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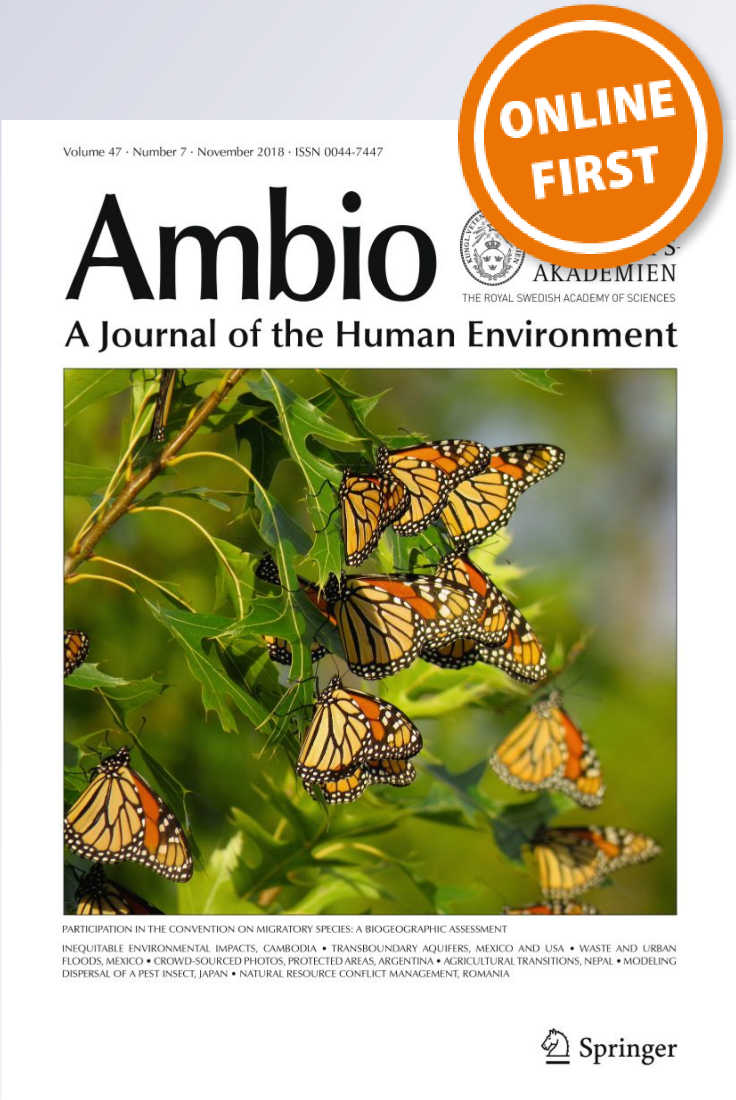

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RESEARCH ARTICLE

Deciphering forest change: Linking satellite-based forest cover change and community perceptions in a threatened landscape in India

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Abstract Global conservation efforts have traditionally focused on biodiversity hotspots and other priority landscapes. However, large areas outside priority sites have high conservation value and are referred to as neglected landscapes. The Eastern Ghats of India is an unexplored forest landscape of high conservation value with several endemic and threatened species reported, and is also home to many indigenous forest-dwelling communities. However, it remains a neglected area for conservation and only 3.53% of this landscape is protected. Here, we examine the effectiveness of protected areas in neglected landscapes in preventing forest degradation, and how community perceptions can be used to understand satellite-based landscape change analyses at village level. This study was conducted in Papikonda National park (PNP) and its unprotected buffers in India's Eastern Ghats. Forest degradation was higher in the buffer (32%) than inside PNP (12%) between 1991 and 2014. Communities attributed shifting cultivation, plantations and over-extraction of forest resources as being the major drivers of forest degradation. Community observations of change were not significantly correlated with spatial measures of change. Forest degradation was higher outside the PA at a landscape level and inside the PA at the village level, therefore the PA was effective in reducing degradation at the landscape level but not at the village level inside the PA. We further discuss the role of community observations in interpreting forest degradation in neglected forest landscapes.

Keywords Community observations · Eastern Ghats · Forest degradation · India · Protected areas

INTRODUCTION

The prominent conservation strategy in recent decades has focused on biodiversity hotspots and priority landscapes such as endemic bird areas and Global 200 ecoregions (Myers et al. 2000; Brooks et al. 2006; Chazdon et al. 2009). However, hotspots only represent 2.3% of the total global land area (Conservation International 2017), whereas other natural landscapes and forest corridors linking protected areas (PAs) have remained neglected in comparison (Fazey et al. 2005; Cardillo et al. 2006; CEPF 2017). The biodiversity value of other natural landscapes outside hotspots can be significant, and there is growing realization of the need to expand conservation beyond hotspots (Barlow et al. 2007). Analysing changes in neglected human modified natural landscapes, and exploring how they are affected by anthropogenic forest dependence is important for understanding future states of biodiversity (Chazdon et al. 2009). This can inform landscape management strategies to conserve biodiversity in neglected landscapes, both within and outside PAs (Bawa et al. 2004; Lindenmayer et al. 2008).

