26

Climate Change and India's Forests

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Forest ecosystems are linked to the climate change problem in several ways. Standing forests are repositories of carbon and growing forests can be net carbon sinks. So, conserving existing forests and creating new or denser forests helps in the mitigation of global climate change. Forests also mediate other climatic processes that are being influenced by global climate change, such as rainfall. However, climate regulation—whether global or regional—is not the only benefit that forests provide to society, especially in a country like India. An exclusive focus on the climate benefits can therefore affect other forest-related benefits. Simultaneously, forests are being affected by climate change, thereby influencing their ability to provide these other benefits. To understand the relationship between forests and climate change in India, we begin by first elucidating the socio-ecological nature of forests in general, and the ongoing contestation in India over the control and management of these forests in particular. We then look at the possible role of India's forests in mitigating climate change through carbon sequestration, and also their role in other climate processes. Finally, we discuss how looming climate change may, in turn, shape India's forests and forest-related benefits.

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Social Ecology of India's Forests

India's forests cover about 70 million hectares or about 21 per cent of the country's landscape (FSI 2015: 38). This bald statement hides the diversity of forest types, histories, and social settings in which forests exist. Ecologically, the forest types in India range from the temperate needle-leaf and broadleaf forests of the Himalayas to the tropical evergreen forests of the Western Ghats, with a large portion in central India covered with dry deciduous teak- or sal-dominated tracts and other regions with drier scrub-thorn vegetation. Given the confusion between legal and dictionary definitions, our 'forests' in fact include the pure grasslands that surround the Nilgiri *shola*, the anthropogenic grasslands in many parts of the Western Ghats, and the savannas of drier central–western India. They also include single-species teak, eucalyptus, and pine plantations developed under colonial and post-colonial forestry.

As elsewhere, Indian society has had a love–hate relationship with forests. While forests have been cleared over millennia for agriculture, and in the last two centuries also for dams, mines, and roads, they are also seen as valuable for various reasons. First, India's forests are extremely rich in biodiversity, harbouring 6 per cent of global flora and 6.5 per cent of global fauna, including 500-odd endemics, in just 1.7 per cent of the world's forests (World Conservation Monitoring Centre [WCMC] 1999). Second, these forests provide important indirect regional environmental benefits, including erosion control on steep slopes, hydrological regulation, microclimatic and regional climate regulation, and pollination services to agro-ecosystems (Brandon 2014). Third, these forests can be sources of timber and softwood for industrial and urban consumers.[1]

Fourth, and most important in the Indian context, these forests have been historically used by the dense population in the subcontinent and continue to be directly important for the livelihoods of at least 275 million rural people (World Bank 2006). These people collect firewood, graze livestock, use timber and bamboo for construction, and harvest and sell non-timber forest products (NTFPs) and a large variety of food and medicinal plants; the last being a vital part of the livelihoods of millions

[1] Alternative sources would be private farm forestry.

of Adivasis in central and north-eastern India. Of course, the climate change debate has also highlighted the fact that forests are repositories of carbon, which means deforestation will contribute to carbon emissions, while reforestation can offset carbon emissions.

The core 'forest problematique' arises because these multiple benefits cannot be simultaneously maximized (Lele and Kurien 2011). Biodiversity conservation is only partly compatible with traditional livelihoods and not at all with plantation forestry (Hall et al. 2012). Even local use is not homogeneous: closed-canopy forests will produce less understorey grass for livestock than open-canopy forests. Similarly, use of wood as fuel is carbon neutral if harvested sustainably, but creating a net carbon sink would require banning all harvesting. Most important, these different benefits flow to different beneficiaries—local firewood collectors, nomadic graziers, downstream farmers, regional economies, or global ecotourists (Lele and Srinivasan 2013). Forests also produce 'dis-services' in the form of wildlife attack or pathogens, the costs of which are typically borne by forest-adjacent communities (Lele et al. 2013). Forest governance therefore involves taking decisions about where to prioritize which benefits, for whom, to what extent, and through what process. The last 200-odd years, beginning with establishment colonial rule, have seen a continuous contestation over precisely these questions (Lele and Menon 2014a). The introduction of carbon sequestration goals into domestic forest policy is bound to exacerbate this contestation.

Forests and Carbon Sequestration

In global climate negotiations, developed countries (the emitters of most of the carbon from fossil fuel burning) have consistently sought to put pressure on developing countries for their high deforestation rates. Unlike tropical forested countries such as Brazil or Indonesia, however, India has warded off this pressure by pointing out that its forest cover has been relatively stable (Ravindranath, Somashekhar, and Gadgil 1997).[2] Indeed, post 1995, official

[2] Countries like Brazil and Indonesia have a very high fraction of their land under forest cover, whereas in India, historical deforestation has already brought the fraction down to 20 per cent, leaving less to be deforested.

estimates claim that Indian forests are in fact net sinks of carbon (Indian Network for Climate Change Assessment [INCCA] 2010; Kishwan, Pandey, and Dadhwal 2009; Ministry of Environment, Forest and Climate Change [MoEFCC] 2012, 2015b), and several analysts claim that they have the potential to sequester much more (Singh et al. 2013).

