Biodiversity and Conservation (2019) 28:1943–1951
https://doi.org/10.1007/s10531-019-01781-0

EDITORIAL

Recent advances in biodiversity and climate change studies in India

Mukunda Dev Behera[1] · Soumit Kumar Behera[2] · Subrat Sharma[3]

Received: 13 April 2019 / Revised: 16 May 2019 / Accepted: 18 May 2019 / Published online: 23 May 2019

Abstract

Biodiversity is continually transformed by a changing climate. Conditions change across the face of the planet at variable pace leading to rearrangements of biological associations. The carbon cycle and the water cycle, arguably the two most important large-scale processes for life on Earth; depend on biodiversity at genetic, species, and ecosystem levels and can yield feedbacks to climate change. India is no less affected through this feedback mechanism of climate change and had shown its cause and effect association in several studies. In this special issue we present 25 papers contributed by ca 90 authors from India and elsewhere those discuss wide-ranging aspects of biodiversity and climate change. These contributions are based on presentations made at the 2nd International Workshop on Biodiversity and Climate Change (BDCC-2018) held on 24–27-February 2018 at the Indian Institute of Technology Kharagpur, India. The papers are arranged in six sections: Plant (and lichen) Diversity and Climate; Plant Diversity Pattern and Environmental Heterogeneity; Forest Biomass and Carbon; Plant Diversity and Remote Sensing; Species Distribution Modelling; and Animal Diversity, Soil and Biotechnology. Included amongst the contributions are ones using a national database on plant diversity, describing vegetation carbon and biomass sequestration patterns, utilizing remote sensing to assess plant diversity proxies and conservation prioritization, employing species distribution models to analyze climate change scenarios, using acoustics indices for rapid assessment of biodiversity, addressing the soil micro-biome and environmental stress on medicinal plants.

Keywords Environmental heterogeneity · Biomass · Remote sensing · Species distribution model · Acoustic diversity

Communicated by David Hawksworth.

✉ Mukunda Dev Behera
mdbehera@coral.iitkgp.ac.in

[1] Spatial Analysis and Modeling Lab, CORAL, IIT Kharagpur, Kharagpur, W.B., India

[2] CSIR-National Botanical Research Institute, Lucknow, U.P., India

[3] Centre for Environmental Assessment and Climate Change, GB Pant National Institute of Himalayan Environment and Sustainable Development, Kosi, Uttarakhand, India

Introduction

Evidence from the literature suggests that climate change is happening now and has a direct effect on biodiversity, forcing species to adapt either through migrating, changing phenological cycles, or developing new physiological traits (Lohmann et al. 2012). As per the Millennium Ecosystem Assessment (MEA 2005), climate change is likely to become one of the most substantial drivers of biodiversity loss by the end of the present century. Climate change is imposing severe threats to, and having dramatic effects on, a wide range of India's plants and animals (Telwala et al. 2013; Ray et al. 2014). Maintaining and restoring healthy ecosystems plays a key role in adapting to and mitigating climate change through biodiversity conservation, sustainable use, and sustainable land management which yield multiple environmental, economic, and social benefits. Now, accelerated climate change, brought about by human activities, has been added to the natural variability, threatening to accentuate the loss of biodiversity already underway due to other human stressors. There is therefore an urgent need to gather and disseminate to contribute to the development of a strategic plan for climate change mitigation and adaptation.

In response to this need, the 2nd International Workshop on Biodiversity and Climate Change (BDCC-2018) was held on 24–27 February 2018 at the Centre for Oceans, Rivers, Atmosphere and Land Sciences (CORAL), Indian Institute of Technology Kharagpur, India. The workshop focused on functional biodiversity and climate change, Himalayan biodiversity, biodiversity, and geomatics tools. The main aims of the workshop were to introduce new methods and developments in biodiversity and climate change science, to address gaps in various ecological fields, and to recommend new strategies for adaptation and mitigation towards sustainable developments. The key question of the workshop were:

(1) How can we better understand feedback mechanism between climate change and biodiversity?
(2) How a predicted warming world discourages biodiversity?
(3) Is spatial biodiversity special from Geomatics perspective?
(4) Does temperature dominantly modulate Himalayan biodiversity patterns?
(5) Are there examples of biodiversity conservation strategies exacerbating effects of climate change?