Although the global PA network is vital for preventing biodiversity loss, PA coverage is limited and their functionality is threatened by changes in the surrounding landscape (Barlow et al. 2007). Most tropical PAs are located within a heterogeneous landscape matrix that experiences varied anthropogenic pressures (Daily et al. 2001; DeFries et al. 2005). Studies have shown that larger unprotected habitats surrounding PAs, including agroforestry mosaics, forest patches and plantations, support significant biodiversity and therefore need conservation-oriented management to complement PAs (Fischer et al. 2006; Lindenmayer et al. 2008). However, these unprotected habitats outside PAs also experience higher land-use

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change pressures than PAs themselves (Barlow et al. 2007; Harvey and Villalobos 2007). Landscape change is intensifying around many PAs, with little understanding of their impacts on ecosystems (Janzen 1983; Hansen and DeFries 2007). For instance, DeFries et al. (2005) found that 66% of 198 reserves in the tropics had undergone forest conversion around their surrounding lands since 1980 (Hansen and DeFries 2007). There is increasing recognition of the biodiversity value of the larger landscapes surrounding PAs (Fischer et al. 2006; Vandermeer and Perfecto 2007) and of neglected landscapes (Fazey et al. 2005; Cardillo et al. 2006). Analysing dynamics of landscape change in PAs and their surrounding buffers by quantifying land-use change in neglected tropical forests can reveal important information about forest conversion rates and the role of unprotected buffers for long-term conservation (Bawa et al. 2004; Fischer et al. 2006; Barlow et al. 2007).

Although PAs in tropics have been found to be generally effective at minimizing habitat conversion and land clearing in comparison to their unprotected buffers (Naughton-Treves et al. 2005), they continue to experience pressures from various drivers (Nagendra 2008) including agriculture, increasing isolation within landscapes (Hansen and DeFries 2007; Newmark 2008; DeFries et al. 2010), overextraction of forest resources (Murali et al. 1996; Somanathan and Borges 2000), and population growth and urbanization particularly in India (Karanth et al. 2006; McDonald et al. 2008; Wittemyer et al. 2008). However, few studies have been conducted on what effect human habitations within PAs have on them through local resource dependence, in comparison to their unprotected buffers, across India (Kumar and Shahabuddin 2005; Karanth et al. 2006).

In India, research and conservation efforts have remained concentrated in the biodiversity hotspots and tiger landscapes (Myers et al. 2000). For instance, land-use and land-cover change studies have been done in the Himalayas (Wakeel et al. 2005), Western Ghats (Menon and Bawa 1997; Joseph et al. 2009) and other forest landscapes (Nagendra et al. 2006; Sarma et al. 2008) but the Eastern Ghats forests, stretching over 1600 km along India's eastern coast, has remained largely neglected.

Recent surveys have reported several rare, endemic and threatened species from the Eastern Ghats including the Jeypore ground gecko (Agarwal et al. 2012), yellow-throated bulbul (Sreekar and Srinivasulu 2010), Blewitt's owl (Kumar et al. 2010), leopard cat, rusty spotted cat and stripe-necked mongoose (Aditya and Ganesh 2016, 2017), highlighting the conservation significance of this landscape. However, this ecologically important area is currently under severe threat from mining (Kumar et al. 2010; Oskarsson 2010), long-fallows shifting cultivation (*podu*) and infrastructure development particularly large dams (Gujja et al. 2006; NRSC 2017). It has received little research or conservation attention (Reddy et al. 2009) compared to other priority landscapes. Moreover, only 3.53% of its total area is protected, significantly below the global average (11.9%) and India's coverage (4.89%) (Cardillo et al. 2006; WDPA 2015).

Here, we present a novel approach to understanding the dynamics and drivers of landscape change in the Northern Eastern Ghats (NEG) that combines satellite analysis of landscape change with community observations of the same. First, we examine the extent of forest degradation and loss at the landscape level of Papikonda National Park (PNP) and a 5-km contiguous forested buffer (BUP) around PNP. The BUP is similar to PNP in area, forest types and tribal communities and their populations. PNP and its BUP have long been inhabited by indigenous tribal communities who are economically and culturally linked to the landscape and have substantial knowledge of the forest. Second, we compare changes at a local level in forests around villages, deciphered from tribal communities' questionnaire responses, with changes observed using satellite imagery to examine how sensitive community observations are to forest changes. Finally, we examine how communities' level of dependence on forests influences their deciphering changes in forests.

We hypothesize that *in a neglected forest landscape, forest degradation is independent of forest protection*. This is because enforcement in PAs is likely to be less in neglected landscapes because of access, awareness and resource constraints. We examine this hypothesis through two questions—(1) how does forest cover change between 1991 and 2014 inside and outside PNP? (2) what are the drivers of change, and are these different between the two? We further hypothesize that *peoples' perceptions of change are dependent on their associations with the forests and independent of where their village is located in the conservation matrix*. This is likely as forest-dependent communities work closely with forests regularly while others may seek a less forest-dependent livelihood. We therefore ask (3) how do communities perceive change in forests and (4) how do these perceptions vary with their level of forest dependence?