On this basis, India has pushed for an expansion of the REDD (reducing emissions from deforestation and degradation) programme, which sought to reward countries like Brazil and Indonesia if they reduced deforestation rates, to a REDD+ programme that rewards increases in forest cover and sequestered carbon (MoEFCC 2014: Section 2.4). With the adoption of REDD+ at the 15th Conference of the Parties (COP 15) in Bali (United Nations Framework Convention on Climate Change [UNFCCC] 2008), the Indian government's actions focused on efforts towards 'REDD-readiness' (Vijge and Gupta 2014), in anticipation of large-scale international funding.[3] An important component requirement for REDD is reliable measurement, reporting, and verification (MRV). The international negotiations, however, only led to draft agreements on MRV processes by 2013 (MoEFCC 2014: 22). The Indian government claims to have a robust top-down forest monitoring system (Aggarwal et al. 2009) to build this on. Other studies have argued that community-based monitoring would be cheaper (Singh, Tewari, and Phartiyal 2011). However, hardly any REDD+ projects actually got under way—only one in Meghalaya (Poffenberger 2015) has garnered payments in the voluntary carbon market.

Gradually, the policy emphasis appears to have shifted away from garnering external funds towards using internal funds for sequestration (Vijge and Gupta 2014). In its Intended Nationally Determined Contribution (INDC) for the Paris COP 21 Agreement in 2015, India committed to sequester an additional 2.5–3 billion tonnes of carbon dioxide (CO_2) equivalent in its forest sector by 2030 (MoEFCC 2015a), probably on the basis of a massive US$ 6 billion compensatory afforestation fund (Compensatory Afforestation Fund Management and Planning Authority [CAMPA]) that has

[3] One official estimate was of US$ 3 billion over three decades (MoEFCC 2010).

accumulated (Lahiri 2015). This pledge (hereinafter INDC3) has been the subject of much public debate (Kohli and Menon 2015; Lahiri 2015; Pulla 2015). Common to debates on INDC3 and the earlier REDD+ related goals are two questions:

1. How accurate are the biophysical estimates on which claims of current net sequestration, and therefore the technical feasibility of the INDC, are based?
2. If there are biophysical (and hence social) trade-offs involved in prioritizing carbon sequestration over other forest benefits, who will decide on whether and how much to prioritize which benefits? Alternatively, what might be the socio-environmental consequences of the government trying to force a particular priority or goal at the cost of others?

Biophysical Estimates: Optimistic and Opaque

There is a divergence between academic and official estimates of current rates of carbon sequestration in India's forest sector in recent years. Official estimates range from +68 megatonnes of carbon dioxide equivalent ($MtCO_2$-eq/yr) in 2005–7 (INCCA 2010) to +203 $MtCO_2$-eq/yr for the year 2000 (MoEFCC 2012) and +200 $MtCO_2$-eq/yr for the year 2010 (MoEFCC 2015b). However, some academic studies estimate net sequestration to be negative, from –185 $MtCO_2$-eq/yr in 2005–7 (Sheikh et al. 2011) to –198 $MtCO_2$-eq/yr during 2005–13 (Reddy et al. 2016).[4] The reasons for this divergence may be several. First, differences in definition of forest is one reason. Official estimates include all tree cover (including monocultural plantations in forest lands as well as horticultural crops in private lands), which results in a rising 'forest cover' trend, while only natural tree cover shows a declining trend (Reddy et al. 2016). Second, the official estimates include the amount of sequestration due to growth in forests that remained forests (termed FL-FL) and addition in carbon due to conversion of non-forest to

[4] The academic estimates exclude changes in soil carbon, but these are anyway estimated to be negative in official estimates, so their inclusion would only increase the divergence.

forest (termed L-FL); but they appear not to include the carbon emissions from forest to non-forest transitions (termed FL-L), which are non-zero (Dubash et al. 2018). Third, there is variation within official estimates themselves: the Forest Survey of India (FSI) data show declining growing stock for most of 2003–13 in spite of stable or increasing forest cover, but national communications have come up with a positive trend (MoEFCC 2012, 2015b).

The ambitious INDC3 appears to be driven by the optimistic estimates of current net sequestration. Indeed, if India is already sequestering forest carbon at the rate of 200 $MtCO_2$-eq/yr, then it just needs to maintain this rate for 15 years to meet INDC3! This is because the pledge contains no claim of additionality (Grassi et al. 2017). However, the poor record of afforestation programmes in India does not lend credence to this official claim of massive net sequestration (Kohli and Menon 2015), nor does it seem plausible given the government's own estimates for 2005–7 (INCCA 2010). If in fact India's forests are net *emitters* due to ongoing degradation, then reversing the degradation and further meeting this target would require fast-growing monoculture plantations and draconian protection measures.

How can this debate about the quantum (and even the existence) of net sequestration be resolved? A persistent lacuna in the government's approach to this quantification has been the lack of transparency and credible independent verification. The FSI does not offer its forest cover maps in downloadable and usable format that can be verified or corrected by others. Nor are the data and locations of the state-funded National Carbon Pool project (Dadhwal et al. 2009: 200) available in the public domain. Given the conflict of interest in the ministry monitoring its own achievements, a more independent and transparent monitoring process is clearly required (Lele 2012).

Recognizing and Addressing the Trade-offs

Do Indian policymakers, which means primarily the MoEFCC, recognize that pursuing sequestration goals could come at the expense of other forest-related goals? There is no evidence of this recognition in government documents. As Vijge and Gupta (2014) point out, the Green India Mission (GIM), which is the key strategy for achieving

INDC3, ‘does not entertain the possibility of tradeoffs’ between ‘carbon and non-carbon benefits of forests, such as biodiversity’.