Symstad and Tilman (2003) defined functional biodiversity as "the value and the range of those species and organismal traits that influence ecosystem functioning", where function could take the form of adaptation through evolutionary processes to trophic levels. Functional biodiversity is of high ecological importance due to its capability to influence several aspects of ecosystem functioning, such as ecosystem dynamics, stability, nutrient availability, and hydrological regulations. It could therefore provide useful insights in analyzing potential climate change responses of biodiversity and inputs into dynamic global vegetation models (DGVMs).

The Himalayas are remarkably diverse and globally important as center of biological diversity and are important in terms of provisioning the ecosystem services that sustain a huge human population and also high levels of biodiversity. However, they are at high risk of threats due to anthropogenic influences, intensive grazing, and climate change. Climate and non-climate stressors are projected to have a direct effect on forest ecosystems that will cause biodiversity loss and reduced ecosystem services. Evidence suggests greater temperature increases can be expected at higher altitudes. It is therefore essential to anticipate possible impacts of climate change on the structure and functions of these unique ecosystems, and to assess their sustainability via long-term monitoring and modelling so these are accorded special attention here.

The contributions included here were selected from 27 institutes located in India (Fig. 1) and one from Nepal who participated in the BDCC-2018 workshop. In May 2012, a special issue on *Biodiversity and Climate Change* accommodated 13 papers from the proceedings of the first international workshop, BDCC-2010 (Behera and Kushwaha 2012). This marked the start of studies on the interrelationship between biodiversity and climate change in India are some of the recent advances.

We expect that future research and observations will build on those and the newly presented proceedings to continue to contribute to better understanding of the interrelations in India and the worldwide forests. The papers we included provide critical new information and indications of approaches that can be taken to address different aspects.

Fig. 1 The location of various institutes contributed to the special issue. The size of each circle is proportional to the number of contributing Institutes, with a maximum of four (from Dehradun, Uttarakhand state)

Plant (and lichen) diversity and climate

Lichens, in contrast to vascular plants, have been established as cost effective indicators of measuring ecosystems responses to environmental change. The variations in microclimatic attributes and their effects on photosynthetic efficiency and distribution of lichens were studied in the ecologically fragile ecosystem of Govind Pashu Vihar National Park in Garhwal Himalayas (Sahu et al. 2019). At mid-elevation levels with more canopy gaps, most of the lichen growth forms receive optimum photosynthetically active radiation (PAR) levels coupled with high thallus hydration levels leading to higher species diversity. Among the suite of microclimatic variables, combined and interactive effects of PAR, CO_2 and ambient humidity along the elevation gradient primarily regulate lichen species richness.

Analysis of plant species distribution and functional diversity (FD) could provide indication of future changes in plant communities as both are responsive to environment and strongly influence ecosystem functioning and stability. Thakur and Chawla (2019) sampled vegetation across southern and northern aspects along an elevation to estimate species rarity, niche width and different FD indices [community-weighted mean traits (CWM), functional richness (FRic), functional divergence (FDiv), functional dispersion (FDis) and functional specificity (FSpe)]. They reported that CWM plant height, FRic, FDiv, FDis and FSpe significantly decreased with increasing elevation. Influence of gradients of aridity (across aspect) and decreasing temperature (along elevation) on species distribution and FD suggest that the functioning of high altitude communities is very likely to be affected in future climate change scenarios.

In the tree-line ecotone, a change in species composition may result in a conspicuous change in physiognomy of vegetation and carbon storage, whereas climate warming may cause the upslope movement of tree-line species, and grazing pressure may depress tree-lines. Singh et al. (2019) reported that the Himalayan tree-line is highly heterogeneous with regard to plant species composition (58 species in 10 genera), and elevation (3200–4900 m). Tree-line elevation increases from: (1) NW to SE; (2) the periphery (from both north and south sides) to the central region of the ranges; and (3) northern to southern aspect. A shift in dominance from deciduous *Betula utilis* (birch) to evergreen Rhododendrons is discernible from the NW to SE, while biomass accumulation rate declines rapidly towards the upper reaches of the tree-lines.

