Biological Conservation 178 (2014) 193–199

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Short communication

Spatio-temporal variation in forest cover and biomass across sacred groves in a human-modified landscape of India's Western Ghats

Anand M. Osuri [a,b,*], M.D. Madhusudan [b], Vijay S. Kumar [a], Sannuvanda K. Chengappa [a], Chepudira G. Kushalappa [c], Mahesh Sankaran [a,d]

[a] National Centre for Biological Sciences, Tata Institute of Fundamental Research, GKVK Campus, Bellary Road, Bangalore, Karnataka 560065, India
[b] Nature Conservation Foundation, 3076/5, IV Cross, Gokulam Park, Mysore, Karnataka 570002, India
[c] College of Forestry, Ponnampet, University of Agricultural and Horticultural Sciences (Shimoga), Ponnampet, Karnataka 571216, India
[d] School of Biology, University of Leeds, Leeds LS2 9JT, UK

ARTICLE INFO

Article history:
Received 18 March 2014
Received in revised form 7 July 2014
Accepted 12 August 2014
Available online 9 September 2014

Keywords:
Aboveground biomass
Communities
Conservation
Deforestation
Forest fragments
Remote sensing
Sacred groves
Western Ghats
Trends

ABSTRACT

Although the potential for community-conserved areas (CCAs) to extend conservation beyond formal protected areas is widely acknowledged, the scarcity of conservation assessments and monitoring hinders the rigorous evaluation of their effectiveness in many regions. In India, which hosts a high density and diversity of CCAs, the need for more assessments of the ecological and socio-economic properties of these systems to guide conservation planning and policy has been emphasised in recent years. We inventoried the extant sacred grove network against official records of 407 groves across 70 villages in the Kodagu District of India's Western Ghats, and interviewed local communities about their management and conservation. We also evaluated recent trends in aboveground biomass of sacred groves using time-series satellite data from six time-points during the 2000–2010 period, and made comparisons to corresponding trends in nearby State-managed protected forests. Although most of the larger (>2 ha) groves officially listed were forested at present, over two-thirds of the smaller groves listed were either not forested or could not be located. Local communities attributed these declines to encroachment and illicit logging. Time-series satellite data revealed aboveground biomass declines of ~0.5% annually across the sacred grove network over the 2000–2010 period. In contrast, biomass increased during this period at the interiors and edges of State-managed forests in the landscape. Our results highlight that the conservation status of even well-protected CCAs can vary considerably over time, especially given the dynamism in socio-economic, cultural and ecological factors that govern their status. We argue that understanding and addressing this dynamism is crucial to the conservation of CCAs.

1. Introduction

Protected areas (PAs) are today the cornerstone of biodiversity conservation across terrestrial ecosystems worldwide (Gaston et al., 2008). From covering a mere 3.5% of the Earth's land surface in 1982 (Harrison et al., 1982), they now account for over 12% of the Earth's land area (Brooks et al., 2004; Chape et al., 2005). While PAs remain crucial in preventing deforestation and conserving biodiversity in the tropics, a variety of species, communities and ecosystems of conservation importance still occur beyond PA boundaries, on lands under diverse tenure and use (Chazdon et al., 2009). Improving the opportunities for biodiversity conservation on such lands, therefore, remains an important concern. In this context, sacred natural sites and other community-based institutions for protection and management of natural resources are seen as important opportunities to extend conservation beyond PAs, especially in the rapidly developing and densely-populated tropics (Sodhi et al., 2011; Verschuuren et al., 2010). In these community-conserved areas (CCAs), natural resources are managed and protected by locally-developed norms rather than formal legislations, adding conservation value at both local and landscape scales (Bhagwat et al., 2005a; Colding and Folke, 2001; Gadgil and Vartak, 1975; Salick et al., 2007). Yet, there is still uncertainty over the conservation status and conservation potential of CCAs, owing to a relative paucity of documentation and long-term

* Corresponding author at: National Centre for Biological Sciences, Tata Institute of Fundamental Research, GKVK Campus, Bellary Road, Bangalore, Karnataka 560065, India. Tel.: +91 80 67176221; fax: +91 80 23636662.

E-mail addresses: moanand@gmail.com (A.M. Osuri), mdm@conservation.in (M.D. Madhusudan), vijaykumar326@gmail.com (V.S. Kumar), chenga.coorg@gmail.com (S.K. Chengappa), kushalcg@gmail.com (C.G. Kushalappa), mahesh@ncbs.res.in (M. Sankaran).

http://dx.doi.org/10.1016/j.biocon.2014.08.008
0006-3207/

assessments (Berkes, 2009; Kothari, 2006; Shahabuddin and Rao, 2010).

