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Forest Biodiversity Index of the Western Himalayas – an aggregate index based on the National Forest Inventory of India

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Abstract. Assessing biodiversity through criteria and indicators has been suggested but rarely put into practice. Documenting and monitoring global biodiversity change is challenging due to limited or biased data and a lack of agreed obligations, but indicators play a key role in studying this problem. For the Western Himalayas we have developed the Forest Biodiversity Index (FBI), based on national forest inventory data. The FBI combines various indicators weighted by experts to assess overall forest biodiversity, including factors reflecting naturalness, vegetation structure, soil (erosion and depth), disturbance, and response. The weight of factors was determined using the group conversion method, considering experts' opinions while giving justification for assigning a particular value. The sum of all weighted indicator values for 3549 forest inventory points gives us a map illustrating variation in biodiversity: from low to very high. Thus, the FBI is a comprehensive index, which can be used to communicate and provide a workable platform to detect and monitor any biodiversity change over a given period. The FBI in the Western Himalayas shows that more than 89% of the area is in high and very high biodiversity zones, with an accuracy of about 74.8% via validation.

Key words: forest biodiversity, biodiversity-related indicators, group convergence method, Himalayas

1. Introduction

Since the United Nations Decade on Biodiversity (UNDoB 2010-2020), the concern has become urgent and existential as well. The negative trend in changing biodiversity across the world (Tittensor *et al*. 2014), signifies the need to curb the disturbance, monitor the undergoing change, and act holistically towards a healthier situation.

In India, committed to the Convention on Biological Diversity, the assessment and monitoring of biodiversity is a national priority for its linkages to livelihood (CBD 2014). It is more relevant in the Himalayas as India's National Mission for Sustaining Himalayan Ecosystem aims at sustainable development of forest resource conservation in the Himalayas (NMSHE 2016).

India has an operational National Forest Inventory (NFI) since 2002-2003, collecting comprehensive qualitative/quantitative data to produce estimates of forest resources (Tewari & Kleinn 2015), and a report published biennially, the latest in 2024 (FSI 2024). It has a comparable and competent dataset of forest biodiversity parameters with a further potential to achieve biodiversity-related targets: assessment, monitoring or evaluation (Thakur *et al*. 2018).

Many publications concern biodiversity characterization at the national level (Roy *et al*. 2012) and regionally (Pragasan & Parthasarathy 2010; Bhatt *et al*. 2016; Bahera & Roy 2019), but we need spatial biodiversity information in both space and time for its monitoring and identifying priority areas for conservation planning (Myers *et al*. 2000; Henle *et al*. 2013). This is crucial because biodiversity is declining, due to factors like changes in land use and land cover, overexploitation, invasive species, etc. (Marchese 2015).

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Creation of a geospatial database on Himalayan Biodiversity is a target of the National Mission on Himalayan Studies by India (NMHS 2018-19), signifying mountain ecosystem dynamics in relation to global climate change (Rawal *et al.* 2003). If we seriously want to map the spatial pattern of biodiversity, we need to look beyond modelling individual biodiversity entities and shift the focus from individual entities to collective properties (Austin 1999) of biodiversity. Forest biological diversity is a broad term that refers to all life forms found within forested areas and the ecological roles they perform – not just encompassing trees but the multitude of plants, animals, fungi, microorganisms, and their associated genetic diversity (https://www.cbd.int/forest/what.shtml).

All biodiversity indicators are not equally reliable or effective at detecting biodiversity changes, as their performance depends on factors such as the type of ecosystem, the scale of monitoring, and the specific ecological processes being studied (Nagendra & Southworth 2008). Capturing all biodiversity aspects in one indicator is hard; simplifying it may miss key dimensions. Single indicators are easier but are unlikely to represent forest ecosystems fully, challenging biodiversity indicator creation (IPBES 2019). Besides, forest biodiversity indicators may be influenced by political and economic factors, leading to biased assessments. Stakeholders may manipulate or omit data to downplay biodiversity loss, particularly in economically valuable forests (Lambin & Meyfroidt 2011). Species richness and abundance are key biodiversity indicators but may not fully represent forest ecosystem functions, like carbon sequestration and water regulation, important for human well-being. Incorporating these functions into indicators is complex (Díaz *et al.* 2018). Biodiversity indicators must also be aligned with the specific objectives of environmental policies, such as those related to climate change, conservation goals, or sustainable development (Pereira *et al.* 2013).

