of evidence at regional level during the time of field work. However, this research can provide empirical evidence that giving rights to the community for extended periods can bring about effective management of the forest.

This research found that participation from local people is important, especially from the point of view of rule-making and equitable management of resource use. This research has demonstrated that local participation in forest management has led to better forest management as this provides rights to make and modify rules for the use of common pool resources and also maintain the tree diversity of the forest patches. Whereas FD has increased restrictions on local communities over the use of forest resources which had adverse impacts on their livelihoods. This has alienated local communities by taking away the sense of belonging from them. It also has in a way discouraged communities to continue with their informal practices of sustainable use. In contrast, there was positive social implication in the villages with active participation in forest management.

This research also demonstrates how information on spatial changes in pattern, derived from RS coupled with forest change and fragmentation analysis, can be linked to social surveys to understand the underlying social drivers, establishing a clearer understanding of the pattern-process linkage. Such interdisciplinary research helps develop a better understanding of the human factors shaping deforestation at a regional scale and can help design solutions that go beyond the dominant PA-centric approach, to address the reality of conservation in the human-dominated contested landscapes of the tropics.

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Appendices

Appendix 4.1. Comparison between villages with forest division based on Mann–Whitney U test

Vegetation Variable	Forest Division	Statistic	*p* Value
Tree density (no. of trees/ha)	Bhandara	7033.5	<00.1***
	Brahmapuri	7137	<00.1***
	Chandrapur_non_buffer	5994	<00.1***
	Gadchiroli	5701.5	<00.1***
	Gondia	5895	<00.1***
	Nagpur	3789	0.4
	Wadsa	6525	<00.1***
Species richness	Bhandara	5980.5	<00.1***
	Brahmapuri	7497	<00.1***
	Chandrapur_non_buffer	5251.5	<00.1***
	Gadchiroli	5242.5	<00.1***
	Gondia	4923	0.01**
	Nagpur	3609	0.2
	Wadsa	6129	<00.1***
Tree biomass	Bhandara	6012	<00.1***
	Brahmapuri	7254	<00.1***
	Chandrapur_non_buffer	3159	0.01**
	Gadchiroli	3492	0.11
	Gondia	4473	0.22
	Nagpur	3978	0.8
	Wadsa	2412	<00.1***

Significance codes: *** 0.001, ** 0.01, * 0.05, · 0.1, 1.

Appendix 4.2. Names of the ten most abundant tree species in the forest patch of villages with and without forest institutions

S.no	Forest institutions	Species name	Tree Abundance	Percent
1	Present	*Terminalia alata*	1982	20.93
2	Present	*Cleistanthus collinus*	1529	16.15
3	Present	*Diospyros melanoxylon*	874	9.23
4	Present	*Tectona grandis*	845	8.92
5	Present	*Chloroxylon swietenia*	796	8.41
6	Present	*Woodfordia fruticosa*	714	7.54
7	Present	*Maytenus emarginata*	701	7.40
8	Present	*Lagerstroemia parviflora*	701	7.40
9	Present	*Holarrhena antidysenterica*	677	7.15
10	Present	*Anogeissus latifolia*	649	6.85
11	Absent	*Terminalia alata*	1170	15.81
12	Absent	*Diospyros melanoxylon*	1022	13.81
13	Absent	*Lagerstroemia parviflora*	974	13.16
14	Absent	*Chloroxylon swietenia*	877	11.85
15	Absent	*Cleistanthus collinus*	797	10.77
16	Absent	*Woodfordia fruticosa*	565	7.63
17	Absent	*Maytenus emarginata*	522	7.05
18	Absent	*Anogeissus latifolia*	508	6.86
19	Absent	*Tectona grandis*	502	6.78
20	Absent	*Holarrhena antidysenterica*	464	6.27

Appendix 4.3. Names of the ten tree species contributing most biomass in the forest patch of villages with and without forest institutions

S.no	Forest institutions	Species name	Biomass (kg)	Percent
1	Present	*Terminalia alata*	6730.374	25.52
2	Present	*Tectona grandis*	3728.489	14.14
3	Present	*Madhuca longifolia*	2921.323	11.08
4	Present	*Pterocarpus marsupium*	2275.779	8.63
5	Present	*Anogeissus latifolia*	2239.507	8.49
6	Present	*Dalbergia paniculata*	1998.019	7.57
7	Present	*Schleichera oleosa*	1918.482	7.27
8	Present	*Soymida febrifuga*	1691.137	6.41
9	Present	*Chloroxylon swietenia*	1493.544	5.66
10	Present	*Lannea coromandelica*	1380.202	5.23
11	Absent	*Terminalia alata*	5876.973	27.47
12	Absent	*Madhuca longifolia*	3278.234	15.32
13	Absent	*Tectona grandis*	2249.574	10.51
14	Absent	*Chloroxylon swietenia*	1729.708	8.08
15	Absent	*Anogeissus latifolia*	1636.883	7.65
16	Absent	*Diospyros melanoxylon*	1613.406	7.54
17	Absent	*Soymida febrifuga*	1553.449	7.26
18	Absent	*Butea monosperma*	1288.063	6.02
19	Absent	*Lannea coromandelica*	1085.699	5.07
20	Absent	*Cleistanthus collinus*	1083.536	5.06

Appendix 4.4. Tree species richness, tree abundance, and tree biomass among sampled villages

Village code	Tree species richness	Tree abundance	Tree Biomass (kg)
V1	61	1823	5820.11
V2	51	816	2007.44
V3	58	2613	2564.65
V4	15	1199	511.84
V5	60	1504	5309.44
V7	53	1327	2338.50
V8	49	864	5558.28
V9	66	1512	7502.82
V10	42	1073	7710.47
V11	54	1382	6621.03
V12	38	773	5858.85
V13	53	1174	4271.88
V14	51	1361	4004.17
V15	57	2552	3357.02
V16	52	1930	4858.17

Appendix 4.5. Tree species richness, tree abundance, tree height, tree DBH, and biomass among sampled plots

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
1	V1	1	4	29	923.1	42.52	18.04	13.5	9.08	9.08	207.86
2	V1	2	2	8	254.65	55.13	22.93	16	10.56	10.56	112.77
3	V1	3	10	55	1750.7	24.89	15.93	11	4.71	4.71	79.37
4	V1	4	5	28	891.27	38.00	35.75	7	4.64	4.64	69.24
5	V1	5	5	24	763.94	50.21	46.94	15	7.65	7.65	542.57
6	V1	6	11	32	1018.6	22.63	19.38	6	4.13	4.13	38.11
7	V1	7	8	22	700.28	35.27	56.84	25	6.05	6.05	780.66
8	V1	8	7	18	572.96	37.44	35.71	12	5.33	5.33	57.78
9	V1	9	6	38	1209.6	42.61	31.21	26	8.14	8.14	302.83
10	V1	10	5	17	541.13	87.24	80.08	12	7.34	7.34	119.57
11	V1	11	12	63	2005.4	15.02	10.40	8	2.64	2.64	25.06
12	V1	12	10	42	1336.9	14.86	7.18	6	3.54	3.54	13.53
13	V1	13	14	37	1177.7	43.43	46.85	28	7.75	7.75	355.14
14	V1	14	12	42	1336.9	20.60	15.70	15	3.89	3.89	71.95
15	V1	15	7	28	891.27	22.96	27.14	8.5	3.57	3.57	72.71
16	V1	16	11	32	1018.6	30.97	31.51	15	4.04	4.04	140.76
17	V1	17	5	12	381.97	55.08	47.95	12	6.17	6.17	189.07
18	V1	18	11	71	2260	17.13	9.09	5	2.93	2.93	23.99
19	V1	19	8	71	2260	22.44	15.93	8	3.32	3.32	60.25
20	V1	20	9	77	2451	23.52	25.53	15	3.81	3.81	180.03
21	V1	21	7	34	1082.3	47.15	40.14	9.5	5.66	5.66	86.30
22	V1	22	9	39	1241.4	35.92	26.14	10	5.70	5.70	89.59
23	V1	23	8	26	827.61	38.54	44.28	20	6.00	6.00	445.09
24	V1	24	9	29	923.1	43.59	28.95	18	8.28	8.28	125.74