MATERIALS AND METHODS

Study area

The Eastern Ghats are a series of discontinuous hills extending between 11°03′–22°00′N and 76°05′–86°03′E[1], roughly parallel to India's east coast. The northern section of

[1] http://www.eptrienvis.nic.in/Introduction.html.

the Eastern Ghats (NEG) spreads over 16 948.35 km^2 in Andhra Pradesh. PNP, occupying an area of 1012 km^2 is located between 18°29′N–19°10′N and 79°32′–83°14′E in the NEG (Fig. 1). The topography of PNP is hilly and undulating, with altitudes ranging between 20 and 850 masl. The dominant forest type is southern tropical mixed moist deciduous, with some semi-evergreen patches. Among the tribal communities of PNP, the *Konda Reddis* primarily inhabit hills and subsist on forests, the plains-dwelling *Koyas* are cultivators and other communities depend to varying extents on forests. Their chief occupations include farming/farm-labour, *podu* cultivation, collection of Non Timber Forest Produce (NTFP) and work in government employment guarantee schemes. The BUP of PNP includes all forests types around PNP and beyond, part of a larger contiguous forest landscape in the NEG. The BUP (1908 km^2) is comparable in area and forest type ith PNP (1012 km^2).

NDVI analysis of forest change between 1991 and 2014

We procured dry season (Dec-Jan) cloud-free LANDSAT-5 and LANDSAT-7 imagery from NOAA-GLOVIS (https://glovis.usgs.gov/) (Table 1). Topographical maps of 1:50000 scale of the NEG were procured from the Survey of India and the PNP boundary shapefile from the Andhra Pradesh Forest Department. All villages and roads around PNP were mapped with a GPS. A shapefile of villages and roads in PNP and its BUP was prepared. We geo-referenced all satellite images and shapefiles to the WGS: 84 datum on the EPSG: 4326 coordinate system. We calculated NDVI (Normalized Difference Vegetation Index) from the 1991 and 2014 images. We estimated forest change between 1991 (the earliest available satellite imagery of NEG), and 2014 based on changes in NDVI (Pettorelli et al. 2011).

We overlaid the PNP boundary, village and road map on the 1991 and 2014 NDVI images. We calculated the mean NDVI of the 1991–2014 images to analyse change between the two periods. We used NDVI to classify the landscape and assess temporal change (Jha et al. 2000) by assigning pixels with NDVI above 0.6 to forest and those below 0.6 to non-forest classes (Holm et al. 2003; Coppin et al. 2004). This decrease in NDVI means does not necessarily imply deforestation, but indicates that forest canopy and vegetation density has decreased. NDVI being a measure of canopy vegetation density can therefore be used to assess forest degradation. We ground tested this classification between 2014 and 2015 through field visits. We calculated area under forest and non-forest classes in 1991 and 2014. We overlaid the classified NDVI image of 2014 on the classified image of 1991 and calculated change in forest area between 1991 and 2014. All RS/GIS analyses were performed using IDRISI TerrSet and Quantum GIS 2.8.2.

Drivers of forest cover change

(a) *Landscape level* To understand drivers of forest degradation, we identified 212 villages in PNP and

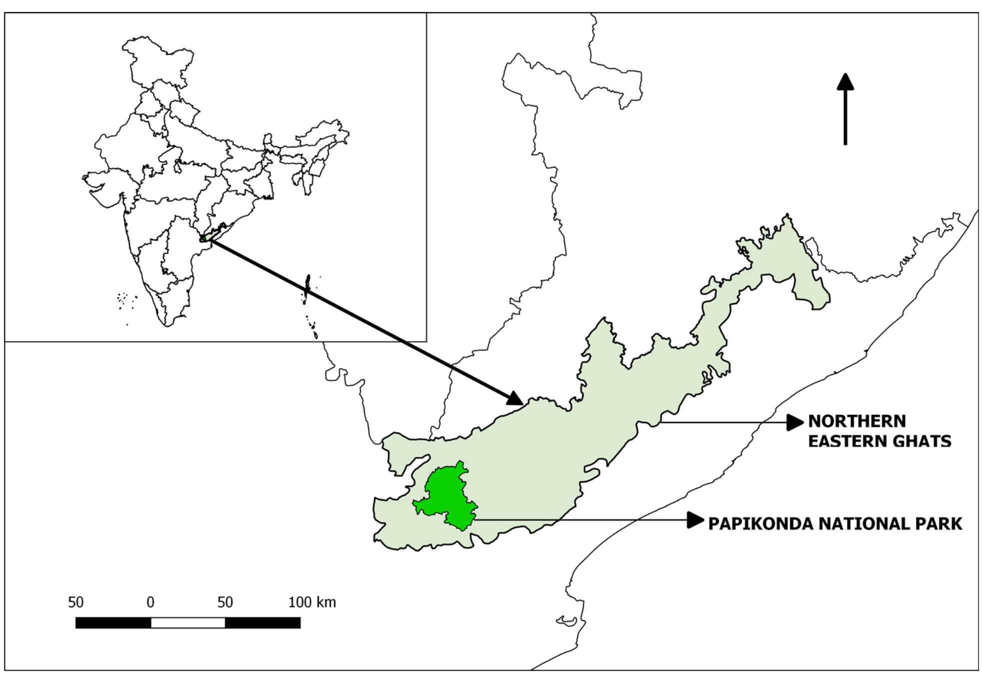

Fig. 1 The location of Papikonda National Park in the NEG in Andhra Pradesh, India