This is part and parcel of the overall tendency in official Indian forest policy documents to gloss over trade-offs between forest-related benefits and to treat all types of forests as universally good. This tendency is already institutionalized in the FSI’s forest cover monitoring strategy wherein ‘forest cover’ is defined as ‘all lands, more than 1 hectare in area, with a *tree* canopy density of more than 10%’ (FSI 2015: 25). Indeed, from a carbon perspective, forest cover and tree cover are almost interchangeable. However, as academics and activists have repeatedly pointed out, this approach clubs (for instance) single-species timber plantations with mixed-species natural forests, thereby hiding major differences in biodiversity levels and other benefits that these two types of tree covers would provide (Agarwal 1997; Davidar et al. 2010).

Consequently, the question of how these trade-offs are to be resolved, and by whom, has received almost no attention at the policy level. In the public arena, however, this (rather than the quantum of sequestration per se) has been the bigger concern with the government’s pursuit of REDD+ funds and its possibly imprudent INDC3 (Aggarwal 2011). While some activists have categorically rejected carbon sequestration as a goal for community-managed forests, most argue that the decision whether and how much to focus on sequestration versus use of forests for livelihood or conservation purposes must be left to communities to make. From this perspective, the government’s job is to simply make available appropriate incentives for different non-local forest benefits to become part of community decision making, to reduce the gap between carbon market prices and those reaching communities, and to bear the transaction cost of monitoring. All this, however, requires communities to have control over their forests and the authority and autonomy to make their own decisions. This is precisely what is being contested currently.

Forest governance, and specifically the role of communities in it, is currently in a state of flux in India (Lele and Menon 2014b). After decades of pursuing a colonial forest policy of exclusionary forest management, the Government of India finally acknowledged the need to involve local communities in its landmark National Forest Policy document of 1988. Joint Forest Management (JFM) was then initiated as a programme in the early 1990s and slowly spread across most states. However, JFM failed to engender meaningful participation, even by official assessments (Environmental Impact Assessment [EIA] Division 2008). Most rigorous evaluations have found it lacking in genuine participation and becoming an instrument to further the forest departments' agenda, often in the form of monocultural plantations (for a summary, see Lele 2014).

The Forest Rights Act (FRA), 2006, is a landmark legislation that offers communities the right to manage their forests as per their needs, within a broad sustainable use and conservation norm. Villages can claim rights over all the forests that they have traditionally used (not just degraded forests as in most JFM programmes) and can make plans for their management (including harvest and sale of any/all non-timber forest produce) without reference to the forest department. This loss of day-to-day control over possibly more than half of its forest estate is naturally being resisted strongly by the forest bureaucracy. Implementation of the FRA (especially its community forest rights component) has therefore been rather slow in most states (Community Forest Rights–Learning and Advocacy [CFR-LA] 2016; Lele 2017).

What would be the implications of such community control (if and when it happens) for carbon sequestration? Observations by Lele of forest management by villages in eastern Maharashtra that have received (and are exercising) their rights suggest that forests are quite likely be protected and even regenerated, but communities are likely to opt for natural regeneration, or planting of bamboo or other non-timber forest species, or reserving some areas for grazing or fodder plantations, resulting in a much lower rate of net carbon sequestration than in fast-growing single-species tree plantations. Could the state tilt the balance in favour of carbon forestry through a payments for ecosystem services (PES)-type scheme? In theory, yes. However, the price in the global carbon credit market (if it exists) is totally inadequate to compensate households that stand to lose fodder, fuel, and other livelihood benefits if forests are 'fenced off' for carbon (Lele 2013). The voluntary financial support for REDD+ is even more paltry, with the Green Climate Fund having garnered only 10 per cent of its target amount of 100 billion US$ (Sunderlin et al. 2015).

Unfortunately, the GIM plan and other official reports do not engage with this question adequately. They make assumptions of a smooth transition from JFM to FRA (Sud, Sharma, and Bansal 2012: 201) or glibly talk of 'harmonization' of JFM with other laws (that is, the FRA), as the draft National Forest Policy, 2018 does. In reality, there is no sign that the forest bureaucracy is willing to give up control over the forest estate, that it has enjoyed for 150 years, in favour of multilayered governance. It continues to use CAMPA funds (the biggest source of afforestation funding) for conventional plantation activities on any land it chooses, notwithstanding the conflict that this has generated with local communities (Land Conflict Watch n.d.) and notwithstanding its notional commitment to participatory forest management. If carbon-centric forestry is prioritized for the sake of INDC3, then forest governance will get further re-centralized (Vijge and Gupta 2014), something predicted globally for REDD+ as well (Phelps, Webb, and Agrawal 2010). Resolving the governance issue will be crucial to improving the synergies and reducing trade-offs between carbon sequestration, local livelihoods, and conservation, and for seeing lasting impacts on the ground.

Forests and Other Climate Impacts

Change in forest cover not only influences atmospheric carbon stocks, but can impact both albedo and evapotranspiration that can have local, regional, and global impacts depending on the location and scale of the change. Here, we summarize briefly what is known about the role of forests in rainfall in South Asia.

There is growing evidence from direct observations and modelling across the globe about the positive (or negative) impact of forest cover (or deforestation) on rainfall through recycling of evapotranspiration and other mechanisms (Bonan 2008; Spracklen, Arnold, and Taylor 2012). This has, however, been demonstrated unambiguously only for large forested regions, such as the Amazon and Congo basins. In India, Meher-Homji (1991) first drew attention to the influence of forest on rainfall and microclimate, using simplistic (and possibly unconvincing) correlation analysis in the absence of detailed data and modelling tools.