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
25	V1	25	6	27	859.44	36.15	20.48	13	8.99	8.99	103.71
26	V1	26	5	10	318.31	84.50	70.56	28	15.4	15.46	957.40
27	V1	27	10	56	1782.5	21.16	29.63	15	3.69	3.69	233.37
28	V1	28	10	36	1145.9	31.19	29.63	13	5.72	5.72	137.02
29	V1	29	9	48	1527.9	17.69	9.68	10	3.86	3.86	31.10
30	V1	30	10	46	1464.2	25.52	25.85	18	3.83	3.83	163.27
31	V2	1	12	53	1687	20.68	15.02	12	4.40	4.40	88.57
32	V2	2	11	37	1177.7	21.19	16.60	10.5	4.87	4.87	46.15
33	V2	3	7	25	795.77	15.60	9.34	4	2.42	2.42	5.68
34	V2	4	3	10	318.31	31.00	51.75	12	3.37	3.37	76.40
35	V2	5	4	8	254.65	22.13	31.48	8	2.50	2.50	16.50
36	V2	6	2	4	127.32	48.00	71.35	11.5	4.75	4.75	74.19
37	V2	7	5	14	445.63	39.21	40.03	15	3.84	3.84	150.83
38	V2	8	2	2	63.662	58.00	67.88	4.5	3.50	3.50	14.80
39	V2	9	7	16	509.3	38.25	40.32	11	3.89	3.89	100.43
40	V2	10	4	10	318.31	66.90	55.83	18	5.00	5.00	213.80
41	V2	11	8	17	541.13	40.65	44.97	10.5	4.14	4.14	142.96
42	V2	12	6	18	572.96	27.06	25.54	9	3.08	3.08	65.91
43	V2	13	5	8	254.65	21.75	22.08	7	3.28	3.28	13.54
44	V2	14	2	2	63.662	147.50	60.10	12	9.00	9.00	139.44
45	V2	15	2	5	159.15	13.80	3.83	2	1.72	1.72	0.58
46	V2	16	4	8	254.65	58.88	59.66	12	5.31	5.31	178.87
47	V2	17	5	21	668.45	37.90	26.79	8	3.43	3.43	62.52
48	V2	18	9	15	477.46	28.80	13.92	8.5	5.21	5.21	25.11
49	V2	19	3	5	159.15	21.60	18.98	6	3.00	3.00	5.89
50	V2	20	3	14	445.63	37.71	59.26	15	3.66	3.66	122.37
51	V2	21	7	54	1718.9	18.09	9.84	10	3.95	3.95	47.99

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
52	V2	22	6	11	350.14	27.45	19.85	10	5.14	5.14	36.50
53	V2	23	14	22	700.28	18.23	12.34	8	3.80	3.80	15.64
54	V2	24	7	12	381.97	23.75	17.94	6	3.75	3.75	8.69
55	V2	25	2	4	127.32	18.00	12.33	3.5	2.68	2.68	1.35
56	V2	26	7	8	254.65	41.13	31.83	11.5	5.50	5.50	28.81
57	V2	27	4	6	190.99	48.00	45.74	6.5	3.78	3.78	18.76
58	V2	28	3	3	95.493	59.67	64.61	9	5.50	5.50	33.20
59	V2	29	7	9	286.48	44.67	40.85	17	4.92	4.92	58.38
60	V2	30	9	21	668.45	46.71	48.92	18	6.25	6.25	210.26
61	V3	1	9	26	827.61	56.00	22.67	13.5	9.58	9.58	251.37
62	V3	2	9	60	1909.9	35.88	25.79	11	6.06	6.06	200.43
63	V3	3	4	28	891.27	46.96	20.02	10	6.36	6.36	126.21
64	V3	4	5	37	1177.7	39.84	18.57	12	7.80	7.80	229.98
65	V3	5	8	57	1814.4	22.89	13.35	6	3.74	3.74	41.96
66	V3	6	6	49	1559.7	12.59	7.36	8	2.21	2.21	13.51
67	V3	7	17	86	2737.5	22.59	19.39	11	4.96	4.96	133.87
68	V3	8	14	61	1941.7	21.56	15.66	8.5	4.34	4.34	67.02
69	V3	9	10	45	1432.4	33.18	24.06	12	5.78	5.78	138.37
70	V3	10	12	59	1878	29.00	22.07	9	4.72	4.72	116.07
71	V3	11	12	58	1846.2	30.90	25.48	8.5	5.03	5.03	103.58
72	V3	12	12	51	1623.4	30.33	29.03	9	4.60	4.60	123.24
73	V3	13	6	27	859.44	31.41	18.88	8.5	5.46	5.46	59.27
74	V3	14	10	44	1400.6	28.05	18.80	12	5.72	5.72	128.62
75	V3	15	9	40	1273.2	30.40	19.51	10	5.12	5.12	89.73
76	V3	16	8	31	986.76	32.65	22.06	11	5.72	5.72	122.74
77	V3	17	5	17	541.13	29.12	14.73	8.5	4.82	4.82	23.84
78	V3	18	4	18	572.96	30.33	21.17	6.5	4.31	4.31	31.43