While monitoring the effectiveness of conservation strategies over time is generally desirable, it is particularly important in CCAs, where conservation is often one among various other objectives, and sometimes simply a by-product (Alvard, 1993; Rutte, 2011). There is widespread evidence of recent and emerging challenges to CCAs arising from changing cultural beliefs, practices, and socioeconomic forces (Bhagwat and Rutte, 2006; Ormsby, 2011). Moreover, as areas that are under human use, CCAs frequently experience anthropogenic disturbances in the form of resource extraction, hunting, fire and fragmentation (Shahabuddin and Rao, 2010), which, in turn, may affect ecological processes and result in changes over time in habitat structure, species composition, ecosystem function and conservation value. Therefore, monitoring the status of CCAs over time is vital to understand how they add value to mainstream conservation efforts like PAs in a changing world.

Here, we document the current status, evaluate recent trends and explore drivers of change associated with forest cover and biomass of a network of community-managed sacred groves in Kodagu District, located in the Western Ghats Biodiversity Hotspot of peninsular India. This network of sacred forest fragments is interspersed within a production landscape primarily of shade coffee and paddy. These sacred groves harbour a wide variety of native rainforest biodiversity, including rare, threatened plants and endemic bird species (Bhagwat et al., 2005b; Page et al., 2010). Moreover, they complement and enhance conservation by State-owned and managed forests (including PAs) by boosting habitat connectivity in the region (Bhagwat et al., 2005a; Kushalappa and Bhagwat, 2001). Weakening local institutions, diminishing cultural importance and growing demand for forest land, timber and other natural resources feature prominently among a variety of established and emerging threats facing these sacred groves (Chandrakanth et al., 2004; Garcia and Pascal, 2006; Kushalappa and Bhagwat, 2001). However, apart from official lists of sacred groves, which are possibly outdated, and biodiversity assessments from a few relatively well-protected groves (e.g. Bhagwat et al., 2005b), little is known about the current extent, status, trajectories and conservation prospects of this fragmented ecosystem as a whole.

We inventoried the extant sacred grove network and compared their current status to widely-cited official records compiled during the 1980s. We then used time-series satellite data to evaluate recent trends in the forest biomass of sacred groves across gradients of grove size and annual rainfall, and made comparisons to trends in State-managed forests within the same landscape. Finally, we conducted interviews with members of the local community involved in the management and conservation of sacred groves to explore perceptions of cultural values associated with sacred groves, their perceived trends in sacred grove forest cover, and challenges associated with the conservation of sacred groves.

2. Materials and methods

2.1. Study site

The study was conducted in the Virajpet Forest Division in Kodagu District, Karnataka state, in the Western Ghats of peninsular India (12.17°N, 75.8°E; Fig. 1). The study area features mid-elevation tropical wet-evergreen and semi-evergreen forest types (Pascal, 1982, 1986). Administratively, these forests largely fall within one of two categories: forests which are owned and managed by the State (e.g. Brahmagiri Wildlife Sanctuary and adjoining Reserved Forests) and sacred groves, most of which are owned by the State but managed by local communities through decentralised village temple committees (Kushalappa and Bhagwat, 2001; Raghavendra and Kushalappa, 2011). These ancient sacred groves mostly occur as forest fragments embedded in a landscape matrix dominated by shade coffee plantations, which also comprises rice paddies and human settlements (Bhagwat et al., 2005b). According to records compiled by the Karnataka Forest Department in the 1980s, the study area had over 550 sacred groves, totalling over 1000 ha in area (Raghavendra and Kushalappa, 2011). There are at least 18 resident communities involved in management of sacred groves in Kodagu district, with members of the Kodava, Gowda, Amma Kodava and Hegde communities being prominent in the study area (Kushalappa and Bhagwat, 2001).

2.2. Sacred grove inventory and habitat assessment

Between November 2009 and February 2010, we conducted field surveys to inventory the extant sacred grove network in 70 of the 109 villages in Virajpet Forest Division that have sacred groves recorded (Fig. 1a). According to official records of sacred groves published by the Karnataka Forest Department in 1985, these 70 villages contained 407 sacred groves (Raghavendra and Kushalappa, 2011). We visited each village and using information on village name, sacred deity name and listed area, and in consultation with experts and local residents, we attempted to locate these sacred groves. Each site thus located was classified into one of three categories: (1) sites with continuous, closed-canopy tree cover, (2) sites with discontinuous, open canopies, exposed bare ground and invasion by non-native understory species, and (3) sites under non-forest land cover (e.g. plantations, constructions). In the first two cases, the physical forest boundary of the sacred grove was mapped using global positioning system (GPS).

2.3. Trends in aboveground biomass

We evaluated trends in aboveground biomass of sacred groves and other forests in the study area using a six-point time series of satellite images from the 2000–2010 period (years 2000, 2003, 2004, 2006, 2008, 2010). The analysis focused on two main questions: (1) do trends in aboveground biomass of sacred groves vary across space in relation to sacred grove size and location along an E–W gradient of annual rainfall, and (2) how do biomass trends in sacred groves compare to trends in nearby State-managed forests over the 2000–2010 period? Trends in aboveground biomass were assessed using a remotely-sensed index derived from Landsat ETM+ imagery captured by the Landsat 7 satellite. This index comprised the ratio of band 4 (near infrared) to band 5 (short-wave infrared) pixel values – hereafter, ratio45 – which, based on rigorous field testing using biomass estimates from 38 forest inventory plots (3.15 ha in total), was found to be strongly and positively associated with aboveground biomass ($r = 0.66$, $p < 0.00001$; see Appendix A for methodological details). A robust linear method which estimates the median across all pairwise slopes between the six time-points, sometimes called the Sen Slope (Sen, 1968), was used to detect monotonic trends in pixel values of ratio45. The trend estimates were translated to an annual rate of change in percentage terms by dividing by the corresponding baseline value (ratio45 in year 2000) and multiplying by 100.