Recently, however, three studies have simulated the likely impacts of deforestation—*outside* and *within* India—on rainfall in India, covering both the Western Ghats and north-east India (Devaraju, Bala, and Modak 2015; Paul et al. 2016, 2018). They suggest significant connections: for example, the contribution of Western Ghats forests to summer rainfall in Tamil Nadu plains is estimated to be 25–40 per cent, adding a significant new dimension to the ecosystem services of the Western Ghats forests. Although these studies suffer from several limitations,[5] it appears that there is some evidence that, despite major decline in forested area over the last century, India's forests play some role in recirculating moisture and thereby adding to precipitation in the subcontinent. This strengthens the argument for conserving forests, but the questions about who decides and who maintains what kind of forests, and so on, remain.

Impact of Climate Change on India's Forests

Although conserving or even enhancing India's forest cover may not make a big dent in global carbon emissions, India's forests, their inhabitants, and their users, are likely to be affected by climate change in complex and as yet unclear ways. This uncertainty is a combination of the uncertainties around how climatic conditions will shift and about how forest vegetation and wildlife in it might respond to these shifts.

Possible Impacts on Forests

In trying to predict impacts on forest vegetation, scientists have focused on different (broad) outcome variables: forest productivity and standing stock; soil carbon stocks; and the broad type of plant–animal community that may occur in a particular area, that is,

[5] Such as use of inaccurate land cover classification, questionable assumptions about evapotranspiration being minimal from the Western Ghats forests in the dry season, and a focus on the south-west monsoon when Tamil Nadu receives much of its rain from the north-east monsoon.

biome.[6] The methods of prediction vary from using historical data on vegetation response to climate shifts as a surrogate, to building statistical models linking current vegetation distribution to current climate, to building more realistic but complex models of multiple biophysical processes including photosynthesis, leaf growth, and so on, to empirically correlating field observations of plant growth over last few decades (perhaps aided by remote sensing) with climatic trends during this period. All of them, of course, hinge on how well future climate is predicted and which of those variables (not just temperature, rainfall, and atmospheric carbon, but also extreme events, summer temperatures, rainfall in particular seasons, soil moisture stress, among others) are incorporated into the forest–climate model. Predicting impacts on animals is more complicated, because they are mobile and their presence depends upon vegetative conditions as well as climatic conditions.

Initial studies on 'biome shifts' characterized climate primarily in terms of average temperature, average rainfall, and CO_2 concentrations. Using the differential manner of carbon isotope absorption in plants with different photosynthetic pathways, a study in the Nilgiri sholas of the southern Western Ghats (Sukumar, Suresh, and Ramesh 1995) suggested that under higher CO_2 and moisture conditions, an expansion of montane forest and a shift in the composition of grassland species can be expected. Subsequent studies grappled with conflicting predictions about the direction of climatic shifts, giving rise to different conclusions about whether forest productivity would increase and forests' vegetation would shift to moister types or whether drier types of forest would expand and tree mortality might increase because of decreasing rainfall and soil moisture (Ravindranath and Sukumar 1998).

More recent studies that use more sophisticated regional climate models and process-based vegetation models suggest that over 70 per cent of India's forests would shift towards moister forest types

[6] Biomes are 'distinct biological communities that have formed in response to a shared physical climate' (https://en.wikipedia.org/wiki/Biome). One popular classification of world biomes recognizes 11 major biomes in India (the World Wildlife Fund ecoregions maps, quoted in Rasquinha and Sankaran [2016]).

under enhanced CO_2 levels and future climate (Chaturvedi et al. 2011; Ravindranath, Sukumar, and Saxena 2006). Correlation-based approaches (Rasquinha and Sankaran 2016) predict less dramatic changes, but they seem to agree that the extent of the tropical and subtropical moist broadleaf forest biome (which includes wet evergreen and moist deciduous forests) is likely to increase, whereas the Himalayan temperate broadleaf forests (oak) may see the most reduction in area.

That the Himalayan forests may be affected significantly appears to be corroborated by recent trends. These mountains already have the highest rates of warming globally (Shrestha, Gautam, and Bawa 2012). A remote sensing-based study highlighted ongoing temperature-induced moisture stress and the resultant browning of vegetation in certain elevation bands (Krishnaswamy, John, and Joseph 2014). This browning is corroborated by ground measurements (Singh et al. 2000; Singh, Singh, and Skutsch 2010). Higher elevation trees, such as the Himalayan birch, that survive on water from snowmelt may be most vulnerable to the warming trend (Liang et al. 2014).

The other biome that may shrink significantly is the one containing desert and semi-arid grasslands. Large areas of this biome have already become wooded because of introduction of invasive species such as *Prosopis*. The wetting trend predicted by most climate models will further shrink this biome (Rasquinha and Sankaran 2016). However, the presence of *Prosopis* also alerts us to the fact that anthropogenic influences may in some places exacerbate and in other places limit the influence of climate change. For instance, in the Western Ghats, the predicted shift from dry deciduous to moist deciduous forest may be limited by the presence of another invasive species (*Lantana*) (Hiremath and Sundaram 2005) and ongoing changes due to fire and fragmentation (Kodandapani, Cochrane, and Sukumar 2004).