The presented work was inspired by the Austrian Forest Biodiversity Index (Geburek *et al*. 2010), of course with our own set of biodiversity-related indicators available in the NFI of India. The study aimed to evaluate the accuracy of the Forest Biodiversity Index (FBI) in measuring biodiversity in the Indian part of the Himalayas by using the NFI.

2. Material and methods

The Western Himalayas (WH) are one of the 14 physiographic zones of India and lie in northernmost part of the country (Fig. 1A). It comprises 20 studied districts belonging to 3 different states of India: Jammu, Kashmir, Himachal Pradesh, and Uttarakhand (Fig. 1B), monitored in the NFI in 2002-2015. The WH receive higher precipitation during winter, in the form of snow, and are dominated by temperate broadleaf forests, largely by oaks (*Quercus* spp.), constituting an important natural resource base. The WH include major mountain ranges, like the Pir Panjal and Zanskar, with deep river valleys, such as the Kashmir and Beas valleys. The region also features significant glacial landforms, e.g. the Siachen Glacier, and is shaped by ongoing tectonic activity along fault lines: the Main Central Thrust, etc. These physical features influence the region's biodiversity, climate, and human settlements (Rana & Chandra 2002; Thakur & Rana 2006).

Details of the survey, sample design, field inventory exercise, and the descriptions of the NFI variables are available in the "Manual of instructions for field inventory 2002" (FSI 2002). In total, 3549 plots (0.1 ha each) were established in 2002-2015 in the WH and were used for the study. In 2230 plots at least one tree species was identified (diameter at breast height ≥10 cm). Beside the species codes given in the manual, we created also one species code for an identified tree species that was not given any code in the NFI manual, and one species code for unidentified (miscellaneous) species. Overall, 226 tree species were found in the WH. The available literature permitted us to select 20 indicators from the NFI for their contribution towards maintenance and enhancement of overall forest biodiversity. Each of these can be scored from 1 to 4 (i.e. low to high), indicating plot biodiversity level in accordance with the NFI manual. We used the group convergence method that ensures equity of all stakeholders irrespective of gender, class or entitlements. Typically, this method works on a round-by-round basis and enhances the quality of discussion and inputs in every round till the convergence in valuation is reached among group members. In this case we considered weightage assigned by 4 experts and first author's weightage and derived the mode value given in the column "weightage" in Appendix 1. (The experts are eminent scientists working in the forestry sector for over 15 years who assigned a weightage between 1 to 4 to these 20 indicators.) To relate the relevance of every indicator to forest biodiversity, we decided to use the values 1, 2, 3, and 4 to represent low, moderate, high, and very high biodiversity, respectively. Only 4 classes were considered to avoid the neutral category.

We randomly split 3549 forest inventory (FI) points into 2 subsets with a roughly 8:2 ratio, i.e. 2849 and 700 FI points (Fig. 2A-B). The ratio of 8:2 was used, considering that about 1/5 of the total (i.e. 700 points) would be optimal for validating the biodiversity model prepared by using the other 4/5 (i.e. 2849 FI points). The layers were created using interpolation technique in ArcGIS 10.1 (GIS software) with ordinary kriging method and linear semi-variogram, with the output cell size equal to that of climatic data available (=30") for