Ecological resilience describes the capacity of an ecosystem to persist and maintain its functioning while undergoing through disturbances. Das and Behera (2019) have used an open source tree canopy cover percent (TCC %) data to map the spatial distribution of forest, scrub and treeless areas in relation to annual precipitation using binary logistic regression. Only 2.77% of the total forest cover in India as a whole were estimated as highly change prone. In contrast, the forests of wet climate regimes were predicted to have high resilience, particularly in the Western Ghats and North-East India. On evaluation of the precipitation stress, they observed a positive correlation with forest cover resilience.

Plant diversity pattern and environmental heterogeneity

Behera and Roy (2019) analyzed a national database on Indian plant richness with 7761 species from 15,565 nested quadrants to offer maiden and indicative angiospermic plant richness patterns across latitudinal and longitudinal gradients in India. They reported two peaks in species richness curves along both latitudinal and longitudinal gradients, due to the higher species richness in the Western Ghats and the Himalayan hotspots. Using a generalized additive model (GAM), they observed that geographic area and topography explained (98.8% deviance) the species richness pattern across longitude, while all three explained (99% deviance) the pattern along latitude.

Plant invasion is highly responsive to rising temperature, altered precipitation, and various anthropogenic disturbances. Climate anomalies may therefore provide opportunities to identify the relationship of past climate in explaining the distribution of invasive species and to detect their probable future distribution. Using a geographically weighted regression (GWR) model, Tripathi et al. (2019) reported a spatial correlation of invasive species distribution with temperature ($r2 = 0.73$, $AIC = 2206$) and precipitation anomalies ($r2 = 0.74$, $AIC = 2221$), and a better spatial correlation ($r2 > 0.75$) when temperature and precipitation anomalies were considered. The significant correlation of plant invasion and climate anomaly revealed an affinity of invasive species towards warmer, drier, and wet places–with consequent management implications.

Plant–disperser relationship is fundamental in explaining the co-existence of species that depends on the nature and physical strength of the disperser. Mahanand and Behera (2019) compared two mainland–island pairs of India that exhibit different insular isolation conditions, to understand the plant dispersal mechanisms and their determining predictors (plant richness, geographic area, perimeter, elevation, and distance). The plant commonality was found to positively correlated with the plant richness, geographic area, and perimeter; whereas it was negatively correlated with the shortest distance and elevation of the selected mainland–island pairs. They reported that these predictors were important to maintain habitat suitability and connectivity and so support more newly dispersed plants.

Plant richness pattern along mountain elevation gradients is still debatable. Sharma et al. (2019) investigated plant richness pattern of vascular plants along an elevation gradient of 500–3300 m in 100, 200, and 300 m elevation steps, and detected a hump-shaped pattern that was attributed to the ecotone effect of different forest types. They reported reduction in tree height and richness above 2300 m, allowing dominance of herbs as a consequence of climatic constraints. Using a GAM, temperature explained deviance of > 47%, followed by soil (36.4%), and precipitation (21.6%) of the observed plant richness.

Forest biomass and carbon

Forests play a crucial role in regulating global and local weather through the exchange of atmospheric gases and water vapor. Quantifying and monitoring the carbon flux in forests is essential on account of national carbon inventory and meeting the targets of the Kyoto Protocol (Ghosh and Behera 2018). Modelling approaches were also used to examine and lower uncertainty in estimating ecosystem productivity in complex terrestrial biomes for different time periods at the ecosystem scale. Behera et al. (2019) investigated the applicability of a widespread bio-geochemical model (Biome BGC) to simulate monthly net primary productivity (NPP) and leaf area index (LAI) of Indian tropical deciduous forests by parameterizing 11 major eco-physiological parameters from in situ physiological measurements gathered from three plant functional types (PFTs). In all PFTs, the model underestimated LAI, and in turn NPP. This study served to evaluate the operational application of the Biome BGC in Indian tropical deciduous forests.