In terms of other outcomes, current studies all point to increases in productivity, ranging from 50 per cent to 70 per cent (Chaturvedi et al. 2011) or 70 per cent to 100 per cent (Ravindranath, Sukumar, and Saxena 2006), and consequently in above-ground biomass, by about 17 per cent of India's current estimated above-ground carbon stock (Chaturvedi et al. 2011; Chhabra and Dadhwal 2004; Ravindranath, Somashekhar, and Gadgil 1997).

However, these estimates need to be treated with caution as they miss out on many variables, both biophysical (other climatic variables, soil variables, and so on) and anthropogenic (how forests are actually used and managed). On the biophysical side, the climate models themselves are quite incomplete. Downscaling global climate models to regional climate models is particularly unreliable in the Indian context, because such approaches do a poor job of predicting the outcome of the Indian monsoon. Nor do these predictions tell us much about unique moisture regimes, such as cloud stripping or fog and mist in the winter. Moreover, the vegetative response to changes in conditions may be non-linear. For instance, the only rigorous experimental study of thermotolerance of forest trees reveals that upper limits of leaf functions are critically close to observed maximum temperature (Sastry, Guha, and Barua 2018). On the social side, gross changes in productivity may matter little if livelihood-relevant species, such as *Diospyros melanoxylon* (tendu) in central India, disappear as the forest becomes wetter.

Possible Impacts on Wildlife

Climate change can affect wildlife in general or individual species by changing their habitat, disrupting ecological linkages, or directly threatening their survival. Traits that make species sensitive to climate change include factors such as: dependence on specialized habitat; life cycle stages tightly coupled with temperature or moisture thresholds; dependence on environmental triggers for initiating life cycle functions or dependence of inter-specific interactions; and rarity.

Some of the candidate species that fit these criteria are: the grizzled giant squirrel (*Ratufa macroura*) that prefers riparian forests in dry zones (Seavy et al. 2009); the snow leopard (*Panthera uncia*) that is restricted to a particular (high) elevation band (Forrest et al. 2012) in the Himalayas; and the blue sheep (*Pseudois nayaur*) (Aryal et al. 2016), a prey species for the snow leopard, and the Nilgiri tahr (*Nilgiritragus hylocrius*) (Sony et al. 2018). For instance, it is estimated that 30 per cent of snow leopard habitat may be lost due to a shifting treeline and consequent shrinking of the alpine zone. An extreme example of a species that could be severely affected in a specific pocket is the tiger (*Panthera tigris*) in the Sunderbans mangrove.

It is estimated that with a predicted 28-cm rise in sea-level over the next 50–90 years (as compared to the levels in the year 2000), the remaining tiger habitat in Bangladesh's Sundarbans would decline by 96 per cent (Loucks et al. 2010). Thus, the tigers of the Sundarbans in India and Bangladesh may soon join the Arctic's polar bears as early victims of climate change-induced habitat loss.

Nevertheless, major uncertainties remain. The ability of animals to migrate when biomes shift will depend upon the connectivity of their older and newer habitats. The study of blue sheep also points to the complexity introduced by prey–predator relationships—if the snow leopard population declines, will its prey increase even though climate change may make conditions more unsuitable for the sheep?

In short, the currently available coarse climate models and the limited understanding of plant, and even more so animal, responses seriously limits what can be said about the long-term impacts of climate change, and especially about its implications for forest-based livelihoods and economies, whether based on products or on wildlife tourism.

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Forests are complex socio-ecological entities as they provide multiple benefits to multiple stakeholders at different scales, from local to global. In recent times, with the emergence of climate change as the 'mother of all environmental problems', the forest question has often been narrowly framed as the forest carbon question. This is problematic in general, and particularly so in India, 'where forests have been settled and used by forest-dwelling communities for centuries, whether in the Himalayas, Western Ghats, or central or north-eastern India, and they are not only enormously rich in biodiversity but also play a critical role in regulating the hydrology of rivers. As we explore the forest–climate link, it is therefore important to keep this broad picture in mind. This then directs our attention to the multiple ways in which climate and forests are connected: forests for climate mitigation; forests in regional rainfall and climate processes; and the reverse impacts of climate change on forests, forest-based wildlife, and forest-dependent people.

The social history and context of India's forests, when coupled with this ecological understanding of climate and non-climate processes, also alerts us to the fact that forests are a highly contested 'resource' in India. Who makes decisions about forests, and how, will have multidimensional implications, not just for the carbon sequestered and India's INDC3, but for the health of the forest ecosystems and the people dependent upon them, including the resilience of these socio-ecological systems to the imminent impacts of climate change.

In this context, researchers must not just work on developing finer resolution climate models and incorporating more ecological variables in impact studies, but must also focus on more socially relevant impact variables. Further, in sequestration studies, they must complement better forest growth models and sequestration data with multi-dimensional analysis of the outcomes of different sequestration strategies for forest-based livelihoods, watershed services, and biodiversity.

Policymakers will have to confront the question of whether they want to follow business-as-usual approaches in which the centralizing tendencies in forest governance reassert themselves, or whether alternative models of decentralized, community-based, multi-objective forestry might be promoted as a longer term and environmentally more just solution.

References

Agarwal, A. 1997. 'Dark Truths and Lost Woods', *Down to Earth*, 15 June, pp. 32–40.

Aggarwal, A. 2011. 'Implementation of Forest Rights Act, Changing Forest Landscape, and "Politics of REDD+" in India', *Journal of Resources, Energy and Development*, 8(2): 131–48.

Aggarwal, Ashish, Soumitri Das, and Paul Varghese. 2009. 'Is India Ready to Implement REDD Plus? A Preliminary Assessment', Discussion Paper, The Energy and Resources Institute, New Delhi.