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
79	V3	19	3	18	572.96	54.39	56.45	7	4.02	4.02	60.56
80	V3	20	3	53	1687	29.53	25.87	7	3.96	3.96	43.54
81	V3	21	5	41	1305.1	31.41	23.52	7	3.23	3.23	36.76
82	V3	22	6	55	1750.7	28.22	23.20	10	2.96	2.96	66.13
83	V3	23	3	13	413.8	10.00	0.00	2.5	1.85	1.85	3.44
84	V3	24	7	23	732.11	25.13	24.82	13	4.35	4.35	74.93
85	V3	25	7	9	286.48	29.22	11.78	7.5	4.44	4.44	19.96
86	V3	26	6	59	1878	22.07	14.30	5.5	2.90	2.90	19.73
87	V3	27	10	50	1591.5	22.86	11.85	10	4.51	4.51	57.57
88	V3	28	8	58	1846.2	23.33	11.91	11	5.10	5.10	88.68
89	V3	29	8	76	2419.2	15.76	10.32	10	4.09	4.09	53.62
90	V3	30	8	55	1750.7	21.11	11.77	6.5	3.38	3.38	34.09
91	V4	1	3	49	1559.7	26.51	12.16	8.5	5.54	5.54	69.76
92	V4	2	4	28	891.27	29.82	23.96	8.5	5.07	5.07	50.34
93	V4	3	4	25	795.77	15.16	12.20	6.5	3.42	3.42	10.53
94	V4	4	3	25	795.77	13.48	8.88	3.5	2.64	2.64	3.32
95	V4	5	4	48	1527.9	13.06	7.11	7	2.60	2.60	12.61
96	V4	6	2	9	286.48	13.00	4.36	4	2.83	2.83	1.49
97	V4	7	2	6	190.99	10.83	2.04	3	2.12	2.12	0.74
98	V4	8	5	12	381.97	16.08	10.26	5.5	3.54	3.54	3.93
99	V4	9	1	2	63.662	12.00	2.83	3.5	3.00	3.00	0.32
100	V4	10	2	5	159.15	11.20	2.68	4	2.80	2.80	0.73
101	V4	11	3	13	413.8	15.00	8.86	6.5	2.90	2.90	4.10
102	V4	12	1	1	31.831	33.00	NA	9	9.00	9.00	2.90
103	V4	13	4	20	636.62	12.15	3.99	4.2	2.54	2.54	3.09
104	V4	14	3	4	127.32	10.50	1.00	3.5	2.75	2.75	0.39
105	V4	15	2	35	1114.1	20.54	6.60	7	5.09	5.09	28.21

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
106	V4	16	4	29	923.1	24.21	6.58	8	5.72	5.72	34.17
107	V4	17	5	31	986.76	15.97	10.26	8	3.32	3.32	21.02
108	V4	18	2	3	95.493	12.33	2.52	4	3.17	3.17	0.52
109	V4	19	6	28	891.27	19.07	13.88	8	3.78	3.78	21.47
110	V4	20	2	2	63.662	18.00	5.66	4	4.00	4.00	0.86
111	V4	21	5	25	795.77	19.20	14.17	7.5	3.70	3.70	25.35
112	V4	22	2	5	159.15	59.60	66.65	12	6.50	6.50	139.97
113	V4	23	1	1	31.831	14.00	NA	4	4.00	4.00	0.23
114	V4	24	3	8	254.65	38.63	41.56	12	5.81	5.81	35.70
115	V4	25	6	21	668.45	19.24	15.56	12	4.02	4.02	26.91
116	V4	26	1	1	31.831	10.00	NA	2.5	2.50	2.50	0.07
117	V4	27	1	1	31.831	10.00	NA	2.5	2.50	2.50	0.08
118	V4	28	1	1	31.831	31.00	NA	6	6.00	6.00	1.82
119	V4	29	1	2	63.662	17.50	10.61	3	2.75	2.75	0.40
120	V4	30	NA	NA	NA	NA	NA	NA	NA	NA	NA
121	V5	1	5	15	477.46	28.87	24.17	8.5	3.51	3.51	39.40
122	V5	2	5	6	190.99	23.50	18.67	4.5	2.88	2.88	5.69
123	V5	3	8	18	572.96	25.00	29.34	11	3.91	3.91	84.64
124	V5	4	7	19	604.79	22.00	20.37	7	2.63	2.63	30.32
125	V5	5	7	50	1591.5	31.70	28.89	12	5.48	5.48	224.09
126	V5	6	9	10	318.31	38.70	30.84	9.5	6.20	6.20	65.90
127	V5	7	7	19	604.79	62.89	47.44	22	11.3	11.39	347.97
128	V5	8	6	15	477.46	56.47	41.58	19	7.93	7.93	218.89
129	V5	9	8	21	668.45	32.43	35.02	17	6.38	6.38	134.36
130	V5	10	7	14	445.63	59.21	48.79	14	7.66	7.66	210.39
131	V5	11	5	9	286.48	53.56	48.20	13	8.11	8.11	167.75
132	V5	12	10	23	732.11	15.91	13.78	4.5	2.35	2.35	9.75

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
133	V5	13	5	6	190.99	61.50	46.47	12	5.67	5.67	70.59
134	V5	14	5	24	763.94	41.71	30.95	16	6.00	6.00	166.85
135	V5	15	10	26	827.61	20.19	16.42	8	4.01	4.01	32.33
136	V5	16	13	36	1145.9	35.33	33.37	17	6.36	6.36	306.20
137	V5	17	9	13	413.8	50.92	40.34	18	8.81	8.81	147.97
138	V5	18	12	23	732.11	41.57	39.38	16	7.26	7.26	284.73
139	V5	19	10	19	604.79	39.63	43.09	16	5.62	5.62	174.22
140	V5	20	9	32	1018.6	16.66	18.44	12	3.56	3.56	40.46
141	V5	21	6	14	445.63	59.50	70.23	20	7.43	7.43	637.27
142	V5	22	7	13	413.8	55.85	41.44	18	10.7	10.78	340.60
143	V5	23	8	24	763.94	34.63	25.23	14	6.58	6.58	142.88
144	V5	24	5	7	222.82	42.86	66.01	15	6.21	6.21	197.97
145	V5	25	7	17	541.13	39.29	26.63	20	9.25	9.25	143.27
146	V5	26	7	22	700.28	48.50	40.20	11	5.19	5.19	69.67
147	V5	27	7	21	668.45	61.29	55.96	20	10.1	10.10	394.77
148	V5	28	6	8	254.65	62.00	18.21	16	12.3	12.38	166.25
149	V5	29	5	11	350.14	75.27	62.71	19	12.6	12.64	331.00
150	V5	30	8	15	477.46	39.60	32.45	20	8.91	8.91	119.55
151	V7	1	6	12	381.97	44.25	69.01	20	8.71	8.71	311.27
152	V7	2	3	15	477.46	36.33	43.10	10	5.69	5.69	122.50
153	V7	3	8	41	1305.1	17.51	7.88	9	3.75	3.75	24.05
154	V7	4	6	11	350.14	21.27	6.42	5.5	3.18	3.18	6.61
155	V7	5	5	14	445.63	23.50	9.40	7.5	4.64	4.64	13.02
156	V7	6	6	9	286.48	46.00	58.96	12	4.83	4.83	181.19
157	V7	7	4	7	222.82	13.57	7.35	3.5	2.36	2.36	0.89
158	V7	8	2	15	477.46	29.60	6.88	8	5.83	5.83	30.03
159	V7	9	3	8	254.65	34.25	9.72	8	4.96	4.96	19.41