Pilai et al. (2019) studied the intra-annual variability of net ecosystem exchange (NEE) of carbon dioxide in a sal-dominated (*Shorea robusta*) moist deciduous forest by integrating eddy covariance (EC) data and a Biome-BGC model from observations from Eddy Co-variance Flux data. They found that sal forest acted as a net sink of carbon in almost all months of 2015 (except April–June) with an annual net ecosystem exchange (NEE) of -526.87 gC m^{-2} $year^{-1}$ and further mapped the NEE using a Random Forest (RF) regression algorithm. This study showed the applicability of the Biome-BGC model in Indian forest by integrating EC observations.

Mangrove ecosystems play an important role in regulating carbon cycling, thus having significant impact on global environmental change. Pandey et al. (2019a, b) provided spatial distribution of species-wise biomass maps for a site in Bhitarkanika Wildlife sanctuary. They used three models (linear, logarithmic, and polynomial-second degree) to estimate biomass derived from enhanced vegetation index (EVI) and normalized difference vegetation index (NDVI) using hyperspectral data (with 30 m resolution); and found positive relationship for all.

Kumar et al. (2019) demonstrated mapping vulnerability of forest ecosystem by analyzing variability and trends of Net Primary Productivity (NPP) in a Himalayan state. They considered NPP to be the receptor of shock and stresses of climatic variability and human disturbances. The trend analysis of NPP and resultant vulnerability matrices can be a potential tool for prioritizing forest management actions in a region to sustain productivity and the overall conservation of forests.

Plant diversity and remote sensing

In order to explore the potential of satellite datasets in identifying the patterns in species richness, Chitale et al. (2019) used generalized linear models (GLMs) to correlate remote sensing based vegetation indices (VIs) and physiographic indices (PIs) with plant species richness. They observed a very high correlation between VIs and plant richness in open canopy vegetation class, low species richness in grasslands, scrubs, and dry deciduous forests, followed by vegetation classes with moderately dense canopy. This provides insights on the utility of satellite datasets as a proxy for estimating plant richness in diverse ecosystems.

Padalia et al. (2019) disentangled the role of remotely sensed environmental proxies for characterization of Plant Functional Types (PFTs) and the prediction of plant species richness. They correlated satellite-derived climate, landscape, topographic variables with richness using a GLM with Poisson distribution to examine environment linkages. They reported that environmental proxies such as vegetation vigor, elevation, landscape diversity, and moisture influence alpine plant richness in the part of Western Himalaya studied.

Reddy et al. (2019) used forest persistence, ecosystem rarity, forest intactness, landscape level ecosystem, above ground biomass carbon stocks, and biological richness amongst biological criteria to analyze ecosystem irreplaceability. Overall representation of habitat coverage in protected area networks of seven south Asian countries revealed an under-representation of several forest types with $<17\%$ coverage. An overlay of the priority areas suggests that there is scope for conserving many species by bringing more areas under protection.

Species distribution modelling

Panda and Behera (2019) assessed harmony in plant invasions of two perennial exotic species of similar origin and naturalization in India (*Chromolaena odorata* and *Tridax procumbens*). They applied Maximum Entropy (Maxent) model to assess habitat suitability, risk area identification, and shifts in range sizes. The distribution of *C. odorata* could mostly depend on temperature and moisture availability and invade the biodiversity-rich regions, while *T. procumbens* could demonstrate greater dependencies on precipitation seasonality and radiation than temperature. The potential to tolerate a wide range of temperature and solar radiation, allowed *T. procumbens* to manage climate change impacts more efficiently than *C. odorata*.

Modeling a species' ecological niche and potential distribution of endemic plants under projected impacts of climate change and distribution of wildfires may contribute to an understanding of their behavior under altered climatic conditions. Chitale and Behera (2019) used a Maxent Model, which indicated a possible significant reduction in the geographic range of selected indicator species under *with wildfire* as compared to *without wildfire* scenarios. This indicated that the future ranges could shift towards the northern and northeastern regions of the study area owing to higher moisture availability, and so induce reduction, expansion, and shift in the distributions of endemic plants of the Himalayas.