Aryal, A., U.B. Shrestha, W. Ji, S.B. Ale, S. Shrestha, T. Ingty, T. Maraseni, G. Cockfield, D. Raubenheimer. 2016. 'Predicting the Distributions of Predator (Snow Leopard) and Prey (Blue Sheep) under Climate Change in the Himalaya', *Ecology and Evolution*, 6: 4065–75.

Bonan, Gordon B. 2008. 'Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests', *Science*, 320(5882): 1444–9.

Brandon, K. 2014. 'Ecosystem Services from Tropical Forests: Review of Current Science', Working Paper 380, Climate and Forest Paper Series #7, Center for Global Development, Washington, DC.

Chaturvedi, Rajiv K., Ranjith Gopalakrishnan, Mathangi Jayaraman, Govindasamy Bala, N.V. Joshi, Raman Sukumar, and N. H. Ravindranath. 2011. 'Impact of Climate Change on Indian Forests: A Dynamic Vegetation Modeling Approach', *Mitigation and Adaptation Strategies for Global Change*, 16(2): 119–42.

Chhabra, Abha and V.K. Dadhwal. 2004. 'Assessment of Major Pools and Fluxes of Carbon in Indian Forests', *Climatic Change*, 64(3): 341–60.

Community Forest Rights–Learning and Advocacy (CFR-LA). 2016. 'Promise and Performance: Ten Years of the Forest Rights Act in India', Citizens' Report, CFR-LA, India. Available at http://cfrla.org.in/resources/citizens%20report%202015.pdf.

Dadhwal, V.K., S. Singh, and P. Patil. 2009. 'Assessment of Phytomass Carbon Pools in Forest Ecosystems in India', *NNRMS Bulletin*. Available at http://www.academia.edu/download/35026248/NNRMS_Bulletin_pages_41-57.pdf; accessed 20 September 2017.

Davidar, Priya, Sasmita Sahoo, Pratheesh C. Mammen, Prashanth Acharya, Jean-Philippe Puyravaud, M. Arjunan, Jean Pierre Garrigues, and Krista Roessingh. 2010. 'Assessing the Extent and Causes of Forest Degradation in India: Where Do We Stand?', *Biological Conservation*, 143(12): 2937–44.

Devaraju, N., G. Bala, and A. Modak. 2015. 'Effects of Large-Scale Deforestation on Precipitation in the Monsoon Regions: Remote versus Local Effects', *Proceedings of the National Academy of Sciences*, 112(11): 3257–62.

Dubash, Navroz K., Radhika Khosla, Ulka Kelkar, and Sharachchandra Lele. 2018. 'India and Climate Change: Evolving Ideas and Increasing Policy Engagement', *Annual Review of Environment and Resources*, 43(2018): 395–424.

Environmental Impact Assessment (EIA) Division. 2008. 'Mid-Term Evaluation of the National Afforestation Programme (NAP) Schemes Implemented through Forest Development Agencies (FDAs)', National Afforestation and Ecodevelopment Board, Ministry of Environment and Forests, Government of India, New Delhi. Available at http://www.naeb.nic.in/MTE-Complete_Report.pdf.

Forest Survey of India (FSI). 2015. *India State of Forest 2015*. Dehradun: Ministry of Environment, Forest and Climate Change.

Forrest, J.L., E. Wikramanayake, R. Shrestha, G. Areendran, K. Gyeltshen, A. Maheshwari, S. Mazumdar, R. Naidoo, G.J. Thapa, K. Thapa. 2012.

'Conservation and Climate Change: Assessing the Vulnerability of Snow Leopard Habitat to Treeline Shift in the Himalaya', *Biological Conservation*, 150: 129–35.

Grassi, Giacomo, Jo House, Frank Dentener, Sandro Federici, Michel den Elzen, and Jim Penman. 2017. 'The Key Role of Forests in Meeting Climate Targets Requires Science for Credible Mitigation', *Nature Climate Change*, 7(3): 220–6.

Hall, Jaclyn M., Tracy Van Holt, Amy E. Daniels, Vincent Balthazar, and Eric F. Lambin. 2012. 'Trade-offs between Tree Cover, Carbon Storage and Floristic Biodiversity in Reforesting Landscapes', *Landscape Ecology*, 27(8): 1135–47.

Hiremath, Ankila J. and Bharath Sundaram. 2005. 'The Fire-Lantana Cycle Hypothesis in Indian Forests', *Conservation and Society*, 3(1): 26–42.

Indian Network for Climate Change Assessment (INCCA). 2010. *India: Greenhouse Gas Emissions 2007*. New Delhi: INCCA, Ministry of Environment and Forests, Government of India. Available at http://www.moef.gov.in/sites/default/files/Report_INCCA_0.pdf.

Kishwan, J., R. Pandey, and V.K. Dadhwal. 2009. 'India's Forest and Tree Cover: Contribution as a Carbon Sink', Technical Paper. Dehradun: Indian Council for Forest Education and Research (ICFRE), Ministry of Environment and Forest.

Kodandapani, Narendran, Mark A. Cochrane, and R. Sukumar. 2004. 'Conservation Threat of Increasing Fire Frequencies in the Western Ghats, India', *Conservation Biology*, 18(6): 1553–61.

Kohli, K. and M. Menon. 2015. 'Growing Forests in the Air', *The Hindu*, 26 October. Available at http://www.thehindu.com/opinion/columns/future-forecast-column-growing-forests-in-the-air/article7802930.ece.