Table 1 Satellite imagery details of multi-date LANDSAT scenes that have been used for this study. All scenes are of Path 128/Row 49. The images were rectified and geo-referenced to the WGS 84 datum on the EPSG: 4326 coordinate systems; Sensor: ETM+

No.	Scene/imagery name	Date acquired	Satellite
1	LC81410472014005LGN00	2014-01-05	LANDSAT-8
2	LC81410482014005LGN00	2014-01-05	LANDSAT-8
3	LC81420472014012LGN00	2014-01-12	LANDSAT-8
4	LC81420482014012LGN00	2014-01-12	LANDSAT-8
5	LE71410472001025SGS00	2001-01-25	LANDSAT-7
6	LE71410482001025SGS00	2001-01-25	LANDSAT-7
7	LE71420472000030SGS00	2000-01-30	LANDSAT-7
8	LE71420482000030SGS00	2000-01-30	LANDSAT-7
9	LT51410471991086ISP00	1991-03-27	LANDSAT-5
10	LT51410481991086ISP00	1991-03-27	LANDSAT-5
11	LT51420471992032BKT00	1992-02-01	LANDSAT-5
12	LT51420481992032BKT00	1992-02-01	LANDSAT-5

BUP, with 51 located inside PNP. We obtained the following village data—(1) population (2) tribal group (*Konda Reddis, Koyas, Nayakpods*, others) (3) percentage of tribal population (2011 Census of India website[2]) (4) proximity of village to forest edge and (5) location in the study area (PNP or BUP).

(b) *Village level* We calculated change in NDVI between 1991 and 2014 in a 1000 m Buffer around these 212 Villages (BUV), based on their proximity from forest edge, and their location in the study area (inside PNP/BUP) as predictors of change.

(c) From this, we selected a subset of 33 villages (18 inside PNP, 15 in BUP) randomly, for relating change in forest NDVI in the BUV with community perception of change. We measured six variables (elevation, slope, village population, village location in PNP or BUP, predominant tribal group and road or river transport access to village) as predictors to identify major drivers of forest change around these villages in PNP and it is BUP.

We checked normality and variance of variables using Shapiro–Wilk and variance tests. We used ANOVA to test for differences between means of change in NDVI in the BUV; and ANCOVA to test the combined effect of elevation and slope on NDVI change. We tested the effects of village population, village location inside or outside PNP, elevation, slope and transport access on change in NDVI in the BUV using ANOVA. We tested the interaction of predictors in driving NDVI changes using ANCOVA and factorial regression.

Community observations of forest cover change (village level)

We conducted semi-structured interviews with 138 randomly selected respondents in the 33 villages between 2014 and 2015. Respondents belonged to three indigenous tribal groups (*Konda Reddy, Koya* and *Nayakpod*) and two other communities (*Vaada Balija, Other Castes*). Questions ranged from observations of forest change, drivers of changes, forest dependence, tree species and changes in their numbers, sightings of animals, hunting practises, livestock depredation and livelihood occupations. We classified responses according to location of villages inside or outside PNP, and across communities.

Using community responses on LC change to interpret NDVI change analysis

First, we used community interview responses to predict forest change in the BUV, by correlating community responses on the extent of forest change observed (decreased significantly, decreased slightly, no change, increased), with NDVI values of forest change between 1991 and 2014.

Next, we tested how these community observations of forest change within the 1000 m BUV around villages were related to predictors of these observations—location of village inside or outside PNP, knowledge regarding existence of PNP (are communities aware of the presence of PNP), presence of plantations around villages, increase or decrease in tree density and changes in sighting of animals.

Statistical analysis was performed to test how communities' responses correlated with NDVI change. Contingency tests and ANOVA were used to test whether

[2] http://censusindia.gov.in/.

communities' observations of landscape change were affected by their awareness and views of various aspects of change such as the establishment of plantations, changes in tree density, animal sightings, declaration of the PA, etc.

RESULTS

Forest change (1991 and 2014)

(a) *Landscape level change* Forest cover inside PNP reduced from 856.35 km^2 in 1991 to 754.21 km^2 in 2014, indicating a loss of 102.14 km^2 (11.9%) with an annual conversion rate of 2.88 km^2/year of forest to non-forest (Table 2, Figs. 2, 3). In BUP, forest reduced from 1499.23 km^2 in 1991 to 1009 km^2 in 2014, a decrease of 490 km^2 (32.68%) with an annual conversion rate of 21.3 km^2/year. The total change in forest cover including PNP and BUP was 592.37 km^2 (25.15%) (Fig. 3a, b).

