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Vegetation Characteristics Based Climate Change Vulnerability Assessment of Temperate Forests of Western Himalaya

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Abstract: Forests are under stress due to variety of climatic and non-climatic factors. Therefore for suitably managing the forests, vulnerability of the forests needs to be understood. The present paper attempts to estimate the vulnerability of various temperate forests of Western Himalaya due to climate change by analyzing the patterns of different taxonomical indices, based on primary data i.e., vegetation data. The paper presents a novel approach for climate change vulnerability assessment based on field data through a bottom-up approach. The vulnerability of the forests was assessed through the IPCC framework by suitably selecting indicators (taxonomy indices and climatic parameters) for the three dimensions of vulnerability i.e., exposure, sensitivity and adaptive capacity. The field data were collected from 17 different temperate forests distributed at the elevation “1600 to 3500 m” in Uttarakhand and Himachal Pradesh, India. Abundance and richness for each forest were collected by randomly laying ten quadrats of size 0.1 ha each. The analysis resulted into identifying the most and the least vulnerable temperate forests of the western Himalaya to climate change. The analysis showed that the Neoza Pine; Moist Deodar; Ban Oak and Dry Broadleaved and Coniferous forest were the most vulnerable forests in the Himalayan temperate forests due to climate change. Moreover, the variation in the levels of the vulnerability status of the selected forests was insignificant with elevational range as well as exposure to climate. The proposed method will serve for vulnerability estimation of forests due to climate change based on the actual realization of the species in the field.

Keywords: adaptive capacity; biodiversity; dominance; ecosystem functioning

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1. Introduction

Temperate forests are considered very prone to fragmentation as well as degradation [1] thereby vulnerable to the climate and anthropogenic factors. The climate of the Himalaya is changing as temperature is increased by 0.2–0.4 °C per decade in western Himalayan region [2], 0.6 °C per decade in central Himalayan region [3] and 1.6 °C in last century in northwest Himalayan region [4]. The change in climate makes the forest vulnerable and shifts the ecological niches of biological diversity [5] such as the upward movement of the dominant plant species due to increased winter temperature [6,7]; shift of temperate tree species as *Pinus wallichiana* [8] and *Rhododendron campanulatum* along an altitudinal transect [9]. Precisely, climate change influences species composition, productivity and biodiversity of temperate ecosystems [10] i.e., shapes the vegetation pattern [9] and also leads to susceptibility. The variations in vegetation structure, richness, diversity and distribution are directly correlated with functioning and ecosystem services provided by the forest [11–13]. For example, biodiversity, structural diversity, forest disturbances and environmental variables affect above ground tree carbon storage [14]; depletion of soil organic carbon (SOC) leads to a declining trend in productivity [15]; soil microbial biomass carbon decreases due to forest fire in Himalayan temperate oak forest [16]. Inevitably, change in the forest community (distribution, density and species composition) due to climatic and non-climatic factors immensely influence the functioning of the forests [17] and make the forest vulnerable. Therefore, effective current and future management of the temperate forest ecosystems under the changing factors should be based on scientifically generated information about the current status of the forests [18,19].

Vulnerability assessments of forest system provide important information for understanding the potential risks, challenges, and opportunities of climate change [20]. Therefore, vulnerability assessment of forests is important not only for identifying the factors causing vulnerability at the local level, but also to facilitate forest managers to develop the most recognizable choice for forest management [21,22]. A top-down approach using global and regional climate and vegetation models has been applied to assess the forest vulnerability at global scale [23]; national scale [24]; and regional scale [25,26]. However, very few studies have attempted the bottom-up approach for vulnerability assessment [27] thereby failing to propose the measures for the resilience of the forests at local level [28]. The adaptation measures for the forests cannot be decided on large scale evaluation of the vulnerability through environmental parameters rather must be based on vulnerability assessment based on ecological parameters i.e., plant diversity, richness, at local scale [29]. Evaluation of vegetation and biodiversity is important to understand the status of forest disturbances of forest [30,31]; forest succession [32–34], and flow of various ecosystem services [35,36] thereby also provides inputs to the development of effective conservation and management plans for the forest [37]. Therefore, the present study aims to analyze the vulnerability of forests due to climate change by developing an index using various diversity indices based on the current vegetation structure and composition of woody species of temperate forests of Uttarakhand and Himachal Pradesh, India. The study hypothesizes that the vulnerability of the various sub-types of temperate forests of the western Himalayan region varies with climate change. The other hypothesis predicts that an association exists between the vulnerability status of the temperate forests of the region and the topographical dimension i.e., elevation ranges of the occurrences of the forest as well as the exposure to climate. The study based on field observation generates the information about the current status of the structure and composition of the forests by collecting primary information from 17 forests. The synthesis of the evaluation would facilitate the current status of forests along with their vulnerability status, thereby supporting the development of a protocol for conservation and management of the forests.