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
160	V7	10	6	21	668.45	23.67	28.06	18	4.15	4.15	121.71
161	V7	11	8	23	732.11	21.74	21.62	7	2.91	2.91	13.95
162	V7	12	5	38	1209.6	25.68	12.22	10	5.03	5.03	62.70
163	V7	13	7	28	891.27	36.71	21.70	16	6.88	6.88	131.48
164	V7	14	3	31	986.76	30.65	16.42	9.5	6.21	6.21	76.06
165	V7	15	6	17	541.13	41.65	33.01	21	7.51	7.51	139.79
166	V7	16	4	9	286.48	45.89	44.57	13	7.61	7.61	67.83
167	V7	17	5	20	636.62	17.05	10.37	4.5	3.35	3.35	6.75
168	V7	18	7	23	732.11	29.00	32.62	11	4.22	4.22	72.29
169	V7	19	7	24	763.94	38.79	39.39	10	6.75	6.75	95.29
170	V7	20	7	31	986.76	25.29	13.32	10	7.19	7.19	51.87
171	V7	21	5	9	286.48	38.56	45.50	14	4.83	4.83	72.09
172	V7	22	12	133	4233.5	13.64	8.45	9	3.00	3.00	39.53
173	V7	23	10	19	604.79	21.16	29.94	18	4.45	4.45	134.35
174	V7	24	5	18	572.96	25.00	17.04	13	7.42	7.42	39.23
175	V7	25	6	29	923.1	33.28	21.76	15	7.46	7.46	126.38
176	V7	26	7	20	636.62	39.50	26.94	12	7.66	7.66	142.08
177	V7	27	8	28	891.27	32.93	20.56	12	7.20	7.20	114.60
178	V7	28	10	58	1846.2	24.05	24.56	16	4.60	4.60	94.97
179	V7	29	9	38	1209.6	17.63	11.62	8	3.93	3.93	20.40
180	V7	30	2	11	350.14	14.91	4.53	4	2.68	2.68	2.41
181	V8	1	5	8	254.65	37.50	33.80	10	4.81	4.81	48.99
182	V8	2	NA	NA	NA	NA	NA	NA	NA	NA	NA
183	V8	3	2	3	95.493	236.67	118.15	12	12.0	12.00	471.81
184	V8	4	6	7	222.82	48.29	31.42	6.5	3.14	3.14	17.78
185	V8	5	NA	NA	NA	NA	NA	NA	NA	NA	NA
186	V8	6	6	11	350.14	52.09	80.65	15	4.94	4.94	441.74

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
187	V8	7	4	7	222.82	87.86	83.86	22	10.86	10.86	613.46
188	V8	8	3	3	95.493	95.67	92.88	18	9.83	9.83	231.04
189	V8	9	5	11	350.14	65.00	39.36	11	6.50	6.50	146.18
190	V8	10	4	22	700.28	18.95	21.98	4.5	2.41	2.41	6.65
191	V8	11	4	26	827.61	21.69	9.45	6	3.56	3.56	16.70
192	V8	12	7	11	350.14	57.82	51.91	11.5	5.59	5.59	144.28
193	V8	13	8	22	700.28	18.64	8.90	6	3.41	3.41	11.62
194	V8	14	8	37	1177.7	28.19	29.36	9.5	3.84	3.84	97.61
195	V8	15	7	10	318.31	50.60	83.60	20	5.20	5.20	575.86
196	V8	16	3	14	445.63	61.93	40.95	9	6.04	6.04	98.77
197	V8	17	5	29	923.1	24.86	21.29	12	3.40	3.40	49.04
198	V8	18	6	14	445.63	29.36	25.73	8	4.07	4.07	31.26
199	V8	19	4	8	254.65	71.88	77.60	16	7.38	7.38	429.65
200	V8	20	5	13	413.8	36.77	38.04	11	4.48	4.48	121.25
201	V8	21	8	18	572.96	53.17	68.91	22	6.57	6.57	767.10
202	V8	22	6	24	763.94	30.29	17.75	15	5.90	5.90	66.39
203	V8	23	2	8	254.65	19.38	9.24	5.5	4.00	4.00	3.56
204	V8	24	3	13	413.8	46.85	41.41	9	5.86	5.86	115.55
205	V8	25	9	29	923.1	31.72	41.25	12	5.23	5.23	266.71
206	V8	26	4	13	413.8	46.92	60.20	18	6.54	6.54	399.45
207	V8	27	3	4	127.32	67.00	57.88	11	4.80	4.80	94.08
208	V8	28	8	14	445.63	32.50	41.65	16	4.59	4.59	107.46
209	V8	29	3	4	127.32	58.00	39.87	10	6.63	6.63	21.70
210	V8	30	3	3	95.493	98.00	97.52	18	7.67	7.67	159.71
211	V9	1	7	21	668.45	32.52	35.12	12.5	4.76	4.76	164.09
212	V9	2	5	9	286.48	32.33	15.46	8	4.81	4.81	18.81
213	V9	3	3	47	1496.1	24.98	20.72	8	4.96	4.96	60.55

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
214	V9	4	8	28	891.27	35.79	25.02	10	5.38	5.38	83.41
215	V9	5	8	28	891.27	47.04	47.98	15	6.54	6.54	251.83
216	V9	6	8	39	1241.4	21.08	21.88	12	3.52	3.52	64.84
217	V9	7	7	11	350.14	65.27	31.61	14	9.27	9.27	199.02
218	V9	8	12	22	700.28	57.55	47.92	25	14.7	14.75	254.51
219	V9	9	13	57	1814.4	31.42	27.79	12	4.96	4.96	202.89
220	V9	10	4	10	318.31	112.90	136.03	18	9.75	9.75	1065.40
221	V9	11	7	26	827.61	23.58	19.47	10	4.30	4.30	42.79
222	V9	12	7	11	350.14	49.00	21.53	12	6.86	6.86	51.83
223	V9	13	10	26	827.61	40.73	33.49	18	6.10	6.10	223.27
224	V9	14	6	29	923.1	44.41	61.96	12	4.05	4.05	322.67
225	V9	15	4	20	636.62	52.80	34.03	10	6.19	6.19	138.31
226	V9	16	5	31	986.76	45.32	25.82	13	6.53	6.53	167.09
227	V9	17	3	6	190.99	79.00	66.52	14	6.58	6.58	206.81
228	V9	18	8	12	381.97	47.33	43.72	14	6.08	6.08	99.50
229	V9	19	6	25	795.77	32.08	19.27	14	6.14	6.14	102.36
230	V9	20	3	21	668.45	62.10	51.89	10	5.98	5.98	185.32
231	V9	21	11	41	1305.1	32.07	33.38	16	4.80	4.80	182.33
232	V9	22	11	34	1082.3	31.15	35.28	12	4.46	4.46	142.46
233	V9	23	12	67	2132.7	26.94	22.00	13	5.10	5.10	168.59
234	V9	24	15	49	1559.7	41.24	29.03	13	6.72	6.72	321.66
235	V9	25	5	13	413.8	34.15	25.53	13	4.85	4.85	51.18
236	V9	26	9	25	795.77	52.48	59.67	18	7.12	7.12	634.87
237	V9	27	11	34	1082.3	60.97	88.17	16	6.52	6.52	1546.50
238	V9	28	5	51	1623.4	19.96	24.36	11	4.35	4.35	83.46
239	V9	29	14	26	827.61	40.00	40.31	15	6.44	6.44	338.88
240	V9	30	6	20	636.62	29.15	36.08	15	4.48	4.48	124.25