A Random Forest algorithm, assuming non-parametric distribution, was employed to predict the potential distribution of *Betula utilis* niche in the Hindu-Kush Himalayan (HKH) region by Mohapatra et al. (2019). The occurrence in the last interglacial, current and future scenarios suggest that it is more likely to occur at elevation ranges of 2601–2800 m, 3801–4000 m, and 4201–4400 m, respectively. The magnitude of advancement was relatively more along elevation and longitude gradients indicating that the treeline species potential distribution in HKH is climate driven. Hamid et al. (2019) modeled the ensemble distribution of *B. utilis* using the Biomod2 package for present and future (RCP's 2.6–8.5 covering 2050 and 2070). They reported that the most suitable area for *B. utilis* could shift towards the eastern parts of Himalayas, with suitability declining towards the western parts. A similarity and equivalency test revealed the *B. utilis* niche as similar but not identical between current and future climate change scenarios. This has wide implications for scientifically informed adaptation and mitigation strategies.

Rathore et al. (2019) used two IPCC AR5 climate change scenarios, RCP 4.5 and RCP 8.5, from a suite of Global Climate Models to study possible changes in the suitable bioclimatic envelope of three oak species in the western Himalayas for probability of current and potential future distributions with the help of ensemble modeling. All three species exhibited a probable north-eastward shift and significant decrease in their climatic niche under projected climate change across both RCP's, with RCP 4.5 showing increased loss of climatic niche (fundamental niche) compared to RCP 8.5.

Ahmed et al. (2019) reported the current and future potential distribution of *Parthenium hysterophorus* (Congress grass) in India under climate change scenarios and described its niche dynamics. Their study predicts an overall decrease in habitat suitability for this invasive species under climate change, with about half of the suitable habitat could reduce under RCP 8.5 (2070). Some of the currently invaded regions, however, could remain equally (North-East) or become highly (Western Himalaya) vulnerable to its invasion under future climate. Interestingly, niche dynamics results revealed that *P. hysterophorus* has shifted its climatic niche in the invaded range in India, apparently due to more niche emptying.

Animal diversity, soil and biotechnology

Decoding the acoustic dynamics of a landscape can ingeniously be crafted as a rapid tool to assess animal species diversity. Rajan et al. (2019) carried out an acoustic analysis using various indices, which they related to corresponding avian diversity in three contrasting soundscapes in Kerala. This study revealed the distinctiveness of sonic characteristics and the status of bird diversity in each soundscape.

Debata et al. (2019) recorded 23 bat species, including two newly recorded species (*Hipposideros galeritus* and *Megaderma spasma*) from ranges of the Eastern Ghats using roost and mist-net survey techniques. They reported one of the highest bat capture rates from the moist deciduous forest, and the suitability of the northeastern part for bat distribution. Climate, physiographic and disturbance variables were found to be crucial in bat distribution, while elevation and potential evapotranspiration were highly significant.

Linking the distribution of microbial diversity and ecosystem functioning is essential to understand ecosystem responses to a changing environment. The soil microbiota is imperative in relation to assessments of the effects of global climate changes as it has important and undisputable roles in biogeochemical cycling, plant growth, and carbon sequestration. Genomic approaches show there is tremendous potential for the identification of uncultured microbial diversity and monitoring shifts in the bacterial communities associated with sensitive and disease tolerant plants, and also in understanding how they could be affected by climate change. Dubey et al. (2019) discuss how climate change can influence soil microbial communities and plant–microbe interactions.

Climatic perturbations in the Himalayan region have imposed severe threats to the survival of medicinal plants and their status in the wild, with consequences for the production of bioactive metabolites. Pandey et al. (2019a, b) review and update information on the various environmental stresses affecting medicinal plants in order to facilitate a thorough understanding of the response of Himalayan plants to different stress factors. This knowledge may assist adaptation to disease management strategies, identifying resilient accessions and optimizing environmental conditions for plant growth and metabolite production.

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