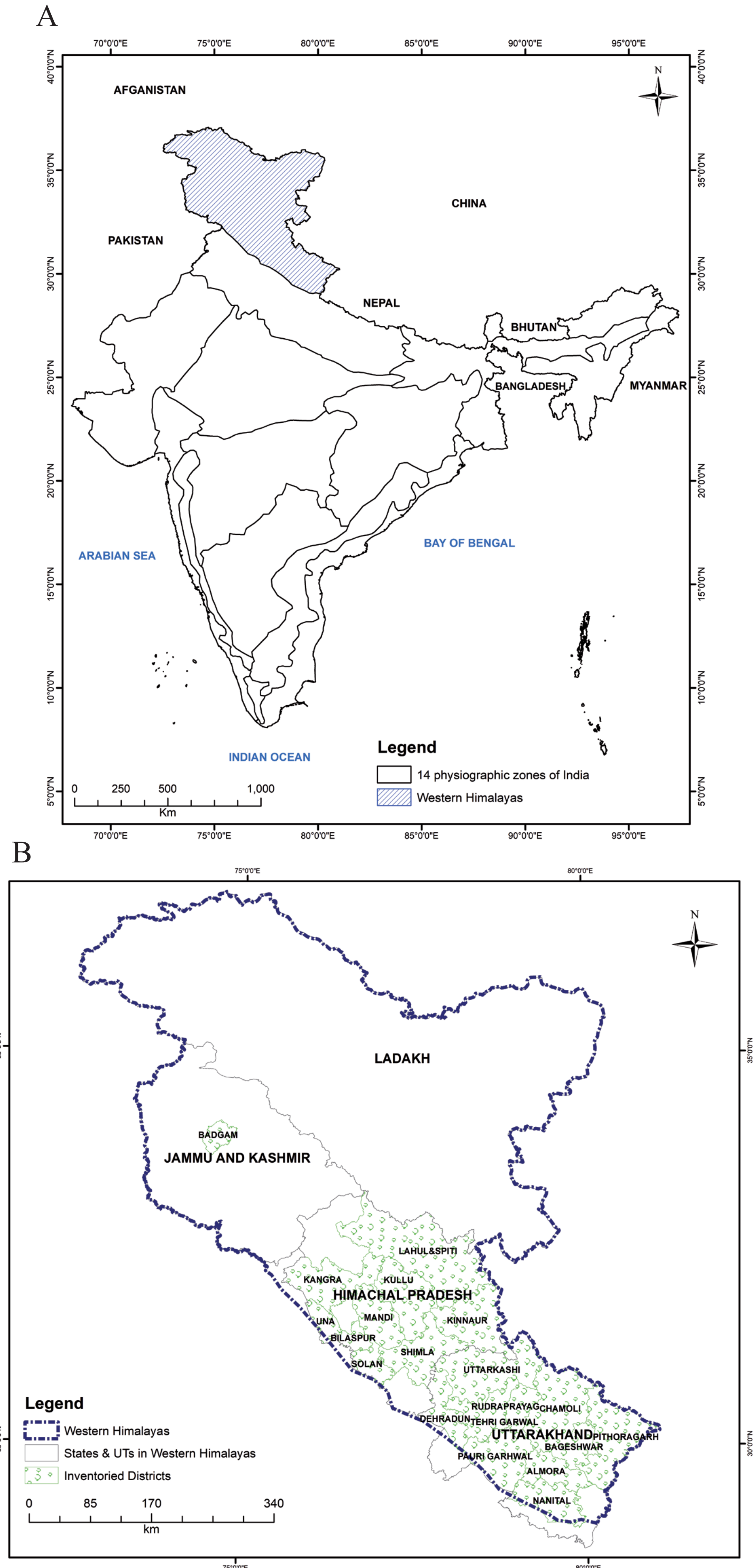

Fig. 1. Study area: location of the Western Himalayas in India (A) and distribution of the inventoried forest districts (B)