Relationships between biomass trends, as indexed by ratio45, and sacred grove area (calculated using the mapped sacred grove boundaries) and mean annual rainfall (extracted from interpolated models at 1 km resolution (Hijmans et al., 2005)) were examined using pairwise correlations. The analysis was conducted for 73 sacred groves falling within an annual rainfall range of 2300–3500 mm: the range within which the field estimates of aboveground biomass used to

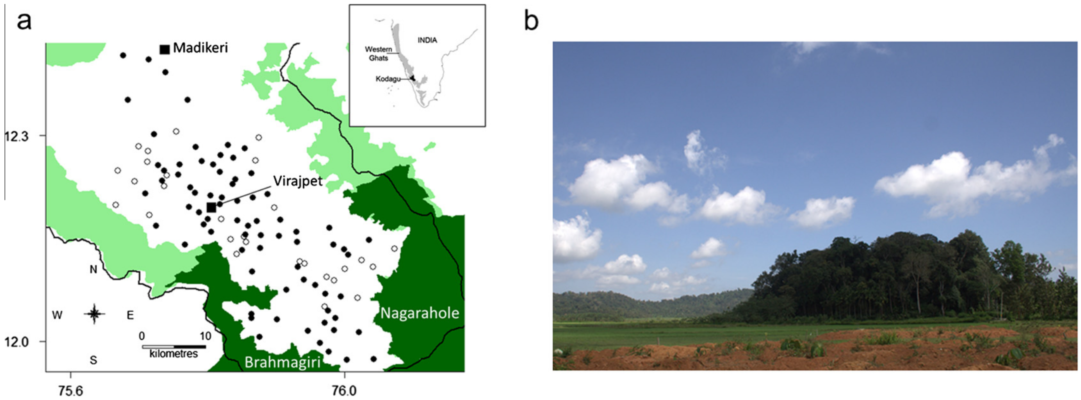

Fig. 1. (a) Map of study area in the Kodagu District (dark outline) in the Western Ghats of southern India. Filled circles indicate locations of 70 villages surveyed for sacred groves and open circles indicate villages in the Virajpet Forest Division which were not surveyed, but where sacred groves exist on record. Shaded areas represent State-protected forests under the National Park/Wildlife Sanctuary (dark) and Reserved Forest (light) categories. (b) A sacred grove, with a tall, continuous canopy, surrounded by rice fields, with shade coffee plantation in the background in the Bilagunda village of southern Kodagu.

calibrate the remotely-sensed index were available. These groves ranged in size from 0.04 ha to 16.43 ha.

Next, biomass trends in sacred groves were compared to corresponding trends in State-managed forests – Protected Areas and Reserved Forests – to ask whether forests under these contrasting conservation models differed in their trajectory of aboveground biomass. The distribution of pixel values of ratio45 trends were compared across three categories: (1) the forested interiors of sacred groves (SG), (2) the interiors of State-managed forests (PA-INT), and (3) the margins of State-managed forests (PA-EDG) bordering the human-modified landscape. Compared to SG locations, PA-INT were remote and inaccessible by people, and therefore served as controls reflecting trends in relatively large, undisturbed forests. On the other hand, PA-EDG locations were in closer proximity to human settlements, with SG and PA-EDG providing a comparison of biomass trends in community-managed and State-managed forests that were more similar in their accessibility by people. PA-INT and PA-EDG locations were digitised from within and close to the edges of the administrative boundaries of State-managed Brahmagiri Wildlife Sanctuary, and Kerti and Padinalknad Reserved Forests by visual inspection of cloud-free Google Earth images captured during 2002–2005. The distributions of ratio45 trend values of PA-INT and PA-EDG pixels (6337 and 1953 pixels, respectively) were compared to corresponding values of 42 sacred groves (2435 pixels) which lie within an annual rainfall range of 2600–3500 mm. The analysis was restricted to pixels in this annual rainfall range as nearly all of the comparable evergreen forests in State-managed forests in the study area lie within this range. The mean and 95% confidence intervals of the biomass trend across pixels were estimated for the SG, PA-INT and PA-EDG categories. The trends were categorised as increasing, decreasing or no trends in aboveground biomass depending on the whether the 95% confidence interval range was positive, negative, or spanned zero, respectively. Pairwise comparisons were made between biomass trends of the three groups using *t*-tests.

While sacred groves also occur in regions of 2300–2600 mm annual rainfall, there were no PA-INT locations and a very limited representation in PA-EDG locations in this zone. Moreover, a large proportion of the State-managed forests in this zone is under open, rocky or bamboo-dominated cover, and was not considered for the analysis. For these reasons, no formal comparison was made between sacred groves and State-managed forests in this zone; however, the trends observed for the small sample of PA-EDG pixels are described in Appendix A.