(b) *Village level change* The analysis of forest degradation in the BUV of 212 villages both in PNP and its BUP, showed a significant decrease in NDVI between 1991 and 2014 (Student's *T* test mean NDVI (1991) = 0.57, NDVI (2014) = 0.51, df = 1, 210, $p = 0.01$). NDVI decreased significantly more inside PNP than in the BUP (ANOVA $p = 0.000$***).

A similar pattern was seen for the subset of 33 interview villages (Student's *T* test $t_{1,51} = 115.7$, $p = < 0.001$) where mean NDVI changed from 0.60 to 0.44 around villages in PNP and from 0.65 to 0.59 around villages in BUP ($t_{1,29} = 11.57$, $p = 0.001$) (Table 4).

Drivers of forest change at village level

The change in NDVI in the BUV was negatively correlated with log of elevation ($F_{1,29} = 9.26$, $p = 0.004$) and weakly correlated with slope ($F_{1,29} = 5.32$, $p = 0.02$, $R^2 = 0.02$).

Table 2 Change in NDVI of Papikonda NP and PNP along with its BUP between 1991 and 2014

	Area in 1991 (km^2)	Area in 2014 (km^2)	Change in area (Kappa = 0.673)	% Change
Papikonda NP	856.35	754.21	102.14	11.9
BUP only	1499.23	1009.00	490.23	32.68
Papikonda NP and BUP	2448.08	1885.71	592.37	25.15

Forests around lower elevation villages experienced greater change in NDVI than higher elevation villages. Log of village population ($F_{1,30} = 6.07$, $p = 0.01$, $R^2 = 0.14$) and location of village inside or outside PNP ($F_{1,31} = 8.23$, df = 1, 31 $p = 0.007$, $R^2 = 0.20$) were significant drivers in determining NDVI change around villages. Villages with higher population, located inside PNP and connected only by River experienced greater decrease in NDVI ($F_{1,31} = 4.228$, df = 1, 31, $p = 0.048$) than in the BUP. Rates of change in NDVI were higher along the River, independent of the presence of the PA.

Community observations of forest cover change around villages

The total population of selected villages was 12 460, with indigenous groups constituting 81% of the population. The largest respondent group was *Konda Reddis* (81) followed by *Koyas* (35) and the rest were *Nayakpods*, *Vaada Balijas* and others. A majority of respondents across all communities (94) reported that forest cover had noticeably decreased around villages (Table 3). When we pooled and averaged responses within each village, 25 villages (or 75% of the total) reported that forest cover had degraded around their village. Of these, 19 (or 76%) villages described degradation as substantial, seven reported no noticeable change, and one reported an overall increase in forest, with significant variation between the PNP and its BUP (Table 3). Communities mentioned 22 factors that drove these changes in the landscape, and most frequently listed ones include *podu* cultivation, Forest Department timber plantations, bamboo cutting, over extraction of forest produce, population growth, timber smuggling, forest fires, livestock grazing and dam building (Fig. 4, Table 4).

Comparing these results to the forest NDVI change map of 1991 to 2014 shows that all villages which indicated that forest cover had diminished greatly, have indeed experienced significant NDVI change from forest to non-forest. The villages reporting either an increase or no change in forest cover showed no significant change in NDVI values.

Community observations of forest change in the BUV as a response variable were strongly correlated with their location inside or outside the PNP (Pearson's $X^2 = 7.5251$, df = 3, $p = 0.05692$), with respondents located inside observing greater change; and a significant change in tree density (Pearson's $X^2 = 65.1773$, df = 12, $p = < 0.000$). Community responses on change were not strongly predicted by other observations.

Communities also identified more plantations around villages that had experienced greater degradation in the BUV (− 0.147 mean decrease) compared to villages where