2. Materials and Methods

2.1. Study Area

The study was focused on the temperate forests of Uttarakhand and Himachal Pradesh of India (Figure 1). Uttarakhand, predominantly a Himalayan mountainous state spreads in 53,483 km^2 and lies between 28°43′ N to 31°28′ N latitude and 77°34′ E to 81°03′ E longitude with varied climate and vegetation along with altitude. The average annual rainfall is 1500 mm with the annual temperature varies from 0 °C in alpine region to 43 °C in plain region. The population density of the State is 189-person per km^2. Himachal Pradesh is a western Himalayan mountainous state with a geographical area of 55,673 sq km and distributed between 30°22′ N to 33°12′ N latitude and 75°45′ E to 79°04′ E longitude. The average annual rainfall is about 1800 mm with varied temperature from sub-zero in alpine region to 35 °C in plain region. The population density of the State is 123 per km^2. Topographically both of these states have all the three major ranges of Himalayas resulting in the formation of alpine pastures in higher altitudes to sub-tropical forests in the lower altitudes. Himalayan moist temperate forest (Group 12) covers 31.64% (Uttarakhand) and 40.24% (Himachal Pradesh) of geographical area and Himalayan dry temperate forest (Group 13) covers 1.01% (Uttarakhand) and 3.32% (Himachal Pradesh) [35] (Supplementary Materials Tables S1 and S2).