The Quantum GIS software (QGIS Development Team, 2012) was used for all GIS operations, and image-processing and statistical analyses were carried out using R-3.0.2 (R Core Team, 2013).

2.4. Interview surveys

We interviewed members of the local community who previously or presently served as members of village temple committees, and therefore had first-hand knowledge and experience of the management and protection of sacred forests in their villages. The interviews comprised both specific questions about individual sacred groves they were involved in managing as well as general questions about sacred groves in the wider landscape. Topics ranged from the values associated with sacred groves and uses by local people, to perceived trends in forest cover and structure, and perceived threats and drivers of change in forest cover and structure over time (see Appendix B for full questionnaire). Here, we focus on three specific and three general questions pertaining to forest cover, forest structure, threats and cultural perceptions (Table 1).

A total of 59 respondents speaking about 53 sacred groves across 48 of the 70 surveyed villages were interviewed during April–October 2013. In villages where interviews were not conducted, it was either because (1) we were unable to confirm the existence of sacred groves, (2) were unable to confirm the existence of a temple committee, (3) were unable to contact temple committee members, or (4) potential interviewees were not available for interview during the study period. Interviews were conducted in one of two local languages, Kodava or Kannada. Interviews were conducted either in person or over telephone, and were audio-recorded whenever permitted by the respondents. Prior to each interview, respondents were informed of the background to the study and assured complete anonymity with respect to the information they provided.

3. Results

3.1. Inventory and habitat assessment

Of the 407 sacred groves officially listed in the 70 villages surveyed, 208 (51%) were conclusively located during the field survey. An additional 37 sacred groves located in these villages were not conclusively linked to groves in the official list due to inconsistencies in names. The remaining groves were not located, and given

Table 1
Interview questions posed to members of village temple committees.

1	Specific	Has there been a change in the size of the sacred grove forest patch over the last ten years? *a. Increase b. Decrease c. No change d. Not aware e. Other (please specify)*
2a	Specific	How would you describe the present condition of the sacred grove forest? *a. Dense vegetation with tall trees everywhere* *b. Dense vegetation with tall trees in most places, open and disturbed in a few places* *c. Dense vegetation with tall trees in few places, open and disturbed in a most places* *d. Open and disturbed everywhere* *e. Not aware* *f. Other (please specify)*
2b	Specific	How would you describe the past condition (10 years ago) of the sacred grove forest? *Options a-f from 2a*
3	Specific	What are the main threats to the size and the quality of the sacred grove forest over the coming ten years?
4	General	As per the official records around the 1990s, there were around 550 sacred groves covering 3500 acres in the Virajpet Forest Division. In your opinion, how have these numbers changed over the years? *a. Increase b. Decrease c. No change d. Not aware e. Other (please specify)*
5	General	What are the main reasons why in some villages, sacred groves are quite disturbed, and sometimes even completely cleared with only the temple remaining?
6	General	If the area of sacred grove is reduced, or if the dense forest becomes more open and disturbed, how does it affect the cultural importance or value of the sacred grove?

our exhaustive effort, quite likely do not presently exist as forested groves. Of the 208 groves located in the field, 161 were forested while the rest had no forest cover. A large proportion of the sacred groves officially listed <2 ha in area were either not located, or did not have any area under forest at the time of survey. In contrast, the majority of the larger groves (>2 ha) were forested, and had closed canopy forest cover (Fig. 2).

3.2. Trends in aboveground biomass

Over the 2000–2010 period, 77% of the sacred groves showed declining trends in aboveground biomass. The trends were not correlated with annual rainfall ($r = 0.03$, $p = 0.78$) or sacred grove size ($r = 0.04$, $p = 0.72$).

SG sites differed from PA-INT and PA-EDG sites in the direction of aboveground biomass trends (Fig. 3). While the remotely-sensed biomass index ratio45 showed declines (mean = −0.58%/year) across SG pixels, with a 95% confidence interval that spanned a negative range (−0.70% to −0.47%), PA-INT (mean = 0.74%; 95% CI = 0.62–0.87%) and PA-EDG (mean = 0.42%; 95% CI = 0.28–0.56%) showed an increasing trend, with a positive 95% confidence interval range. Statistical differences between these groups based on pairwise *t*-tests were all significant at $p < 0.0001$.

3.3. Interview surveys

Interview respondents were, on average, 55 years old, and had spent an average of eight years in their roles on temple committees. While responding to specific questions about sacred groves that they were directly involved in managing, 37% respondents perceived a reduction in forest area and 24% perceived a shift to more open-canopied forests over the last ten years, with 27% identifying encroachment and illegal logging as significant threats. By and large, most respondents did not perceive any changes (size: 61%; canopy cover: 76%) or immediate threats (56%) to these sacred groves.