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
241	V10	1	7	13	413.8	80.00	63.13	20	7.73	7.73	543.09
242	V10	2	8	10	318.31	66.30	39.31	16	7.98	7.98	175.49
243	V10	3	5	9	286.48	61.67	46.93	17	9.13	9.13	229.28
244	V10	4	4	17	541.13	42.88	65.20	10	3.53	3.53	132.20
245	V10	5	8	8	254.65	55.13	49.82	19	8.69	8.69	257.72
246	V10	6	4	32	1018.6	34.00	33.85	13	4.79	4.79	137.22
247	V10	7	4	7	222.82	107.86	43.32	18	13.5	13.57	383.18
248	V10	8	4	21	668.45	41.67	37.66	13	6.27	6.27	132.34
249	V10	9	2	2	63.662	105.50	36.06	21	13.5	13.50	112.02
250	V10	10	5	17	541.13	48.59	37.37	15	6.68	6.68	203.17
251	V10	11	5	9	286.48	111.56	124.35	14	6.41	6.41	214.02
252	V10	12	8	29	923.1	30.69	25.81	12	5.53	5.53	128.40
253	V10	13	5	6	190.99	132.67	47.00	21	15.3	15.33	593.94
254	V10	14	NA	NA	NA	NA	NA	NA	NA	NA	NA
255	V10	15	7	29	923.1	28.69	27.56	7.5	3.83	3.83	72.53
256	V10	16	6	28	891.27	45.32	28.99	15	5.31	5.31	213.88
257	V10	17	9	16	509.3	42.75	23.12	10	5.61	5.61	209.28
258	V10	18	8	25	795.77	32.76	33.12	15	4.39	4.39	156.36
259	V10	19	2	6	190.99	41.50	35.96	9	5.33	5.33	33.07
260	V10	20	7	17	541.13	37.12	27.43	11	4.00	4.00	49.98
261	V10	21	6	9	286.48	61.67	45.27	19	7.61	7.61	337.36
262	V10	22	3	13	413.8	62.38	78.14	20	7.71	7.71	425.80
263	V10	23	5	12	381.97	62.25	64.72	18	6.67	6.67	309.07
264	V10	24	7	21	668.45	32.62	31.31	8.2	4.05	4.05	89.24
265	V10	25	7	25	795.77	38.36	47.77	22	5.36	5.36	460.60
266	V10	26	6	17	541.13	40.94	41.20	12	5.64	5.64	218.42
267	V10	27	6	8	254.65	137.13	126.81	18	10.3	10.38	1360.08

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
268	V10	28	6	34	1082.3	33.85	52.05	10	3.76	3.76	200.82
269	V10	29	9	54	1718.9	35.44	27.07	15	6.49	6.49	265.34
270	V10	30	15	56	1782.5	20.11	13.61	14	5.13	5.13	63.83
271	V11	1	9	53	1687	27.45	27.73	22	5.34	5.34	296.16
272	V11	2	10	48	1527.9	26.46	25.65	17	5.57	5.57	259.72
273	V11	3	9	59	1878	24.56	16.34	12	6.08	6.08	138.63
274	V11	4	11	40	1273.2	24.88	30.84	17	3.68	3.68	240.85
275	V11	5	9	19	604.79	55.89	64.08	20	7.19	7.19	456.81
276	V11	6	6	61	1941.7	28.67	11.52	18	9.71	9.71	249.74
277	V11	7	6	40	1273.2	26.30	24.75	17	6.18	6.18	223.27
278	V11	8	12	21	668.45	43.48	35.11	14	6.35	6.35	180.87
279	V11	9	6	13	413.8	90.54	52.18	18	12.6	12.62	503.78
280	V11	10	7	41	1305.1	16.63	4.54	7	3.34	3.34	14.93
281	V11	11	12	34	1082.3	21.38	13.48	9	4.12	4.12	38.67
282	V11	12	6	28	891.27	27.89	29.07	12	3.86	3.86	106.58
283	V11	13	3	8	254.65	62.63	61.20	9.5	5.13	5.13	101.79
284	V11	14	2	23	732.11	37.22	27.09	13	6.01	6.01	167.13
285	V11	15	6	27	859.44	30.78	30.10	12	4.09	4.09	110.47
286	V11	16	4	30	954.93	24.70	14.16	8.5	3.57	3.57	32.01
287	V11	17	1	4	127.32	91.00	41.48	16	12.5	12.50	201.05
288	V11	18	6	23	732.11	51.00	44.75	19	7.09	7.09	238.27
289	V11	19	4	14	445.63	43.14	31.69	6	3.31	3.31	22.62
290	V11	20	4	13	413.8	30.62	22.37	7	4.12	4.12	26.47
291	V11	21	5	20	636.62	36.70	61.59	22	4.95	4.95	405.41
292	V11	22	4	46	1464.2	26.24	29.12	25	4.23	4.23	227.37
293	V11	23	6	23	732.11	47.70	49.88	22	8.04	8.04	612.73
294	V11	24	18	53	1687	21.00	21.78	9	4.28	4.28	90.58

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
295	V11	25	19	55	1750.7	25.33	23.23	12	5.02	5.02	102.47
296	V11	26	10	26	827.61	29.19	33.51	20	5.06	5.06	286.18
297	V11	27	10	38	1209.6	33.45	33.76	20	5.47	5.47	285.02
298	V11	28	8	20	636.62	62.70	48.27	22	8.40	8.40	505.69
299	V11	29	11	55	1750.7	27.73	20.72	17	5.55	5.55	178.51
300	V11	30	12	51	1623.4	25.33	32.28	25	5.29	5.29	314.98
301	V12	1	3	6	190.99	56.67	23.28	8	6.00	6.00	48.50
302	V12	2	4	9	286.48	75.11	61.09	16	6.67	6.67	281.86
303	V12	3	9	25	795.77	35.04	24.08	12	5.93	5.93	116.58
304	V12	4	11	26	827.61	35.27	24.43	11	6.10	6.10	100.51
305	V12	5	9	26	827.61	32.81	28.25	14	5.50	5.50	147.59
306	V12	6	11	47	1496.1	27.38	19.48	17	6.33	6.33	179.23
307	V12	7	8	44	1400.6	31.68	18.69	12	6.72	6.72	178.64
308	V12	8	13	58	1846.2	24.83	12.35	14	6.28	6.28	108.09
309	V12	9	9	27	859.44	33.74	14.85	14	8.25	8.25	118.52
310	V12	10	5	26	827.61	34.04	17.99	16	8.62	8.62	159.00
311	V12	11	NA	NA	NA	NA	NA	NA	NA	NA	NA
312	V12	12	3	4	127.32	61.50	48.16	15	9.00	9.00	87.67
313	V12	13	3	4	127.32	117.50	63.06	16	10.1	10.13	299.19
314	V12	14	7	19	604.79	28.84	23.75	9.5	4.23	4.23	54.32
315	V12	15	6	25	795.77	26.28	20.84	10	3.60	3.60	41.08
316	V12	16	6	13	413.8	60.69	81.23	17	6.46	6.46	277.80
317	V12	17	3	11	350.14	78.91	56.55	17	10.1	10.11	346.34
318	V12	18	5	5	159.15	79.60	36.07	15	10.1	10.10	127.86
319	V12	19	2	8	254.65	69.00	36.18	22	8.65	8.65	141.76
320	V12	20	5	10	318.31	78.10	34.39	24	11.9	11.92	334.81
321	V12	21	3	9	286.48	58.44	36.51	13	7.08	7.08	74.72