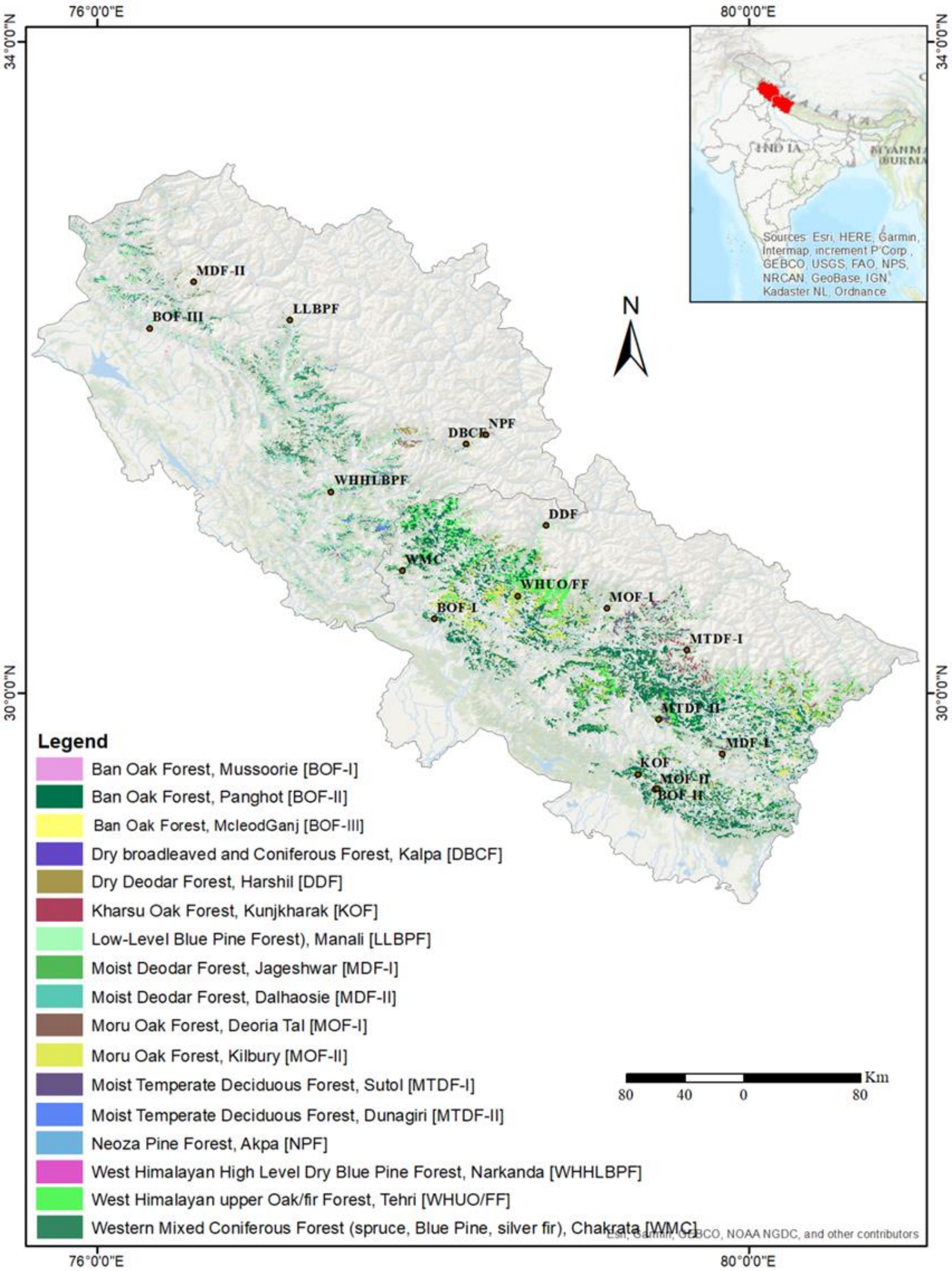

Figure 1. Study area of the selected forests.

2.2. Sampling

Temperate forest in India covers 12.84% of Himalayan region [35] and provides various ecosystem services ranging from consumer goods to durables to the neighboring communities for their subsistence [38]. These forests are vulnerable to varied climatic and non-climatic factors such as temperature [5]. These factors attributed to changes in the composition and structure of the forests and therefore changes in the distribution of areas under various forest density classes from the year 2005 to 2019 [35]. The contribution of the forests to the adjoining communities for their subsistence [38] and their vulnerable status to the climate [25,26] were the contenders for selecting these forests for evaluation. The selection of forest sites was made through stratified random sampling with Forest Type Group as a stratification criterion. Temperate forests of the region have two major group types as Himalayan moist temperate forests and Himalayan dry temperate forests and further classified into two sub-groups each as Lower Western Himalayan Temperate Forests (eight subgroup types) and Upper West Himalayan Temperate Forests (six subgroup types) and Western Types (eight subgroup types) and Eastern Types (one subgroup type) (Supplementary Materials Table S1). These were further classified into subgroup type [39]. Out of these subgroup types, many subgroups have a low geographical area (proportion) and therefore were not considered. A total of seventeen sites (eleven from Uttarakhand and six from Himachal Pradesh) representing the various subgroups of the temperate forest type Groups 12 and 13 were selected at random from both the states (Figure 1) (Supplementary Materials Tables S1 and S2). Climatic details such as precipitation and maximum and minimum temperature of the study area from 2010 to 2018 were obtained from WorldClim data to evaluate climatic changes during the last decades (Supplementary Materials Table S3).

A detailed survey and vegetation analysis were conducted in the selected sites of the forests of both the states. Ten quadrats of 0.1 ha were randomly laid in each of the 17 selected sites following the methodology of forest inventory [35] from September 2020 to March 2021. Tree species were identified with the support of literature and taxonomists of the Forest Research Institute, Dehradun, India. Latitude, longitude, elevation, aspect, and slope were recorded for all the selected forests (Supplementary Materials Table S2). Various taxonomical indices such as Shannon-Wiener Index [36], Simpson's Index [37], Pielou's Equitability Index [40], Menhinick's Index of Richness [41], Degree of Maturity [42] and the ratio of abundance to frequency were calculated using the standard procedures.