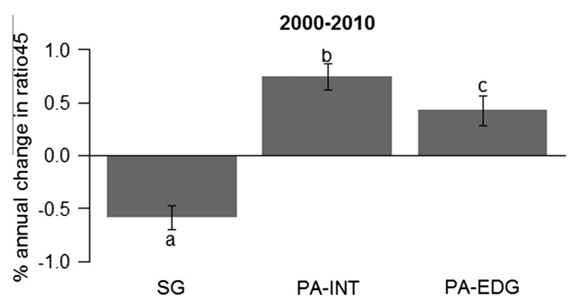

Fig. 3. Trends in the ratio of Landsat ETM+ band 4 to band 5 (ratio45) – an index of aboveground biomass – in SG, PA-INT and PA-EDG pixels. *Y*-axis values represent annual rate of change in ratio45 relative to the year 2000 baseline value (in percentage terms). Bars represent mean pixel values and error bars represent 95% confidence intervals of the mean. Different text characters over bars represent statistical differences between groups.

While responding to more general questions about sacred groves in the landscape, a majority of the respondents (49%) believed there was a reduction in the size of the sacred grove network from the 1990s to present (Fig. 4a). Deforestation and land use change following encroachment along sacred grove boundaries, and the illicit felling of trees for timber were perceived to be the primary reason for loss of forest cover and quality (Fig. 4b). Significantly, no more than 14% of the respondents were

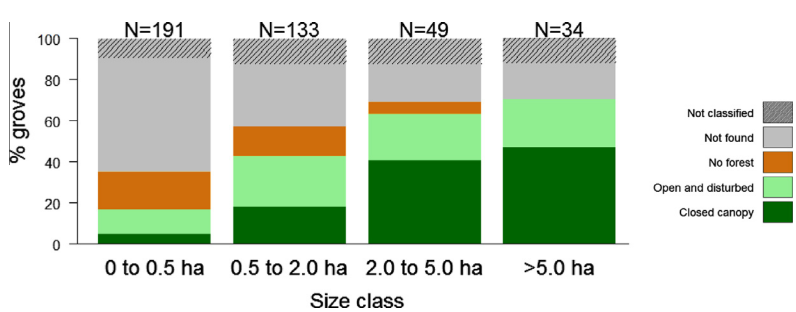

Fig. 2. The numbers and percentages of inventoried sacred groves by size-classes based on listed area. The colour coding reflects forest status and structure. The 'Not classified' category contains groves which were not classified because of ambiguity surrounding grove name or grove location/extent on the ground. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of the opinion that the cultural and religious importance of sacred groves was affected by changes in forest size or quality (Fig. 4c).

4. Discussion

The conservation value of the sacred grove network of southern Kodagu is primarily attributed to the large number and geographic spread of forest fragments across an important conservation landscape (Bhagwat et al., 2005a; Garcia and Pascal, 2006). Our results suggest that the network comprises significantly fewer groves than are reported in official records and conservation assessments, with many sacred groves having degraded or no forest cover in the present day. However, these reductions are largely restricted to smaller sacred groves (<2 ha), with most of the larger (>2 ha) sacred groves retaining forest cover to the present day. This finding does not necessarily indicate that sacred groves were lost during the 1985–2010 period, as there is the possibility that not all groves lost pre-1985 were excluded from the 1985 compilation. However, the perceptions of village temple committee members reiterate that there have been losses of sacred forest cover in recent years, and that the threat of further losses exists. Over a third of our interview respondents perceived that sacred groves that they managed had reduced in area over the last decade, while highlighting encroachment and illegal logging as important threats. Although encroachment and logging are not new threats (Kalam, 1996), current land scarcity, an incomplete land settlement process, prevalent uncertainty over sacred grove administrative boundaries and changing cultural beliefs combine to make the margins of these sacred groves particularly vulnerable to deforestation, logging and land use change (Chandrakanth et al., 2004; Kushalappa and Raghavendra, 2012; Ormsby, 2011). Given this situation, large-scale efforts to update official records, map remaining forest cover, and identify and demarcate administrative boundaries are likely to be highly beneficial not only for protecting these forests from further losses, but also for redefining conservation targets and strategies for the region.

Sacred groves experienced declines in aboveground biomass during the 2000–2010 period, while both the remote interiors of State-managed forests and, to a lesser extent, their more accessible edges increased in aboveground biomass during this period. These contrasting trends suggest that the observed declines are likely to be driven by processes specific to the sacred groves, rather than simply reflecting larger-scale processes which affect all forests in the region. At present, well-protected sacred groves in the study area store ~120 t/ha carbon aboveground – nearly 40% less than large State-managed forests (Osuri et al., 2014). These groves are characterised by relatively more open and discontinuous tree canopies, lower basal area, and shorter tree stands than State-managed forests, alongside marked shifts in species composition towards more deciduous and generalist-dominated communities harbouring fewer endemics and species of conservation importance (Bhagwat et al., 2005b; Garcia and Pascal, 2006; Osuri et al., 2014). While there are no assessments from the study area linking remotely-sensed metrics to other biodiversity and conservation indicators, assessments elsewhere in the central Western Ghats suggest that positive associations may exist between forest biomass and species diversity (Bawa et al., 2002). All these lines of evidence suggest that the ongoing biomass declines recorded in sacred groves may make them less favourable habitats for a suite of rainforest-affiliated taxa, and reduce their conservation value over time.