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
322	V12	22	7	27	859.44	40.33	27.55	20	10.4	10.43	255.38
323	V12	23	6	23	732.11	40.43	40.64	16	8.02	8.02	200.34
324	V12	24	10	30	954.93	47.57	33.00	14	7.30	7.30	196.94
325	V12	25	5	26	827.61	27.65	22.62	11	4.26	4.26	45.19
326	V12	26	7	13	413.8	83.46	80.02	28	11.1	11.15	652.65
327	V12	27	4	25	795.77	35.12	26.41	19	8.27	8.27	166.13
328	V12	28	6	13	413.8	48.77	17.86	25	13.1	13.15	188.99
329	V12	29	10	20	636.62	59.30	54.04	28	8.19	8.19	672.09
330	V12	30	7	7	222.82	79.29	42.54	26	13.0	13.07	255.76
331	V13	1	3	28	891.27	25.93	19.50	10	4.53	4.53	54.04
332	V13	2	8	64	2037.2	24.69	14.73	15.5	6.40	6.40	123.59
333	V13	3	7	17	541.13	34.24	27.67	15	5.76	5.76	108.93
334	V13	4	7	14	445.63	35.36	34.62	15	5.07	5.07	109.90
335	V13	5	12	39	1241.4	31.08	22.37	12	5.73	5.73	167.03
336	V13	6	6	18	572.96	19.17	14.44	8	2.58	2.58	17.29
337	V13	7	9	36	1145.9	21.97	25.25	15	3.97	3.97	116.24
338	V13	8	15	31	986.76	30.45	22.13	12.5	5.92	5.92	108.64
339	V13	9	5	7	222.82	38.43	30.64	16	6.71	6.71	44.63
340	V13	10	12	28	891.27	38.89	27.98	15	7.50	7.50	216.92
341	V13	11	6	18	572.96	52.72	32.02	18	9.29	9.29	273.37
342	V13	12	8	15	477.46	43.13	24.32	14	8.40	8.40	104.94
343	V13	13	3	7	222.82	26.29	22.68	5.5	3.43	3.43	5.98
344	V13	14	8	18	572.96	33.83	23.08	12.5	6.47	6.47	76.23
345	V13	15	8	40	1273.2	17.18	9.62	7	3.46	3.46	16.77
346	V13	16	9	20	636.62	45.00	47.89	16	5.59	5.59	206.37
347	V13	17	6	27	859.44	21.19	11.91	7	3.50	3.50	14.88
348	V13	18	11	28	891.27	40.07	28.68	18	7.20	7.20	203.19

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
349	V13	19	11	35	1114.1	34.57	23.39	14	6.59	6.59	155.91
350	V13	20	9	24	763.94	53.83	29.22	17.5	9.98	9.98	256.39
351	V13	21	14	49	1559.7	39.12	32.35	15	6.70	6.70	239.62
352	V13	22	10	35	1114.1	23.94	19.31	12	4.36	4.36	86.79
353	V13	23	2	19	604.79	51.16	32.87	18	10.91	10.91	376.93
354	V13	24	3	5	159.15	42.40	21.02	10	6.90	6.90	25.61
355	V13	25	6	39	1241.4	22.08	17.28	8	3.86	3.86	41.75
356	V13	26	6	14	445.63	65.14	59.61	20	7.46	7.46	185.65
357	V13	27	9	31	986.76	47.00	32.39	15	6.92	6.92	213.13
358	V13	28	11	44	1400.6	34.27	51.60	14	4.21	4.21	493.31
359	V13	29	6	15	477.46	41.47	36.89	15	6.65	6.65	147.98
360	V13	30	8	12	381.97	42.67	32.19	12.5	6.63	6.63	77.72
361	V14	1	10	25	795.77	40.60	32.75	17	7.27	7.27	210.19
362	V14	2	8	65	2069	24.72	14.56	15.5	6.42	6.42	124.61
363	V14	3	3	7	222.82	42.14	50.46	11.5	5.11	5.11	107.95
364	V14	4	6	9	286.48	71.56	104.34	18	6.40	6.40	290.09
365	V14	5	8	76	2419.2	15.11	14.89	8	3.23	3.23	59.57
366	V14	6	17	41	1305.1	29.20	25.14	17.5	5.70	5.70	241.94
367	V14	7	9	25	795.77	33.68	29.66	14.5	5.34	5.34	118.93
368	V14	8	12	57	1814.4	30.42	23.92	15	5.66	5.66	230.77
369	V14	9	11	21	668.45	48.24	37.74	18	7.19	7.19	243.02
370	V14	10	12	45	1432.4	27.16	30.61	17	4.81	4.81	240.44
371	V14	11	9	24	763.94	35.92	33.51	14	5.50	5.50	187.13
372	V14	12	13	39	1241.4	24.44	23.02	13	4.59	4.59	123.67
373	V14	13	13	42	1336.9	22.24	12.81	8.5	4.31	4.31	33.55
374	V14	14	11	20	636.62	29.90	28.55	8	3.60	3.60	54.64
375	V14	15	5	14	445.63	27.00	29.72	11	3.61	3.61	64.19

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
376	V14	16	10	26	827.61	38.46	29.32	18	5.73	5.73	217.79
377	V14	17	NA	NA	NA	NA	NA	NA	NA	NA	NA
378	V14	18	NA	NA	NA	NA	NA	NA	NA	NA	NA
379	V14	19	5	10	318.31	27.00	34.75	4.2	2.89	2.89	7.69
380	V14	20	8	29	923.1	50.31	52.17	16	4.43	4.43	206.24
381	V14	21	8	19	604.79	39.16	30.16	15	5.32	5.32	103.91
382	V14	22	6	14	445.63	42.64	34.29	13	4.80	4.80	88.91
383	V14	23	4	4	127.32	71.50	62.80	12	6.25	6.25	149.67
384	V14	24	4	22	700.28	32.68	30.87	14	4.86	4.86	93.07
385	V14	25	10	21	668.45	50.76	42.96	16	5.79	5.79	214.33
386	V14	26	9	26	827.61	23.35	24.48	13	3.48	3.48	95.85
387	V14	27	8	37	1177.7	31.59	26.32	15	5.04	5.04	170.97
388	V14	28	9	33	1050.4	28.12	27.38	17	5.15	5.15	166.01
389	V14	29	10	49	1559.7	33.16	35.98	7	3.80	3.80	77.03
390	V14	30	12	65	2069	21.02	15.89	10	4.00	4.00	78.75
391	V15	1	8	40	1273.2	35.80	27.60	14.5	5.33	5.33	129.31
392	V15	2	17	83	2642	26.48	18.04	11	5.23	5.23	101.83
393	V15	3	7	15	477.46	30.00	38.14	10.5	3.23	3.23	81.11
394	V15	4	4	36	1145.9	28.06	49.11	5.5	2.76	2.76	38.05
395	V15	5	7	18	572.96	20.56	22.67	8	2.76	2.76	37.04
396	V15	6	11	65	2069	12.43	3.39	3.5	2.30	2.30	9.44
397	V15	7	14	69	2196.3	14.93	6.04	7.7	4.42	4.42	27.63
398	V15	8	12	48	1527.9	18.08	20.68	10.5	3.63	3.63	54.79
399	V15	9	12	38	1209.6	36.08	35.43	15	4.70	4.70	191.26
400	V15	10	14	44	1400.6	24.30	17.68	7.5	4.25	4.25	48.37
401	V15	11	12	50	1591.5	26.26	21.52	9	4.70	4.70	72.07
402	V15	12	11	101	3214.9	17.63	18.00	16.5	3.19	3.19	188.46