Krishnaswamy, Jagdish, Robert John, and Shijo Joseph. 2014. 'Consistent Response of Vegetation Dynamics to Recent Climate Change in Tropical Mountain Regions', *Global Change Biology*, 20(1): 203–15.

Lahiri, S. 2015. 'What India's INDC Does Not Tell You about Its Forests', Global Forest Coalition, 1 December. Available at http://globalforestcoalition.org/indias-indc-not-tell-forests/; accessed on 28 December 2017.

Land Conflict Watch. n.d. 'Conflicts'. Available at https://www.landconflictwatch.org/node/498/67/all/all/all/all; accessed on 11 January 2019.

Lele, S. 2012. 'Standalone Agency to Map Green Wealth', *The Economic Times*, 12 May. Available at http://economictimes.indiatimes.com/opinion/comments-analysis/how-to-arrest-forest-degradation/articleshow/13104106.cms.

———. 2013. 'Buying Our Way Out of Environmental Problems?', *Current Conservation*, 6: 9–13.

———. 2014. 'What Is Wrong with Joint Forest Management?', in S. Lele and A. Menon (eds), *Democratizing Forest Governance in India*, pp. 25–62. New Delhi: Oxford University Press.

———. 2017. 'Forest Governance: From Co-option and Conflict to Multilayered Governance?', *Economic & Political Weekly*, 52(25–6): 55–8.

Lele, Sharachchandra and Amit Kurien. 2011. 'Interdisciplinary Analysis of the Environment: Insights from Tropical Forest Research', *Environmental Conservation*, 38(2): 211–33.

Lele, S. and A. Menon. 2014a. 'Introduction: Forest Governance beyond Joint Forest Management, Godavarman, and Tigers', in S. Lele and A. Menon (eds), *Democratizing Forest Governance in India*, pp. 1–22. New Delhi: Oxford University Press.

——— (eds). 2014b. *Democratizing Forest Governance in India*. New Delhi: Oxford University Press.

Lele, Sharachchandra, Oliver Springate-Baginski, Roan Lakerveld, Debal Deb, and Prasad Dash. 2013. 'Ecosystem Services: Origins, Contributions, Pitfalls, and Alternatives', *Conservation and Society*, 11(4): 343–58.

Lele, Sharachchandra and Veena Srinivasan. 2013. 'Disaggregated Economic Impact Analysis Incorporating Ecological and Social Trade-offs and Techno-institutional Context: A Case from the Western Ghats of India', *Ecological Economics*, 91(July): 98–112.

Liang, Eryuan, Binod Dawadi, Neil Pederson, and Dieter Eckstein. 2014. 'Is the Growth of Birch at the Upper Timberline in the Himalayas Limited by Moisture or by Temperature?', *Ecology*, 95(9): 2453–65.

Loucks, C., S. Barber-Meyer, M.A.A. Hossain, A. Barlow, R.M. Chowdhury. 2010. 'Sea-Level Rise and Tigers: Predicted Impacts to Bangladesh's Sundarbans Mangroves'. *Climatic Change* 98: 291.

Meher-Homji, V.M. 1991. 'Probable Impact of Deforestation on Hydrological Processes', *Climatic Change* 19(1–2): 163–73.

Ministry of Environment, Forest and Climate Change (MoEFCC). 2010. 'India's Forests and REDD+', MoEFCC, Government of India, New Delhi.

———. 2012. 'India: Second National Communication to the UNFCCC', MoEFCC, Government of India, New Delhi.

———. 2014. 'Reference Document for REDD+ in India', MoEFCC, Government of India, New Delhi.

———. 2015a. 'India's Intended Nationally Determined Contribution: Working towards Climate Justice', Government of India, New Delhi. Available at http://www4.unfccc.int/ndcregistry/PublishedDocuments/

India%20First/INDIA%20INDC%20TO%20UNFCCC.pdf; accessed on 21 November 2017.

———. 2015b. 'India: First Biennial Update Report to the United Nations Framework Convention on Climate Change', MoEFCC, Government of India, New Delhi. Available at http://unfccc.int/resource/docs/natc/indbur1.pdf; accessed on 29 December 2017.

Paul, Supantha, Subimal Ghosh, Robert Oglesby, Amey Pathak, Anita Chandrasekharan, and R.A.A.J. Ramsankaran. 2016. 'Weakening of Indian Summer Monsoon Rainfall due to Changes in Land Use Land Cover', *Scientific Reports*, 6: 32177.

Paul, Supantha, Subimal Ghosh, K. Rajendran, and Raghu Murtugudde. 2018. 'Moisture Supply from the Western Ghats Forests to Water Deficit East Coast of India', *Geophysical Research Letters*, 45(9): 4337–44.

Phelps, Jacob, Edward L. Webb, and Arun Agrawal. 2010. 'Does REDD+ Threaten to Recentralize Forest Governance?', *Science*, 328(5976): 312–13.

Poffenberger, M. 2015. 'Restoring and Conserving Khasi Forests: A Community-Based REDD Strategy from Northeast India', *Forests*, 6(12): 4477–94.

Pulla, P. 2015. 'Can India Keep Its Promises?', *Science*, 350(6264): 1024–7.

Rasquinha, D.N. and M. Sankaran. 2016. 'Modelling Biome Shifts in the Indian Subcontinent under Scenarios of Future Climate Change', *Current Science*, 111(1): 147–56.