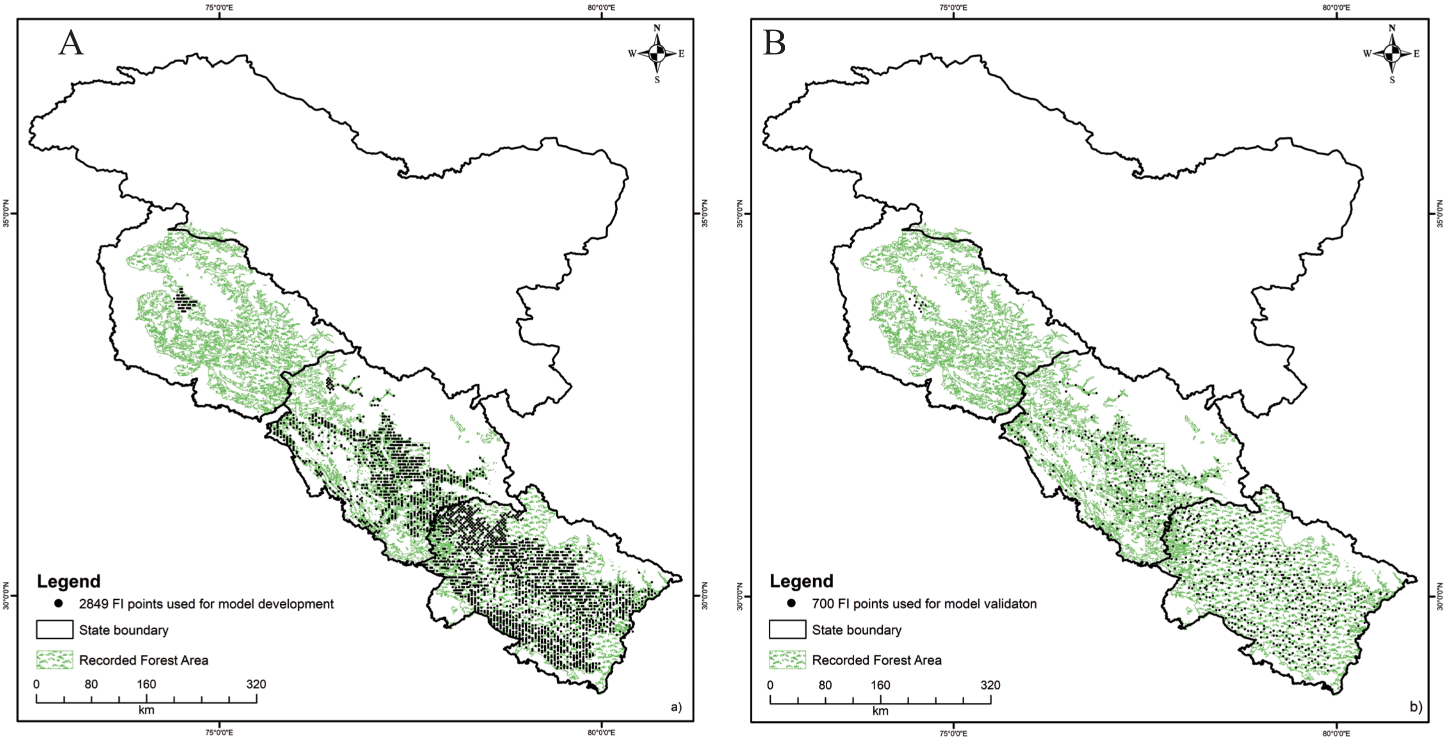

Fig. 2. Distribution of 2849 forest inventory (FI) points used for Forest Biodiversity Index model development (A) and 700 randomly selected FI points used for validation (B)

further correlation study. Two spatial layers were created: one from 2849 FI points and another from 700 FI points, for various indicators. A minimum outer boundary was created using the recorded forest area to delimit the predictive FBI model. The final FBI was derived as the sum or product of the weights assigned to various indicators as follows:

$FBI = \sum^{n}_{i=1}$ {(Origin of forest stand $_i \times Wt_{i1}$)/4 + (Dbh class qualitative $_i \times Wt_{i2}$)/4 + (Dbh class quantitative $_i \times Wt_{i3}$)/4 + (Canopy storeys $_i \times Wt_{i4}$)/4 + (Crop composition $_i \times Wt_{i5}$)/4 + (Undergrowth $_i \times Wt_{i6}$)/4 + (Grasses $_i \times Wt_{i7}$)/4 + (Land use $_i \times Wt_{i8}$)/4 + (Legal status $_i \times Wt_{i9}$)/4 + (Regeneration intensity $_i \times Wt_{i10}$)/4 + (Soil depth $_i \times Wt_{i11}$)/4 + (Soil erosion $_i \times Wt_{i12}$)/4 + (Species richness $_i \times Wt_{i13}$)/4 + (Grazing $_i \times Wt_{i14}$)/4 + (Girdling $_i \times Wt_{i15}$)/4 + (Lopping $_i \times Wt_{i16}$)/4 + (Fire $_i \times Wt_{i17}$)/4 + (Fragmentation $\times Wt_{i18}$)/4 + (Deadwood $_i \times Wt_{i19}$)/4 + (Litter $_i \times Wt_{i20}$)/4)},
where Wt = weightage (the mode value); i = values of selected indicators from the NFI; Dbh = diameter at breast height.