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
403	V15	13	16	93	2960.3	21.23	22.10	24	5.75	5.75	454.01
404	V15	14	12	65	2069	24.88	18.80	8	4.92	4.92	86.46
405	V15	15	8	44	1400.6	26.09	24.02	14	5.08	5.08	134.39
406	V15	16	11	42	1336.9	26.14	31.72	12	3.63	3.63	214.70
407	V15	17	18	88	2801.1	25.38	18.59	6.5	3.84	3.84	80.56
408	V15	18	16	30	954.93	24.20	21.78	13	3.55	3.55	82.88
409	V15	19	15	37	1177.7	33.92	31.62	16	4.69	4.69	179.70
410	V15	20	20	101	3214.9	16.73	10.00	6.5	3.66	3.66	49.34
411	V15	21	11	57	1814.4	22.96	21.35	13	4.39	4.39	183.43
412	V15	22	20	92	2928.5	16.36	7.24	7	3.95	3.95	42.52
413	V15	23	14	47	1496.1	17.79	10.50	12	4.54	4.54	35.86
414	V15	24	11	57	1814.4	21.89	15.73	8	4.75	4.75	59.55
415	V15	25	15	61	1941.7	23.80	21.29	22	4.74	4.74	206.08
416	V15	26	10	53	1687	19.13	9.99	8	4.13	4.13	38.37
417	V15	27	8	55	1750.7	20.31	13.05	14	4.05	4.05	90.32
418	V15	28	10	66	2100.8	19.05	17.21	14	3.95	3.95	129.41
419	V15	29	9	39	1241.4	23.18	18.98	14	4.09	4.09	98.39
420	V15	30	10	43	1368.7	35.84	24.06	16	6.37	6.37	208.45
421	V16	1	10	37	1177.7	28.62	24.74	14.5	6.18	6.18	162.06
422	V16	2	9	20	636.62	45.25	34.70	15	8.13	8.13	161.23
423	V16	3	16	38	1209.6	36.58	21.80	15	6.12	6.12	171.07
424	V16	4	5	18	572.96	52.39	46.54	10.5	6.28	6.28	149.83
425	V16	5	10	40	1273.2	37.15	42.51	15	5.90	5.90	430.84
426	V16	6	6	28	891.27	31.25	25.73	11	6.09	6.09	101.13
427	V16	7	14	51	1623.4	25.24	21.26	11	4.86	4.86	122.21
428	V16	8	9	41	1305.1	32.12	28.45	11	5.52	5.52	156.32
429	V16	9	9	56	1782.5	28.68	20.04	12	5.61	5.61	138.05

S.no.	Village code	Plot number	Species richness	Tree abundance	Tree density/ha	Tree DBH mean	Tree DBH standard deviation	Maximum tree height	Tree height mean	Tree height standard deviation	Biomass (kg)
430	V16	10	8	33	1050.4	26.18	20.49	13	5.64	5.64	84.08
431	V16	11	9	22	700.28	59.86	41.94	27	9.25	9.25	482.74
432	V16	12	10	36	1145.9	32.19	29.26	10	4.99	4.99	66.54
433	V16	13	8	19	604.79	39.26	35.35	13	5.48	5.48	139.80
434	V16	14	10	27	859.44	40.85	19.27	13	7.52	7.52	130.73
435	V16	15	5	71	2260	23.97	29.77	15	4.97	4.97	213.71
436	V16	16	12	30	954.93	33.90	21.25	13	6.35	6.35	129.85
437	V16	17	5	50	1591.5	21.42	21.60	12	4.51	4.51	91.94
438	V16	18	12	62	1973.5	23.66	23.41	12	4.72	4.72	150.66
439	V16	19	12	28	891.27	48.18	27.54	13	7.05	7.05	193.53
440	V16	20	11	28	891.27	56.32	44.19	14	7.26	7.26	274.17
441	V16	21	8	23	732.11	45.39	42.28	12	6.03	6.03	112.54
442	V16	22	7	42	1336.9	31.02	19.50	13	5.61	5.61	135.59
443	V16	23	4	15	477.46	36.40	37.41	14	5.27	5.27	121.90
444	V16	24	6	29	923.1	40.48	32.55	12	7.03	7.03	246.66
445	V16	25	9	28	891.27	32.32	27.70	11	4.89	4.89	148.37
446	V16	26	5	32	1018.6	25.19	17.02	10.5	5.58	5.58	73.88
447	V16	27	8	25	795.77	39.92	28.25	14	7.47	7.47	173.70
448	V16	28	7	27	859.44	30.11	22.66	11	6.07	6.07	93.32
449	V16	29	9	18	572.96	26.94	23.14	13	5.22	5.22	68.41
450	V16	30	10	44	1400.6	25.02	19.33	15	5.59	5.59	127.65

Appendix 5.1. Comparison of responses to questions relating to constitution of forest management committee between villages monitored by people and FD

Sl. no.	Theme	Monitored by people's participation	Monitored by forest officials
1	JFM or any other institution involved in forest management	All the selected villages had JFM committees. In one village the JFM committee recently in 2010 changed to eco-development committee	Only two out of six villages had JFM committees
2	Timeframe of the committee set up	The committees were set up during 1998-2000	The committees were set up in 2003 and 2006
3	Presence of formal or informal forest management committee in the past	Three out of five villages had an informal arrangement to protect the forest	None of the villages had the informal arrangement to protect the forest
4	Committee initiated by	Committees were mostly initiated by villagers and also had FD and NGO support	Committees were mostly initiated by FD
5	Executive committee member	The numbers varied from 8 to 15. Women were also part of the committee	The numbers varied from 11 to 13
6	General body member	One or two members from each household	One member from each household
7	Member selection	Members were nominated by villagers and then unanimously selected through village meetings	Members were selected by FD
8	Presence of village committee member in JFM executive committee	All the villages had members other than from village committees	Members from the village committee were present in the executive committee such as the village president
9	Changes in structure after the committee was formed	Around 2-4 committee members were re-elected and 50% of the committee members were represented by women	Number of members increased, however no change in the president and executive committee members

Appendix 5.2. Comparison of the responses to questions relating to functionality of forest management committees between villages monitored by people and FD

Sl. no.	Theme	Monitored by people's participation	Monitored by forest officials
1	Rules	Local residents could collect fuelwood and NTFPs. The villagers had to take permission from the committee if they needed logs from the forest. Villagers were allowed to cut the branches of the trees. Villagers should take forest resource only as per their need. There were restrictions on people not belonging to the village from using the forest resource.	There were restrictions on logging and hunting. Local residents could collect fuelwood only through headloads. There were allowed to collect the NTFPs after FD permission. Taking bullock cart, bicycle and axe for wood collection was prohibited.
2	Who made the rules	Villagers made the rules in V3, V9, and V15 villages. In the remaining two villages V5 and V11, villagers with the influence of the FD made the rules.	In all the villages' FD made the rules
3	Committee meeting	In villages V3, V5, V9, and V15 meetings were held at least once a month and V11 held meetings based on issues.	Committee meetings were never conducted
4	Good understanding of rules	Villagers had good understanding of rules made by the villagers as well as of the common RF rules	Villagers had good understanding of the rules made by FD as well as of other norms. However, they did not follow the rules.
5	Rules differ from FD's rules	Yes	No
6	Clearer forest boundaries	All villages had clearly defined boundaries. In village V11 some part of the forest was transferred to Wildlife Sanctuary (WLS) in 2012.	FD assigned one or more compartments to each of the villages. However, villagers used the forest 2-3 km around their village according to their convenience.