2.3. Vulnerability Analysis

In this study, vulnerability is considered as the susceptibility of forest ecosystem in terms of species composition and diversity under the exposure to the climate change. Moreover, temperate forests of Uttarakhand and Himachal Pradesh are vulnerable to the precipitation and number of wet days' frequency [25]. The impact of warming on temperate forests has huge implications for changing vegetation i.e., composition, net primary productivity [24]. Temperature is responsible for changes in the structure and composition of Ridge Top forests of Uttarakhand and Himachal Pradesh [22]. Moreover, evaluation of statistics showed that areas under different selected temperate forest types of Uttarakhand and Himachal Pradesh are already changed (Supplementary Materials Tables S4 and S5) with changes in shifting to lower density classes [35].

The vulnerability of the forest ecosystem was assessed through the IPCC framework considering the three dimensions of vulnerability i.e., exposure, sensitivity and adaptive capacity using bottom-up approaches [43]. Exposure in the present case is degree to which a system is exposed to climatic variations and determined based on of temperature and precipitation. Sensitivity is the degree to which the forest ecosystem is affected by climate-related stimuli and determined through the composition and structure parameters of the forests [24] i.e., abundance, number of species, basal area, Simpson's Index and Menhinick's Index of Richness Index. Adaptive capacity is the ability of a forest ecosystem to adjust to climate change to moderate potential damages, and or to cope with the consequences and therefore determined using Equitability Index, Shannon-Weiner Diversity Index and

Degree of maturity. Indicators for each dimension of vulnerability were considered based on the conceptualization of vulnerability. The indices have different scales and therefore, normalization was used to make them comparable and to facilitate aggregation. All indicators except the maturity index which was considered adversely related to adaptive capacity due to facilitation of succession were normalized to values between 0 and 1 based on the following formula [44].

$$\textit{Normalized Value},\ \mathrm{Xij} = \frac{\mathrm{Xi} - \mathrm{MinXj}}{\mathrm{MaxXj} - \mathrm{MinXj}}$$

where Xij is the *normalized value* of indicator (j) with respect to forest type (i), Xi is the actual value of the indicator with respect to forest type (i), and MinXj and MaxXj are the minimum and maximum values, respectively, of indicator (j) among all forests type.

Exposure index (EI) was calculated based on the mean of minimum (Tmin), mean of maximum temperature (Tmax) and mean of precipitation (Pr). Sensitivity Index (SI) was calculated based on number of individuals (NI), number of species (NS), basal area (BA), Simpson's Index (Sim) and Menhinick's Index of Richness Index (Men). Adaptive Capacity Index (AI) was measured using Equitability Index (EqI), Shannon-Weiner Diversity Index (SW) and Degree of maturity (DM). Following formula were used for calculating the EI, SI and AI for each selected forest subtypes based on relevant data collected from the subtypes:

$$\mathrm{EI} = \frac{\mathrm{Tmin} + \mathrm{Tmax} + \mathrm{Pr}}{3}$$

$$\mathrm{SI} = \frac{\mathrm{NI} + \mathrm{NS} + \mathrm{BA} + \mathrm{Sim} + \mathrm{Men}}{5}$$

$$\mathrm{AI} = \frac{\mathrm{EqI} + \mathrm{SW} + \mathrm{DM}}{4}$$

The limits of the three indices were $0 \leq$ EI, SI, AI ≤ 1. The three dimensions were aggregated to obtain a composite vulnerability index (VI) using Manush approach. The approach is based on a Displaced Ideal method and was applied to assess the vulnerability with the premise that a better system should have less distance from the ideal. In this approach, the ideal system was considered as a most vulnerable system. The ideal vulnerable system would have no adaptive capacity i.e., value zero and highly sensitive i.e., value one under highly exposed system i.e., value one [43,44]. The Euclidean distance from the ideal was used to assess the vulnerability based on the premise that the impact realized in the system due to exposure (climate) on sensitive systems was countered by the adaptive capacity of the system. The following formula was applied to assess the vulnerability:

$$\text{Vulnerability index (VI)} = [(1 - \mathrm{EI})\ (1 - \mathrm{SI}) - \mathrm{AI}]$$