All biodiversity variables (as indicators) are explained in Appendix 1, with reasons as found in literature how well they relate to low or high biodiversity in forest. They include 13 state indicators, 5 disturbance indicators, and a response indicator. The state indicators reflect higher biodiversity in forests that mimic characteristic natural processes or contain elements of old-growth forest (cf. Vellend & Geber 2005). Biodiversity indicators help us present and manage complex datasets in a simple manner to evaluate significant changes and impacts in developing approaches to biodiversity conservation at strategic and policy levels.

3. Results and Discussion

Three out of 4 experts gave the same weightage to the first indicator and this pattern was found consistently in all indicators. Therefore, the mode value was considered (instead of the mean) and used for developing the FBI model. The weightage of 4 (very high biodiversity) was recorded for the origin of stand, legal status, tree species, and deadwood. The weightage of 3 (high biodiversity) was given to qualitative and quantitative dbh classes of trees, canopy storeys, crop composition, undergrowth, forest regeneration, soil depth, and litter. The weightage of 2 (moderate biodiversity) was noted for presence of grasses, land use, grazing, girdling, lopping, and forest fragmentation, while soil erosion and forest fire received the weightage of 1 (low biodiversity) in the WH.

The generated FBI model (Fig. 3) shows that biodiversity is low in 0.05% of the study area, moderate in 10.51%, high in 64.41%, and very high in 25.02%. Validation was done by using 700 FI points based on spatial windows of varying size and varying accuracy was achieved (Fig. 4). The accuracy of 18.77% was

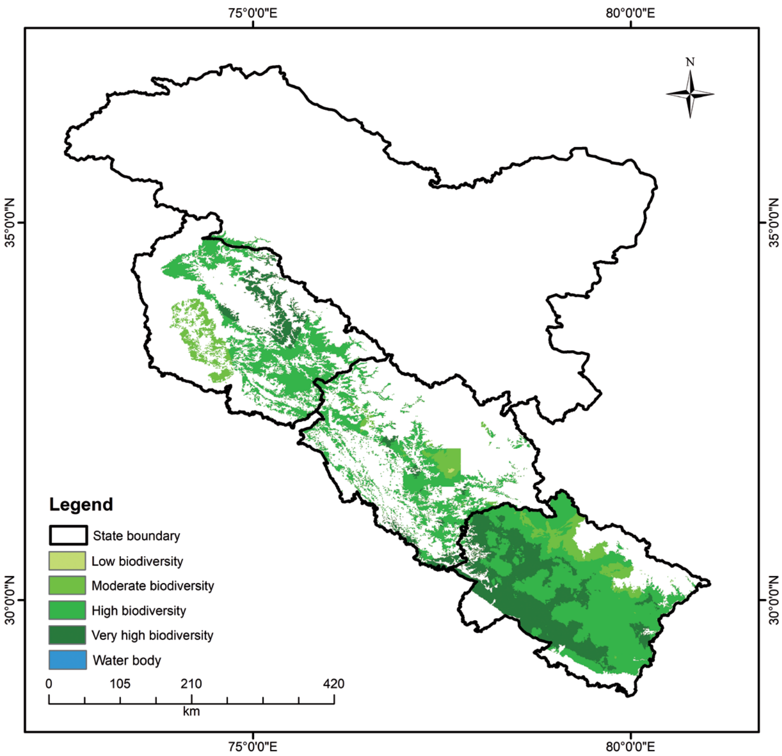

Fig. 3. Map of forest biodiversity based on its index (FBI) developed for the Western Himalayas by using various parameters of the National Forest Inventory

observed at pixel size but increased with increasing window size and reached 74.79% for a 4500 m × 4500 m window, corresponding to 2.5' × 2.5' grid size (the ground resolution of the NFI dataset represented by 2 sample points).