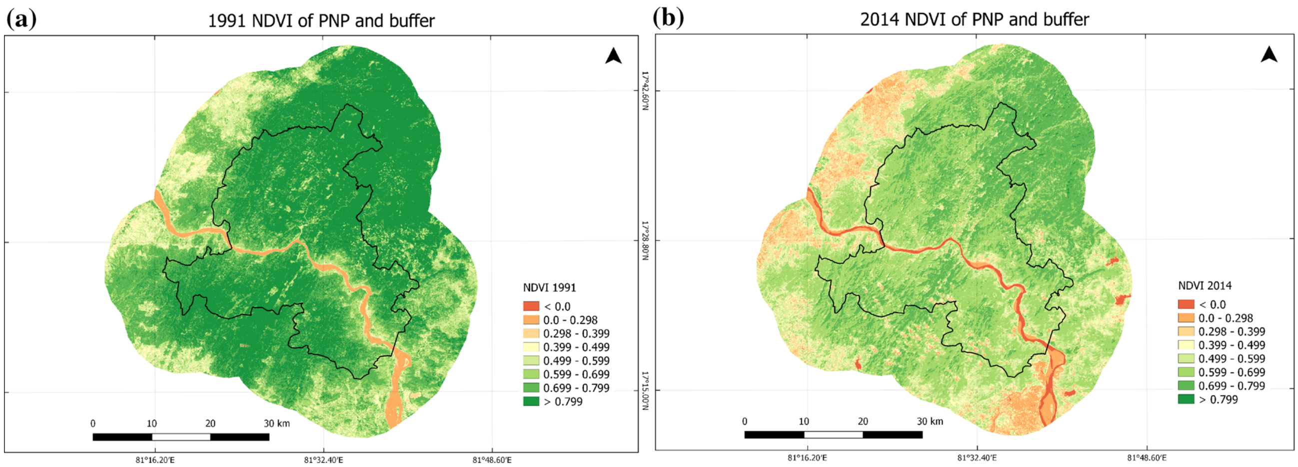

Fig. 2 NDVI of Papikonda NP along with its BUP in 1991 (**a**) and 2014 (**b**)

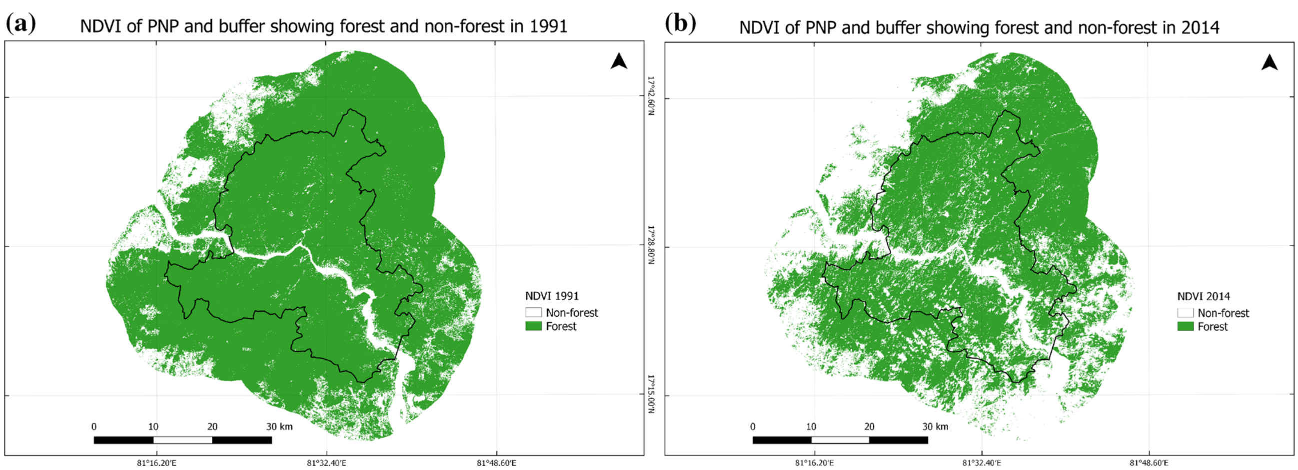

Fig. 3 NDVI of Papikonda NP along with its BUP classified as forest (pink) and non-forest (black) in 1991 (**a**) and 2014 (**b**)

respondents reported no plantations (− 0.116 mean decrease) ($p = < 0.01$).

DISCUSSION

Forest degradation in the Eastern Ghats

Our study presents the first estimates of the extent and rates of forest degradation in the NEG. 25% of the forests in PNP and its BUP were degraded in the 24 years between 1991 and 2014. Most forest degradation occurred in the lower foothills that corresponded strongly with the presence of roads and the Godavari river, both of which facilitated access to forests, resulting in the lower elevation forests becoming more deforested. Similar percentages of forest loss and rates of deforestation have been reported from forest landscapes in India like the Western Ghats (Jha et al. 2000). Shifting cultivation, conversion of forest for plantations observed in this study are also recognized as drivers of deforestation in other landscapes like the Himalayas (Wakeel et al. 2005; Lele et al. 2008), the Western Ghats (Joseph et al. 2009) and across India (Tian et al. 2014), indicating that the NEG landscape is experiencing similar pressures and undergoing conversion into cropland and other land-uses as Western Ghats and Himalayas. However, our analysis shows that in addition to *podu* cultivation, timber plantations and agricultural expansion consistent with other landscapes, extensive tree felling and overextraction of forest produced by locals along with pressures from mining and dam building are the largest drivers of forest change in particular to the NEG.

The socio-economic drivers of these changes in the NEG include incentives by the Integrated Tribal Development Agency (government agency in charge of administration in tribal areas), such as providing seedlings of cashewnut, sweet lemon, mango, etc., and technology and tools for supporting agriculture and enhancing livelihoods. This has in part facilitated the rapid proliferation of *podu* for raising plantations in the landscape, which is a major driver of NDVI change. In addition, large areas of forest understory are decimated every year by forest fires set to enable hunting and to clear forests for *podu*. Another factor exacerbating forest degradation across the NEG is shortage of adequate field-level department staff.