Extraction of woody biomass by humans is likely to be an important driver of biomass declines in sacred groves. Most groves are easily accessible, given their close proximity to human settlements, and have traditionally been used not just by local communities but also by the State for timber and biomass extraction (Kalam, 1996). In addition to physical proximity, there is evidence that local communities perceive these groves to be less restricted than State-managed forests in terms of access and use (Garcia and Pascal, 2006). Although sacred groves have been protected from timber extraction by law in recent decades, other forms of biomass extraction persist, and illicit logging continues to be perceived by local communities as a significant threat to sacred groves. While the edges and interiors of State-managed forests too may be subject to illegal tree felling and encroachment on occasion (e.g. Kumar et al. (2014)) and experience biomass declines at some locations (see Appendix A), on the whole these forests appear to have increased in aboveground biomass in the study area in recent years.

In addition to direct anthropogenic impacts, the fact that most sacred groves are small and isolated forest fragments also exposes them to ecological gradients which alter forest structure and species composition, and reduce aboveground biomass over time (Laurance et al., 1997; Nascimento and Laurance, 2004). Given the likely synergistic effects of cultural, anthropogenic resource use and ecological drivers on the structure and biomass of these sacred forest fragments, conservation efforts too would need to be multi-faceted. Better protection, resource management and habitat restoration need to go alongside efforts to reinforce the links between the integrity of sacred forests and religious and cultural values (Bhagwat et al., 2013): a link which was acknowledged by a small minority of our interviewees. Conservation efforts are also likely to benefit by emphasising linkages between sacred groves and ecosystem services (e.g. crop pollination: (Krishnan et al., 2012)), which were widely-recognised by our interview respondents (Appendix B).

In terms of conservation prospects of the sacred grove network of south Kodagu, our findings evoke a mix of optimism and caution. On the one hand, hundreds of community-protected sacred groves still persist in the landscape, while other forests have been reduced in recent decades (e.g. private forests: (Garcia et al., 2009)). Some of these sacred groves harbour old-growth forest stands, endemic and threatened rainforest species, and species of cultural and commercial value (Bhagwat et al., 2005b; Boraiah et al., 2003; Osuri et al., 2014). This is a testament to the strong and ancient linkages local communities share with these sacred sites. The efforts of the

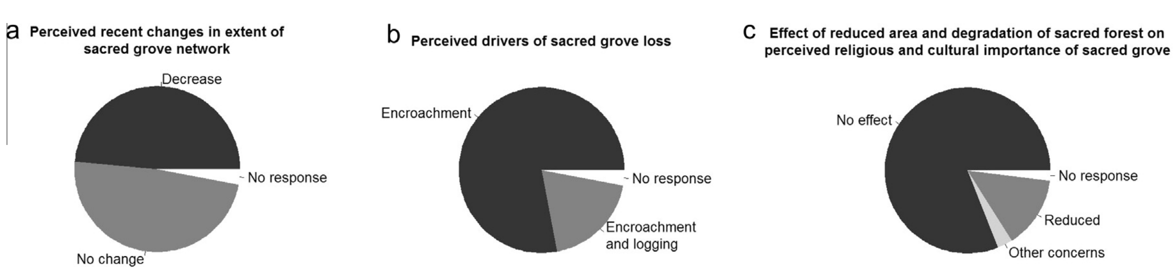

Fig. 4. Interview responses of village temple committee members to general questions on (a) recent changes in sacred grove network, (b) drivers of sacred grove loss and (c) religious and cultural implications of loss of sacred grove area and integrity.

Karnataka Forest Department to support local community efforts through joint forest management schemes and eco-development committees are also noteworthy (Kushalappa and Raghavendra, 2012). At the same time, a large number of sacred groves in the landscape are degraded, or have been converted to other land uses, reinforcing concerns regarding their long-term conservation (Chandrakanth et al., 2004; Kalam, 1996). Clearly, there is variation across sacred groves in their status and conservation value, just as there is variation across villages and local communities in the level to which sacred groves are protected and the means by which this is done. These variations are likely to be influenced by proximity of settlements to groves, nature of use by local communities, local beliefs, customs and management practices. Understanding how these geographic, cultural and institutional factors influence the ecological and conservation status of sacred groves represents an important requirement in order to take forward the discussion on CCAs and conservation.

5. Conclusions

Our findings reiterate the importance of improved documentation and frequent monitoring to aid conservation planning for CCAs, especially those more exposed to anthropogenic resource use, altered ecological gradients and societal change. Even while CCAs have been relatively successful at preventing deforestation (Porter-Bolland et al., 2011), they are likely to experience changes in forest structure, species composition and other conservation indicators (Shahabuddin and Rao, 2010). In this context, our results underscore the utility of long-term monitoring of forest biomass as a barometer of conservation value and to strengthen conservation planning. Similarly, it is essential to monitor changes in community institutions, cultural beliefs and perceptions over time, many of which may influence forest and biodiversity conservation in CCAs. This may be particularly important in the light of widespread concerns over the challenges posed to community-based conservation approaches arising from weakening linkages between societies and nature (Bhagwat and Rutte, 2006). On the whole, better documentation and monitoring serve not only to better identify conservation opportunities (Kothari, 2006), but also in setting informed and realistic conservation targets.