The approach presented here clearly proves that the NFI of India database holds a very useful set of biodiversity-related indicators, allowing us to develop an aggregate index to represent overall forest biodiversity. The predicted model with the accuracy of 75% provides evidence of the effective impact of the ground data at which the NFI is being implemented. The predicted model indicates that 89.44% of the WH holds high and very high biodiversity. Thus, the NFI database can help in highlighting the areas with varying intensity of biodiversity, which can be used in prioritizing the area for

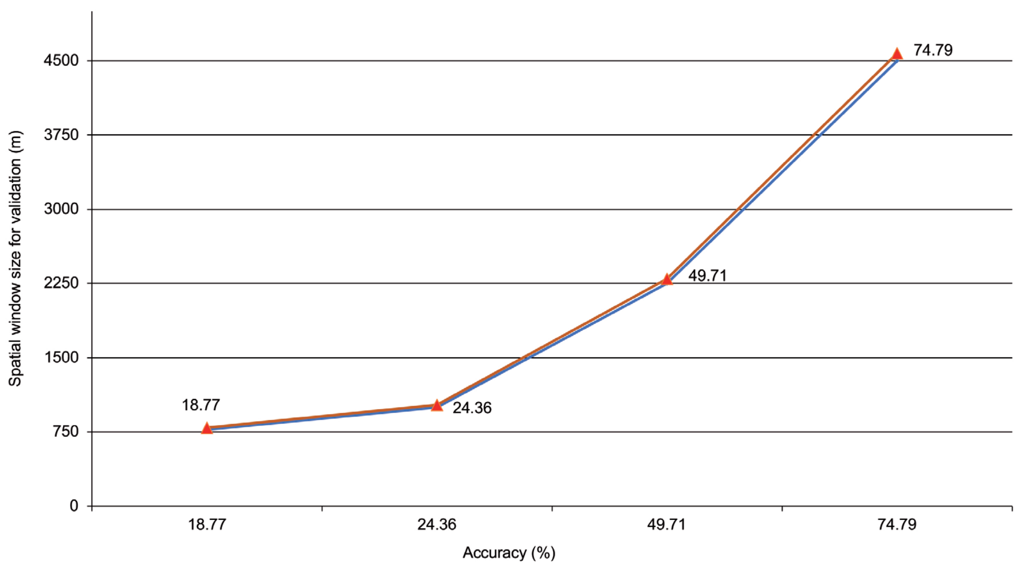

Fig. 4. Accuracy of the Forest Biodiversity Index model in relation to the spatial window size used for validation

bioprospecting, designing the protected area network, regulating the human interference, and monitoring landscape level change.

Unlike the Austrian Forest Biodiversity Index, which fulfils targets defined by scientific experts in the context of management to monitor seed orchards and red-listed species (Geburek *et al*. 2010), the inclusion of all relevant biodiversity indicators from the NFI of India gives a holistic picture that can be effectively used after prolonged periods to reflect major biodiversity changes. The assigned weightage to various components may be modified to get some specific details of biophysical parameters of forest, although this would require rigorous exercise and inputs from many experts in varying fields. The approach is practically viable. The use of our forest biodiversity index would be more effective if the data used for developing it came from permanent plots, subsequently multiplying the number of data to be used in conservation and protection of forest biodiversity.

4. Conclusions

Comprehensive and spatially explicit distribution of various biodiversity indicators are the basic requirements for biodiversity conservation, which is not readily available especially in the topographically challenging mountainous region of the Indian Himalayas. It is expected that various government agencies and the stakeholders vested with the responsibility to manage and conserve natural resources of the country shall make good use of the NFI repository of baseline geospatial database for monitoring the natural resources, developing strategies for their conservation, and putting in place a credible system of bio-resource monitoring in this mountainous, hardly accessible region. This subsequently might contribute to achieving India's national mission to sustain Himalayan ecosystems.