Ravindranath, N.H., N.V. Joshi, R. Sukumar, and A. Saxena. 2006. 'Impact of Climate Change on Forests in India', *Current Science*, 90(3): 354–61.

Ravindranath, N.H., B.S. Somashekhar, and Madhav Gadgil. 1997. 'Carbon Flow in Indian forests', *Climatic Change*, 35(3): 297–320.

Ravindranath, N.H. and R. Sukumar. 1998. 'Climate Change and Tropical Forests in India', *Climatic Change*, 39: 563–81.

Reddy, C. Sudhakar, F. Rakesh, C.S. Jha, K. Athira, Sonali Singh, V.V.L. Padma Alekhya, G. Rajashekar, P.G. Diwakar, and V.K. Dadhwal. 2016. 'Geospatial Assessment of Long-Term Changes in Carbon Stocks and Fluxes in Forests of India (1930–2013)', *Global and Planetary Change*, 143(Suppl. C): 50–65.

Sastry, Aniruddh, Anirban Guha, and Deepak Barua. 2018. 'Leaf Thermotolerance in Dry Tropical Forest Tree Species: Relationships with Leaf Traits and Effects of Drought', *AoB Plants* 10(1): plx070. Available at https://doi.org/10.1093/aobpla/plx070.

Seavy, Nathaniel E., Thomas Gardali, Gregory H. Golet, F. Thomas Griggs, Christine A. Howell, Rodd Kelsey, Stacy L. Small, Joshua H. Viers, and James F. Weigand. 2009. 'Why Climate Change Makes Riparian

Restoration More Important than Ever: Recommendations for Practice and Research', *Ecological Restoration*, 27(3): 330–8.

Sheikh, Mehraj A., Munesh Kumar, Rainer W. Bussman, and N.P. Todaria. 2011. 'Forest Carbon Stocks and Fluxes in Physiographic Zones of India', *Carbon Balance and Management*, 6(1): 1–10.

Shrestha, Uttam Babu, Shiva Gautam, and Kamaljit S. Bawa. 2012. 'Widespread Climate Change in the Himalayas and Associated Changes in Local Ecosystems.' *PLoS One*, 7(5): e36741.

Singh, Anju, Seema Unnikrishnan, Neelima Naik, and Kavita Duvvuri. 2013. 'Role of India's Forests in Climate Change Mitigation through the CDM and REDD+', *Journal of Environmental Planning and Management*, 56(1): 61–87.

Singh, Surendra P., Ashish Tewari, Shirish K. Singh, and Girish C. Pathak. 2000. 'Significance of Phenologically Asynchronous Populations of the Central Himalayan Oaks in Drought Adaptation', *Current Science*, 79 (3): 353–7.

Singh, Surendra P., Vishal Singh, and Margaret Skutsch. 2010. 'Rapid Warming in the Himalayas: Ecosystem Responses and Development Options', *Climate and Development*, 2(3): 221–32.

Singh, Surendra P., Ashish Tewari, and Pushkin Phartiyal. 2011. 'Community Carbon Forestry to Counter Forest Degradation in the Indian Himalayas', in Margaret Skutsch (ed.), *Community Forest Monitoring for Carbon Market: Opportunities under REDD*, pp. 118–33. London, UK: Earthscan.

Sony, R., S. Sen, S. Kumar, M. Sen, and K. Jayahari. 2018. 'Niche Models Inform the Effects of Climate Change on the Endangered Nilgiri Tahr (Nilgiritragus hylocrius) Populations in the Southern Western Ghats, India'. *Ecological Engineering*, 120: 355–63.

Spracklen, Dominick V., Steve R. Arnold, and C.M. Taylor. 2012. 'Observations of Increased Tropical Rainfall Preceded by Air Passage Over Forests', *Nature*, 489(7415): 282.

Sud, R., J.V. Sharma, and A.K. Bansal. 2012. 'International REDD+ Architecture and Its Relevance for India', Ministry of Environment and Forests, Government of India, and TERI, New Delhi.

Sukumar, R., H.S. Suresh, and R. Ramesh. 1995. 'Climate Change and Its Impact on Tropical Montane Ecosystems in Southern India', *Journal of Biogeography*: 533–6.

Sunderlin, W., E. Sills, A. Duchelle, A. Ekaputri, D. Kweka, M. Toniolo, S. Ball, N. Doggart, C. Pratama, and J. Padilla. 2015. 'REDD+ at a Critical Juncture: Assessing the Limits of Polycentric Governance for Achieving Climate Change Mitigation', *International Forestry Review*, 17: 400–13.

United Nations Framework Convention on Climate Change (UNFCCC). 2008. 'Report of the Conference of the Parties on Its Thirteenth Session, Held in Bali from 3 to 15 December 2007: Decisions Adopted by the Conference of the Parties', FCCC/CP/2007/6/Add.1, UNFCCC, Geneva.

Vijge, Marjanneke J. and Aarti Gupta. 2014. 'Framing REDD+ in India: Carbonizing and Centralizing Indian Forest Governance?', *Environmental Science & Policy*, 38(April): 17–27.

World Bank. 2006. 'India: Unlocking Opportunities for Forest-Dependent People in India: Main Report: Volume I. No. 34481-IN'. New Delhi: Agriculture and Rural Development Sector Unit, South Asia Region, The World Bank.

World Conservation Monitoring Centre (WCMC). 1999. 'Biodiversity Profile of India', UNEP-WCMC, Cambridge, UK.