Acknowledgements

This project was funded by Rufford Small Grants Foundation, CEPF-ATREE Western Ghats Small Grants programme and UK-India Education and Research Initiative, with administrative and logistical support from National Centre for Biological Sciences, Nature Conservation Foundation and College of Forestry (Ponnampet). Satellite data were provided by the U.S. Geological Survey. MDM thanks Ecosystem Alliance and The Whitley Fund for Nature for funding support. We record our gratitude to members of the local community who encouraged our work and provided valuable information on sacred groves. We thank the Karnataka Forest Department for permissions and logistical support in the field. We are grateful to Shivani, Sathish S., Praveen N. and Santhosh Uthappa for assistance in data collection. We thank Varun Varma, Dr. Raghavendra S., Dr. Sathish BN, Dr. Divya Mudappa, Dr. T.R. Shankar Raman and Uttara Mendiratta for advice and suggestions, and two anonymous reviewers whose comments helped to substantially improve this manuscript.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2014.08.008. These data include Google maps of the most important areas described in this article.

References

Alvard, M.S., 1993. Testing the "ecologically noble savage" hypothesis: interspecific prey choice by Piro hunters of Amazonian Peru. Hum. Ecol. 21, 355–387.

Bawa, K., Rose, J., Ganeshaiah, K.N., Barve, N., Kiran, M.C., Umashaanker, R., 2002. Assessing biodiversity from space: an example from the Western Ghats, India. Conserv. Ecol. 6, 7.

Berkes, F., 2009. Community conserved areas: policy issues in historic and contemporary context. Conserv. Lett. 2, 20–25.

Bhagwat, S.A., Rutte, C., 2006. Sacred groves: potential for biodiversity management. Front. Ecol. Environ. 4, 519–524.

Bhagwat, S.A., Kushalappa, C.G., Williams, P.H., Brown, N.D., 2005a. A landscape approach to biodiversity conservation of sacred groves in the Western Ghats of India. Conserv. Biol. 19, 1853–1862.

Bhagwat, S.A., Kushalappa, C.G., Williams, P.H., Brown, N.D., 2005b. The role of informal protected areas in maintaining biodiversity in the Western Ghats of India. Ecol. Soc. 10.

Bhagwat, S.A., Nogué, S., Willis, K.J., 2013. Cultural drivers of reforestation in tropical forest groves of the Western Ghats of India. Forest Ecol. Manage. 329, 393–400.

Boraiah, K.T., Vasudeva, R., Bhagwat, S.A., Kushalappa, C.G., 2003. Do informally managed sacred groves have higher richness and regeneration of medicinal plants than state-managed reserve forests? Curr. Sci. 84, 804–808.

Brooks, T.M., Bakarr, M.I., Boucher, T., Da Fonseca, G.A.B., Hilton-Taylor, C., Hoekstra, J.M., Moritz, T., Olivieri, S., Parrish, J., Pressey, R.L., 2004. Coverage provided by the global protected-area system: is it enough? Bioscience 54, 1081–1091.

Chandrakanth, M.G., Bhat, M.G., Accavva, M.S., 2004. Socio-economic changes and sacred groves in South India: protecting a community-based resource management institution. Nat. Resour. Forum 28, 102–111.

Chape, S., Harrison, J., Spalding, M., Lysenko, I., 2005. Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Philos. Trans. Roy. Soc. B 360, 443–455.

Chazdon, R.L., Harvey, C.A., Komar, O., Griffith, D.M., Ferguson, B.G., Martínez-Ramos, M., Morales, H., Nigh, R., Soto-Pinto, L., Van Breugel, M., 2009. Beyond reserves: a research agenda for conserving biodiversity in human-modified tropical landscapes. Biotropica 41, 142–153.

Colding, J., Folke, C., 2001. Social taboos: "invisible" systems of local resource management and biological conservation. Ecol. Appl. 11, 584–600.

Gadgil, M., Vartak, V.D., 1975. Sacred groves of India – a plea for continued conservation. J. Bombay Nat. Hist. Soc. 72, 314–320.

Garcia, C., Pascal, J.P., 2006. Sacred forests of Kodagu: ecological value and social role. In: Ecological nationalisms: nature livelihoods and identities in south Asia. University of Washington Press, Seattle and London, pp. 199–229.

Garcia, C.A., Bhagwat, S.A., Ghazoul, J., Nath, C.D., Nanaya, K.M., Kushalappa, C.G., Raghuramulu, Y., Nasi, R., Vaast, P., 2009. Biodiversity conservation in agricultural landscapes: challenges and opportunities of coffee agroforests in the Western Ghats, India. Conserv. Biol. 24, 479–488.