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Final approval of article: Rajesh Kumar, R. K. Verma, Ranjeet Kumar

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Appendix 1. Biodiversity indicators with assigned weightage (the mode value) used for developing the Forest Biodiversity Index (FBI) for the Western Himalayas (WH)

Indicator's description	Measuring method	Comments	References	Weight
NATURALNESS – biological integrity; natural, old-growth forests for instituting protected areas (Angermeier 2000; Branquart & Latham 2007); variables used:				
Crop composition – distinguished forest types based on dominant species constituting >25%	1 = eucalyptus, Alpine scrub, bamboo, *Anogeissus pendula*, *Tectona grandis* with various species or with *Shorea robusta*: up to 10 tree species 2 = *Senegalia catechu* and *Dalbergia sissoo*, *Tectona grandis*, spruce and/or fir, *Pinus wallichiana*, mixed bamboos or *Cedrus deodara*: 11-36 tree species 3 = mixed conifers, oak-rhododendron, *Senegalia catechu* or *Shorea robusta* with various species: 37-65 tree species 4 = oak, conifers mixed with hardwoods, upland or lowland hardwoods, *Shorea robusta*, *Pinus roxburghii* or other mixed forests: 66-115 tree species	· mixed forests provide more suitable microclimates for fungi (e.g. higher humidity) than monocultures · productivity is often higher in mixed forests	Jules *et al*. 2014; Liang *et al.* 2016	3
Tree species – species richness, i.e. total number of tree species found in a sample plot	plots (0.1 ha) with up to 4, 5-8, 9-12, and 13-17 tree species scored as 1, 2, 3, and 4, respectively	· trees provide mechanical support for arboreal plants and animals · tree microhabitats – like dead/broken tree tops, splintered stems, burst bark etc. – play exceptional roles in biodiversity conservation · growing fungal diversity with increasing tree diversity	Nadkami *et al.* 2001; Peay *et al.* 2013	4
Undergrowth – vegetation under tree canopies (surface cover, assessed visually)	1 = absent; 2 = moderate (10-25%); 3 = dense (25-50%); 4 = very dense cover (>50%)	· provides habitat to wildlife, ensures soil retention, prevents run-off, helps in pollination, etc. · indicator of moisture regime · adds structural diversity to vegetation; dependency of animal species · mere presence increases local biodiversity	Hagar 2007; Stewart 2011	3
Grasses (surface cover assessed visually, including also Cyperaceae and Juncaceae)	1 = absent; 2 = scanty (1-9%); 3 = moderate (10-25%); 4 = dense or very dense cover (25-100%)	· performing functions like soil binding, increased water infiltration, reduced run-off · provides food to grazing and other animals		2
STRUCTURAL – Pommerening (2002) stated a linkage between increased heterogeneity (horizontal and vertical) of forest stand structure and a higher number of species and stands with greater ecological stability; variables used:				
Origin of forest stand – natural or cultivated	2 = planting; 3 = coppice; and 4 = self-sown	· gives an idea of uniformity in composition, constitution, age structure or arrangement		4
Canopy storeys (layers) – forming an upper horizontal stratum in a plant community	1 = no canopy; 2 = one storey, 3 = two storeys, and 4 = three or more storeys of canopy	· canopy provides a habitat conducive to development of flora and fauna hardly seen on forest floor · influences species abundance and life forms	Bhatta & Vetaas 2016	3