Sl. no.	Theme	Monitored by people's participation	Monitored by forest officials
7	Activities in past 10 years	All the villages carried out plantation more than once that mainly included bamboo, mixed species and teak. They also made fire and drainage lines, and forest ponds, and were actively involved in forest monitoring.	Villages V1, V13, and V14 had carried out plantation mainly of bamboo and mixed species. Out of which V1 and V13 had successful plantation. V1 village also made bunds in the forest.
8	Monitoring	Villagers were actively involved in monitoring. In village V5, V9, V11, and V15, 2-4 people from each household on rotation basis went for monitoring. And in village V3 all households paid Rs. 200/year for 2 guards to monitor the forest.	In all the villages monitoring was done by the FD. Mostly interested in plantation patches. In V13, villagers said that they sometimes helped FD when fires broke out.
9	Flexibility of the rules	If someone in a village needed extra timber or any other resources, they had to inform the JFM committee after which they were allowed to procure them.	No
10	Graduated sanctions or punishment	In all villages except V5, after a few warnings, committee members collected a fine depending on the logs and financial condition of the violators. And in V5, the villagers informed forest guards about any issues	In all the villages forest guards collected the fine.
11	Relation with FD	Except in V11 all villages had a positive relationship with the FD. In village V11 the negative relationship was after the transfer of the forest patch into PA. In village V9, committee members were able to resolve the disputes with forest officials through dialogue.	There were conflicts between the FD and villagers.
12	MOU signed between FD and the committee	Yes	Villagers were not aware of any MOU and said that the committee existed in name only.

Sl. no.	Theme	Monitored by people's participation	Monitored by forest officials
13	Benefits received from the FD	All the villages received funds for plantation and forest pond projects. LPG was provided by the FD. Villages V3 and V15 obtained around Rs. 2 lakh as share in timber proceeds. In one village, FD initiated a project to manufacture incense sticks. V3 village also was rewarded Rs. Five lakh for the best JFM committee. All the villages also received entry point benefits to form JFM committees.	Two villages got employment during plantation projects. However, funds were handled by the FD. In one village because of conflict people did not carry out plantation.
14	Bank account	Yes with signatories' from FD	Villages V1 and V13 had bank account with signatories' from FD
15	Corruption	In all villages except V11, forest guards were not taking bribes from the violators. Only in V11 did the forest guard occasionally take bribes from violators.	In all the villages the forest guard, according to the villagers, used to take a bribe.

Appendix 5.3. Comparison of the responses to questions relating to the motivation behind forest management committees between villages monitored by people and FD

Sl. no.	Theme	Monitored by people's participation	Monitored by forest officials
1	Drivers and actors behind initiative	In village V3 the protection of the forest was initiated by a village leader. In V9 some villagers were influenced after attending meeting on forest protection. In three other villages (V5, V11, and V15) people were informally protecting the forest and also received support from the FD later through various plantation projects.	There were conflicts between villagers and FD. Villagers said they had been maintaining the forest in the past but due to the FD's interference, they were not interested anymore. On the contrary the FD wanted to form the committee owing to plantation projects and also due to pressure from central government policies.
2	Motivation behind the formation of the forest management committee	Overall in all the villages these committees provided the villagers the ownership over the forest patch and decreased their struggle over resources. It gave voice for equitable and fair sharing of the resources and also enabled them to restrict outsiders. Forest officials were motivated to help these villages in order to showcase it as their success stories.	Villagers were found demotivated in terms of protecting the forest because of conflict with FD. Forest official were interested in managing the forest because of plantation projects, mainly that of teak, due to its high success rate. Villagers believed that forest officials were interested in earning extra income through bribes.
3	Involvement of villagers in protecting the forest	Yes	No
4	Traditional norms	Villagers worshipped the *Madhuca longifolia* and *Ficus* trees, and the former was not cut. Wildlife and the forest were also worshipped	Villagers worshipped the *Madhuca longifolia* and *Ficus* trees, and the former was not cut. Wildlife and the forest were also worshipped

Sl. no.	Theme	Monitored by people's participation	Monitored by forest officials
5	Forest help the villagers	Villagers were found to be dependent on the forest for their livelihood and also culturally. They also believed that the forest is important for maintaining the biodiversity, soil, air and rain.	Villagers were found to be dependent on the forest for their livelihood and also culturally. They also believed that the forest is important for maintaining the biodiversity, soil, air and rain.
6	Violence	Earlier there were instances of physical violence while protecting the forest from outsiders. The FD helped in minimising the violence by stopping the outsiders from using forest resources.	No such event happened in the past.
7	Perception regarding the condition of forest	In villages V3, V5, V9, and V15 forest density increased due to active involvement of people in monitoring the forest. In village V11 the forest patch was transferred to WLS, after which in the remaining forest patches, tree density decreased.	During the interview people mentioned that in all the villages the tree density had decreased over time. And in villages V1 and V13, people said that the density of trees only increased in plantation plots.

Appendix 5.4. Response from the villages where either people and FD both were not interested in forest management

Sl. no.	Theme	Not monitored
1	Rules	There were restrictions on logging and hunting. Local residents could collect fuelwood only through headloads. Taking bullock cart, bicycle and axe for wood collection was prohibited.
2	Who made the rules	In V4 and V6, villagers said nobody was interested in making rules. In villages V7, V8, and V10, rules were made by FD. However, villagers were not following the rules.
3	Good understanding of rules	General RF rules were known to everyone, however due to lack of proper monitoring nobody followed the rules.
4	Clearer forest boundaries	Villages V4, V6, and V10 had no clear boundary. V7 and V8 villages had clearly defined boundary
5	Condition of forest	In all the villages, tree density in the forest had decreased over time.
6	Monitoring	No monitoring the forest
7	Graduated sanctions or punishment	In all villages except V7, no fines were charged. In V7 forest guard occasionally collected a fine.
8	Relation with FD	Villagers were in conflict with the FD
9	Corruption	In V4, V6, and V10 villages there were no instances of bribing reported. In V7 and V8 villages the forest guard used to take bribe from villagers as well as outsiders.
10	Willingness of the community towards managing the forest without FD's help	All the villages said they were unable to manage the forest without the FD
11	Dependence of villagers on the forest	Villagers were dependent on the forest both for their livelihood, and culturally. Villagers also believed that the forest is important for maintaining biodiversity, health of soil, air quality and rainfall.

Sl. no.	Theme	Not monitored
12	Plantation programs	Villages V4 and V7 had plantation projects in 20-25 ha land but were unsuccessful. The remaining V6, V8, and V10 villages did not have any plantation activity.
13	Reason for villagers and FD not showing interest in forest protection	In villages V4 and V6, the FD neglected the forest patches mainly because of the current degraded condition of the forest patch and absence of plantation projects. V10 village was in an area impacted by militant violence, and V7 and V8 villages were facing difficulties because of violators from neighbouring villages, with local political interference.

Field Photographs

Dry deciduous forest patch

Fuelwood collection

Fuelwood collection

Mahua (*Madhuca longifolia*) flower collection

Grazing inside the forest

Deity inside the forest

Tree measurement

Focus group discussion