Table 3 Community responses on land-cover change around their villages in PNP/BUP

	In PNP (% of total)	In BUP (% of total)
Forest decreased	65 (67.7)	29 (67.44)
Forest increased	9 (9.3)	5 (11.62)
No change in forests	22 (23)	9 (20.9)
Extent of change		
Forests have decreased a lot	38 (39.5)	22 (51.1)
Forests have decreased slightly	26 (27)	7 (16.27)

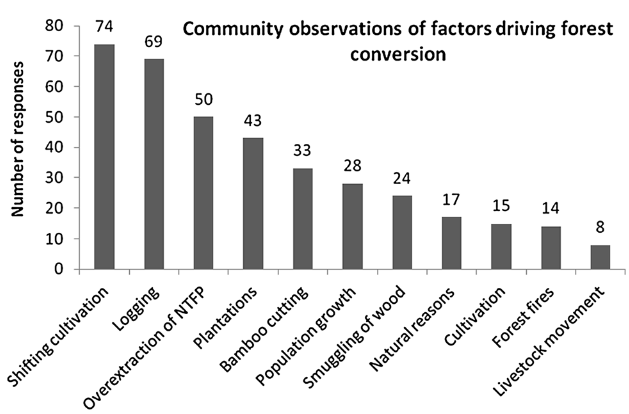

Fig. 4 Community responses on the principal reasons for forest cover decrease in Papikonda NP and its BUP

Protected areas in a changing landscape

Our results indicate that forest change at the landscape scale has been significantly higher outside PNP. This can be partly attributed to the different forest management approaches in PNP compared to its BUP, with the latter mainly oriented towards silviculture, production from plantations, and water conservation measures, and only moderate levels of protection against illegal logging. BUP forests are regularly accessed by locals for harvesting NTFP and for *podu* cultivation. In contrast, forests inside PNP are managed solely for protection with minimal intervention. In addition, the higher density of villages in the BUP (8.3 villages per 100 km^2 in BUP, 5 villages per 100 km^2 in PNP), and a significantly higher road connectivity (281.9 km in BUP, 84.6 in PNP) through which all BUP villages have access to surfaced roads, in contrast to PNP where only some villages have surfaced roads, has also contributed to higher forest degradation in the BUP.

This degradation of the BUP is leading to isolation of forests in PNP from the larger NEG, and is comparable to the global phenomenon of isolation of PAs in tropical forests where the loss of forest buffers is undermining the effectiveness of PAs in conserving biodiversity (Naughton-Treves et al. 2005; DeFries et al. 2005). Tropical Asian forests are among the most threatened globally, experiencing highest rates of deforestation and habitat conversion, with India itself having lost nearly 80% of its forest cover (Laurance 2007). PAs in South Asia have been particularly affected by rapid loss of forest cover in surrounding areas since the past three decades (DeFries et al. 2005). The NEG has large forest tracts outside the PA network which are currently buffering PNP from higher pressures. However, the greater loss of forests outside PNP could exacerbate forest degradation rates further which could place greater conversion pressure on PNP and result in its isolation.

Urgent action needs to be initiated to arrest forest degradation in PNP and its contiguous forests in the NEG.

Table 4 Extent of forest degradation at different scales and major drivers identified by communities

Scale of change	Area in km^2 changed between 1991–2014	Mean NDVI change in BUV between 1991–2014	Prop. agree with forest change	Major drivers of change identified by communities
Forest cover (overall)	592.37 km^2 (− 25.15%)	− 0.126 (− 19.78%)	75%	Tree felling, over extraction of MFP, *podu*, plantations
PNP	102.14 km^2 (− 11.9%)	− 0.153 (− 25.47%)	62%	*Podu*, tree felling, plantations, over extraction of MFP
BUP	490.23 km^2 (− 32.68%)	− 0.064 (− 9.77%)	81%	Over extraction of MFP, tree felling, bamboo cutting, population growth

The creation of new PAs in the NEG could partly ameliorate pressure on PNP. Community involvement in conservation measures including minimizing poaching are essential for curtailing forest loss (Nagendra et al. 2008; Shahabuddin and Rao 2010). Therefore, community education about the importance of protecting forests could help offset forest dependence. Enhanced conservation interventions in the BUP, including alternate livelihood and income opportunities for forest-dependent communities through strengthening the National Rural Employment Guarantee Scheme could alleviate pressure on the forests of PNP, helping in biodiversity conservation in the NEG.