Gaston, K.J., Jackson, S.F., Cantú-Salazar, L., Cruz-Piñón, G., 2008. The ecological performance of protected areas. Annu. Rev. Ecol. Evol. Syst. 39, 93–113.

Harrison, J., Miller, K., McNeely, J., 1982. The world coverage of protected areas: development goals and environmental needs. Ambio 11, 238–245.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A., 2005. Very high resolution interpolated climate surfaces for global land areas. Int. J Climatol. 25, 1965–1978.

Kalam, M.A., 1996. Sacred Groves in Kodagu District of Karnataka (South India): a Socio-Historical Study. Institut Français de Pondichéry (IFP), Pondicherry.

Kothari, A., 2006. Community conserved areas: towards ecological and livelihood security. Parks 16, 3–13.

Krishnan, S., Kushalappa, C.G., Shaanker, R.U., Ghazoul, J., 2012. Status of pollinators and their efficiency in coffee fruit set in a fragmented landscape mosaic in South India. Basic Appl. Ecol. 13, 277–285.

Kumar, G.R.P., Hemanjali, A.M., Ravikumar, P., Somashekar, R.K., Nagaraja, B.C., 2014. Assessing the Historical Forest Encroachment of Kodagu region of Western Ghats, South India using remote sensing and GIS. National Remote Sensing Centre, Indian Space Research Organisation, Hyderabad.

Kushalappa, C.G., Bhagwat, S.A., 2001. Sacred groves: biodiversity, threats and conservation. Forest Genetic Resources: Status, Threats, and Conservation Strategies. Oxford and India Book House, New Delhi, India.

Kushalappa, C.G., Raghavendra, S., 2012. Community-linked conservation using Devakad (sacred groves) in the Kodagu Model Forest, India. Forest. Chron. 88, 266–273.

Laurance, W.F., Laurance, S.G., Ferreira, L.V., Rankin-de Merona, J.M., Gascon, C., Lovejoy, T.E., 1997. Biomass collapse in Amazonian forest fragments. Science 278, 1117–1118.

Nascimento, H.E.M., Laurance, W.F., 2004. Biomass dynamics in Amazonian forest fragments. Ecol. Appl. 14, 127–138.

Ormsby, A.A., 2011. The impacts of global and national policy on the management and conservation of sacred groves of India. Hum. Ecol. 39, 783–793.

Osuri, A.M., Kumar, V.S., Sankaran, M., 2014. Altered stand structure and tree allometry reduce carbon storage in evergreen forest fragments in India's Western Ghats. Forest Ecol. Manage. 329, 375–383.

Page, N.V., Qureshi, Q., Rawat, G.S., Kushalappa, C.G., 2010. Plant diversity in sacred forest fragments of Western Ghats: a comparative study of four life forms. Plant Ecol. 206, 237–250.

Pascal, J.P., 1982. Explanatory Notes on the Bioclimate Maps of the Western Ghats. Institut français de Pondichéry, Pondicherry.

Pascal, J.P., 1986. Explanatory Booklet on the Forest Map of South India. Sheets: Belgaum-Dharwar-Panaji, Shimoga, Mercara-Mysore. Institut français de Pondichéry, Pondicherry.

Porter-Bolland, L., Ellis, E.A., Guariguata, M.R., Ruiz-Mallén, I., Negrete-Yankelevich, S., Reyes-García, V., 2011. Community managed forests and forest protected areas: an assessment of their conservation effectiveness across the tropics. Forest Ecol. Manage. 268, 6–17.

QGIS Development Team, 2012. QGIS Geographic Information System. Open Source Geospatial Foundation Project <http://qgis.osgeo.org>.

R Core Team, 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <http://www.R-project.org/>.

Raghavendra, S., Kushalappa, C.G. (Eds.), 2011. Devarkaadus (Sacred Forests) of Kodagu: A Living Tradition of Community Linked Conservation. Karnataka Forest Department, Madikeri and Virajpet Forest Divisions.

Rutte, C., 2011. The sacred commons: conflicts and solutions of resource management in sacred natural sites. Biol. Conserv. 144, 2387–2394.

Salick, J., Amend, A., Anderson, D., Hoffmeister, K., Gunn, B., Zhendong, F., 2007. Tibetan sacred sites conserve old growth trees and cover in the eastern Himalayas. Biodivers. Conserv. 16, 693–706.

Sen, P.K., 1968. Estimates of the regression coefficient based on Kendall's tau. J Am. Stat. Assoc. 63, 1379–1389.

Shahabuddin, G., Rao, M., 2010. Do community-conserved areas effectively conserve biological diversity? Global insights and the Indian context. Biol. Conserv. 143, 2926–2936.

Sodhi, N.S., Butler, R., Raven, P.H., 2011. Bottom-up conservation. Biotropica 43, 521–523.

Verschuuren, B., Wild, R., McNeely, J., Oviedo, G. (Eds.), 2010. Sacred Natural Sites: Conserving Nature and Culture. Earthscan, London.