Stem diameter classes – based on predominant values of diameter at breast height (dbh)	qualitative evaluation: 1 = regeneration (dbh <10 cm), 2 = pole crop (10-20 cm), 3 = small timber (20– <30 cm) or big timber (≥30 cm); 4 = mixed size class quantitative evaluation: all trees enumerated in sample plots were classified depending on dbh as 10-20 cm, 20-30 cm, 30-40 cm or ≥40, and then plots were scored as 1 = stem dbh in a single class; 2 = stem dbh in 2 classes; 3 = stem dbh in 3 classes; 4 = stem dbh in all 4 classes (then a tree species is more likely to perpetuate itself)	· acts as a wildlife indicator because some animals prefer older forest, while others prefer very young trees		3
Deadwood – all dead woody material in forests (≥5 cm across)	quantified per subplot (5 m x 5 m) by weighing in kg (using a spring balance) at crop composition level, next classified into 4 quartiles and scored as 1 for ≤0.009, as 2 for 0.01-0.26, as 3 for 0.27-0.39, and as 4 for ≥0.40	· correlates to structural, compositional and functional components of ecosystem · essential biodiversity feature · habitat for invertebrates, fungi, and microorganisms	Hodge & Peterken 1998; EEA 2007; Winter *et al.* 2011; McComb 2008	3
Litter – undecomposed woody material (<5 cm across)	quantified per subplot (5 m x 5 m) by weighing in kg (using a spring balance) at crop composition level, next classified into 4 quartiles and scored as 1 for ≤0.91, as 2 for 0.92-1.39, as 3 for 1.40-1.85, and as 4 for ≥1.86	· regulates nutrient cycling · greater litter weight and depth reduce moisture loss and support larger bacterial communities	Odiwe 2003; Dwyer & Merriam 1981	3
Intensity of forest regeneration	2 = none (0 seedlings); 3 = inadequate (<18 seedlings); 4 = adequate (≥18 seedlings)	· a key process ensuring species survival under varied environmental conditions	Khumbongmayum *et al*. 2005	3
Land use (forest cover density) – in 16 land use classes	4 = closed/dense/open forests (canopy density ≥10%) or grassland; 1 = all other land use classes (our target was to develop an aggregate index that includes all 3 forest density classes – along with associated variables mentioned earlier and later – so these 3 classes could not be given different values for biodiversity)	· canopy gaps of varying size support germination and growth of different species, affecting composition and richness · grassland within recorded forest area would be expected to have more species since in WH it includes most of alpine meadows	Vilhar *et al.* 2015	2
EDAPHIC – sustain terrestrial life on earth; variables used:				
Soil erosion – removal of top layer, as evident by gullies, ravines, etc.	1 = heavily eroded; 2 = moderate; 3 = mild erosion; 4 = no erosion-	· physical, chemical and biological properties of soil greatly influence plant ecology and evolution as well as associated biota · soil is richest habitat for fungi · soil erosion reduces forest productivity	Rajakaruna & Boyd 2008; Bilgrami 1997; Swanson *et al.* 1989	1
Soil depth	1 = no soil or very shallow (<15 cm); 2 = shallow (15- <30 cm); 3 = medium (30- <90 cm); 4 = deep (= ≥90 cm)	· holds necessary space, nutrients, and water required by plant communities for growth and stability		3
DISTURBANCE – it can be natural or anthropogenic and may cause sudden/gradual changes at a small or mass scale (affected part assessed visually in an area of 2 ha for all variables except fragmentation); variables used:				
Fire	1 = heavily affected (>50%); 2 = moderately affected (10-50%); 3 = occasionally affected (<10%); 4 = no fire	· causes long-term effects due to carbon emissions and changes in forest ecosystems · major cause of forest degradation in India	Bahuguna & Upadhyay 2002	2

Grazing	1 = heavy (>50%); 2 = moderate (10-50%); 3 = light (<10%); 4 = no grazing	· India's forest and grassland is under severe pressure · WH suffer intense forest cover reduction due to pastoral practices	CBD 2014; Ives & Masserli 1996	2
Lopping	1 = heavy (>50%); 2 = moderate (10-50%); 3 = occasional (<10%); 4 = no lopping	· used for bedding for stall-feeding cattle and for fuel · over-lopping weakens a tree physiologically, renders it prone to attack by insects or fungi, and reduces canopy density, thus increasing soil erosion · lopping of *Quercus leucotrichophora* and removal of litter is intended to replace oak by pine in Central Himalayas · major reason for poor natural regeneration of *Pinus gerardiana*	Negi 1993; Thadani 1999; Kumar *et al.* 2014	2
Girdling/illicit felling	1 = heavy (>50%); 2 = moderate (10-50%); 3 = light (<10%); 4 = none	· major concern for protected forests in WH · observed commonly, by local inhabitants (*Taxus baccata* in WH)	Mahar *et al.* 2012	2
Forest fragmentation	1 = plot with >9 forest patches; 2 = with 7-9 patches; 3 = with 4-6 patches; 4 = with 0-3 patches	· major biodiversity threat at landscape scale · impact on biodiversity well documented at landscape level	Kupfer 2006; Forman & Godron 1986; Roy & Tomar 2000	2
RESPONSE – conveys human response by protecting existing natural assets				
Legal status – giving varying level of permission to intervene in nature	1 = unclassed government-owned; 3 = protected forests; 4 = reserved forests	· legally, in reserved forests all activities are prohibited (except for special permissions), while in protected forests many activities are permitted		3