The value of the VI ranges from 1 (most vulnerable) to −1 (least vulnerable) i.e., where a high value of VI for an ecosystem indicates closeness to the most vulnerable state signifies a most vulnerable state i.e., the positive value shows that sensitivity dominates adaptive capacity; and a high departure from most vulnerable state signifies least vulnerable state i.e., the negative value shows that adaptive capacity overshadows sensitivity [44]. The vulnerability status (class) was estimated based on quartile measures as least vulnerable (up to first quartile), low vulnerable (between first to second quartile), moderate vulnerable (between second and third quartile) and most vulnerable (after the third quartile).

The association between vulnerability status with elevation range and exposure level (measured as exposure index above on the basis of climatic parameters) was also tested through Fisher's Exact test.

3. Results

Total number of species was more in West Himalayan Upper Oak/Fir forest, Maid; Ban Oak forest, Binog; Moru Oak forest, Deoriatal and Moist Temperate Deciduous forest, Dunagiri; however, the number of individuals was more in Ban Oak forest, Mcleodganj (Table 1). The total basal area was highest in Kharsu Oak forest, Kunjkharak whereas minimum in Dry Broadleaved and Coniferous forest, Kalpa and Neoza Pine Forest, Akpa. Simpson's Index was highest in Ban Oak forest, Pangot whereas minimum in Neoza Pine Forest, Akpa. Shannon-Weiner Index was highest in West Himalayan Upper Oak/Fir forest, Maid, whereas minimum in Ban Oak forest, Pangot. Pielou's Index of Equitability was highest in West Himalayan High Level Blue Pine Forest, Narkanda whereas minimum in Ban Oak forest, Pangot. Menhinick's Index of species richness was highest in West Himalayan Upper Oak/Fir Forest, Maid whereas minimum for West Himalayan High Level Blue Pine Forest, Narkanda. Degree of maturity was highest in Moru Oak forest, Deoriatal whereas minimum for Ban Oak forest, Pangot (Table 1).

Table 1. Community attributes of different Himalayan temperate forests.

Forest Type	No. of Individual	Total Species	TBA (m^2/ha)	Simpson's Index	Equitability Index	Menhinick's Species Richness Index	Shannon-Weiner Index	Degree of Maturity
BOF-I	409	12	22.00	0.27	0.69	0.59	1.70	1.25
BOF-II	381	4	35.05	0.96	0.08	0.20	0.11	0.37
BOF-III	930	8	31.24	0.49	0.43	0.26	0.90	0.42
DBCF	313	3	18.63	0.54	0.75	0.17	0.83	0.89
DDF	336	3	53.22	0.53	0.71	0.16	0.77	0.57
KOF	438	6	212.65	0.39	0.68	0.29	1.22	0.64
LLBPF	471	3	24.30	0.47	0.73	0.14	0.80	0.57
MDF-I	708	6	41.14	0.32	0.76	0.23	1.37	0.72
MDF-II	279	5	76.92	0.17	0.24	0.30	0.39	0.75
MOF-I	511	13	47.17	0.22	0.70	0.58	1.78	1.31
MOF-II	705	9	39.82	0.27	0.71	0.34	1.56	0.62
MTDF-I	237	7	87.53	0.52	0.44	0.45	0.86	1.14
MTDF-II	565	12	35.19	0.23	0.70	0.50	1.73	1.10
NPF	182	2	18.84	0.16	0.43	0.15	0.30	0.82
WHHLBPF	387	2	30.02	0.42	0.88	0.10	0.61	0.52
WHUO/FF	404	13	70.59	0.19	0.73	0.65	1.86	1.14
WMCF	400	9	30.49	0.28	0.66	0.45	1.44	1.03