Forest communities and landscape change

Our study finds that at a village scale, forests around villages inside PNP experienced significantly greater degradation forests in the past two decades than forests around villages in the BUP in contrast to other landscapes in India where the unprotected or less-protected buffers experienced greater degradation (Nagendra et al. 2006). Villages had a significant impact in driving forest degradation in PNP and its BUP. This was most strongly correlated with population and location of villages at lower elevations. Protection has helped both lessen and increase forest degradation depending on the scale of the event. Larger drivers like dams and plantations have contributed to degradation outside PA but village level degradation happens because of forest dependence. The PA therefore appears to have been successful in reducing forest cover reduction by large-scale interventions like mining, dams and plantations but not the smaller-scale forest-degrading activities centred around villages such as NTFP collection. Thus, this finding does not support our first hypothesis. PAs in neglected landscapes like the NEG are effective in reducing forest degradation at the landscape level, but they are still ineffective in preventing degradation when examined at a village level. This is probably because villages inside PNP, through their remoteness and isolation, have proportionately higher forest dependence through NTFP collection, broomstick grass harvesting, *podu* cultivation, etc., whereas villages located outside have other livelihood options, such as trading, transport, etc., which substantially reduces their dependence on forests and thereby forest degradation. Other studies have similarly found that communities living in forests both within and outside PAs have high dependence on forests for their livelihoods and this results in forest degradation and deforestation (Karanth et al. 2006; DeFries et al. 2010), albeit differential rates of dependence within PAs and outside (Nagendra et al. 2010). There was also significantly higher forest degradation around villages connected by River inside PNP. This suggests that ease of transport of forest produce by river may have contributed to greater forest degradation around these villages inside PNP despite lack of road access. This indicates lack of vigilance, monitoring and patrolling by forest staff which could have prevented exploitation of forest resources from inside PNP

Our results therefore suggest that PNP reduced forest degradation at the landscape level but not at the village level. Furthermore, substantial forest areas in the territorial forest divisions covering the BUP have been handed over to the indigenous forest dwellers, under the Scheduled Tribes and other Traditional Forest Dwellers (Recognition of) Forest Rights Act, 2006, to inhabit and cultivate. The impacts of these on forests of both PNP and the BUP need to be studied further.

In both PNP and the BUP, community perceptions corresponded well with remotely sensed signals of forest degradation at the local level. This corresponds with the overall trend of NDVI reduction in our satellite analysis. Communities' views on forest degradation corresponded with their location in PNP or BUP and views on change in tree density. Greater dependence on forest resources inside PNP may lead to more precise community observations of changes in tree density, and to an ability to accurately relate this to overall forest cover. Our study therefore provides evidence in support of our second hypotheses, since community observations of land-cover change were fairly accurate, particularly of forests close to villages. This was true regardless of a village's location in the conservation matrix, but it does depend on villagers' level of interaction with forests. Based on this work, community observations of forest change can only be considered reliable at the local village scale.

Further finer-scale village level analyses explicitly exploring the differences between NDVI loss inside and outside the PA and community observations of their drivers would help understand the causes of degradation.

Our study demonstrates that village-level NDVI changes can be interpreted using community observations, especially in a landscape mosaic of forests and villages experiencing varying levels of protection (Nagendra et al. 2008) but this may not be reliable at larger landscape scales. This study throws light on the varied and often contrasting nature of forest degradation at different scales—at a landscape level forests outside the PA have experienced greater overall loss, however, at a local scale, forest degradation was faster around villages inside PA.

CONCLUSION

The NEG is home to several endemic and threatened species, but is among the least protected forest landscapes globally (Cardillo et al. 2006). The region is facing rapid land-cover changes from development activities that are placing severe pressure on PNP. Current rates of natural resource extraction are also resulting in habitat degradation, evident in the noticeable NDVI drop. The pressure on forests in the BUP has been exacerbated manifold in recent years through the ongoing construction of the Indira Sagar Multipurpose Project across the Godavari (Mohan 2006), which will result in loss of large sections of contiguous forests around PNP and impact the habitat of many endemic and vulnerable species. The presence of contiguous forests in the BUP is extremely vital in providing habitat corridors for fauna and for regulating biotic pressure on PNP. Current rates of forest degradation could result in loss of habitat connectivity and corridors for fauna in the NEG.

This study underscores the importance of PAs in neglected landscapes like the NEG with no or few PAs and with little information on ecology and conservation challenges. Large areas outside such PAs need urgent attention and mechanisms for protecting them from developmental and political pressures. This study shows that patterns in forest loss and degradation are dependent on scale of analysis, with landscape level patterns masking finer village scale dynamics. Contrasting patterns in forest degradation may emerge from various drivers which are themselves scale dependent, therefore it is necessary to examine processes at multiple scales. Forest-dependent communities have intimate understanding of the extent and drivers of forest change which largely corroborate remotely sensed patterns of change. Long-term community observations of forests, particularly in neglected landscapes with low protection, management intervention and research attention, can be used to interpret satellite-based land-cover change analyses and identify drivers of changes in forests particularly close to villages. This study therefore also underscores the potential value of future community-based forest monitoring programmes in conservation. We therefore advocate strengthening community-based institutions such as village-based forest management committees and school-level environmental education to reduce continued forest degradation in the landscape. Our findings open avenues for future research on the significance of PAs in such regions, and whether PA systems in neglected landscapes remain neglected in contrast to high-priority landscapes. Future research should focus on understanding the ecological, socio-economic and legal significance of PAs in conservation of neglected forest landscapes where local awareness of conservation is minimal.

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