BOF-I—Ban Oak Forest, Binog; BOF-II—Ban Oak Forest, Pangot; BOF-III—Ban Oak Forest, Mcleodganj; DBCF—Dry Broadleaved and Coniferous Forest, Kalpa; DDF—Dry Deodar Forest, Harshil; KOF—Kharsu Oak Forest, Kunjkharak; LLBPF—Low-Level Blue Pine Forest, Manali; MDF-I—Moist Deodar Forest, Jageshwar; MDF-II—Moist Deodar Forest, Dalhuosie; MOF-I—Moru Oak Forest, Deoria Tal; MOF-II—Moru Oak Forest, Kilbury; MTDF-I—Moist Temperate Deciduous Forest, Sutol; MTDF-II—Moist Temperate Deciduous Forest, Dunagiri; NPF—Neoza Pine Forest, Akpa; WHHLBPF –West Himalayan High Level Blue Pine Forest, Narkanda; WHUO/FF—West Himalayan Upper Oak/fir Forest, Maid; WMC—Western Mixed Coniferous Forest, Deoban.

Vulnerability Status

Exposure level was high in Ban Oak forest, Mcleodganj forest followed by Ban Oak forest, Binog and lowest in Dry Deodar forest, Harshil, Low-Level Blue Pine forest, Manali; Neoza Pine Forest, Akpa. The high exposure level (index) was due to heavy to moderate snow fall with heavy rains in the region, however the low exposure was primarily due to consistency in the weather patterns in the region as the climate of Harshil; Manali; Akpa and Kalpa were more or less consistent and cold with heavy snowfalls during winters (Supplementary Materials Table S3). Sensitivity index was high in Neoza Pine forest, Akpa; High Level Blue Pine, Narkanda; Low Level Blue Pine, Manali and Dry Broad-Leaves Coniferous forests and lowest in West Himalayan Upper Oak/Fir forest, Maid; Kharsu Oak forest, Kunjkharak; Moist temperate Deciduous forests, Dunagiri and Ban Oak forest, Binog. The high sensitivity was attributed to various stand characteristics such as low species diversity along with low species richness and total basal area (Table 1). The adaptive capacity index was low in Moist Deodar forest, Dalhousie; Ban Oak forest, Pangot; Moist Temperate Deciduous forest, Sutol and Neoza Pine forest, Akpa (Table 2) due to their low diversity and equitability (Table 1). The result showed that the four most vulnerable forests were Neoza Pine forest, Akpa; Moist Deodar forest, Dalhousie; Ban Oak forest, Pangot; and Dry Broadleaved and Coniferous forest, Kalpa and the least vulnerable forests were Moru Oak forest, Kilbury; West Himalayan Upper Oak/Fir forest, Maid; Kharsu Oak forest, Kunjkharak; Moist Temperate Deciduous, Dunagiriand Moru Oak forest, Deorital (Table 2 and Figure 2).

Table 2. Vulnerability status of different Himalayan temperate forests.

Forest Type	Exposure Index	Sensitivity Index	Adaptive Capacity Index	Vulnerability	Vulnerability Status
BOF-I	0.85	0.55	0.58	−0.03	Low
BOF-II	0.71	0.66	0.33	0.32	Most
BOF-III	1.00	0.54	0.61	−0.07	Low
DBCF	0.25	0.83	0.57	0.26	Most
DDF	0.1	0.79	0.65	0.14	Moderate
KOF	0.73	0.53	0.7	−0.17	Least
LLBPF	0.14	0.81	0.66	0.14	Moderate
MDF-I	0.71	0.68	0.73	−0.06	Low
MDF-II	0.54	0.78	0.32	0.47	Most
MOF-I	0.43	0.49	0.58	−0.08	Least
MOF-II	0.71	0.60	0.78	−0.19	Least
MTDF-I	0.56	0.61	0.35	0.25	Moderate
MTDF-II	0.76	0.54	0.64	−0.11	Least
NPF	0.16	0.98	0.36	0.63	Most
WHHLBPF	0.34	0.87	0.71	0.16	Moderate
WHUO/FF	0.54	0.48	0.66	−0.18	Least
WMCF	0.56	0.64	0.59	0.05	Low

Vulnerable status was estimated based on quartile and the classes was as Least vulnerable (upto first quartile i.e., −0.08), Low vulnerable (between first (−0.08) to second quartile (0.05)), Moderate vulnerable (between second (0.05) and third quartile (0.25)) and Most vulnerable (above the third quartile (above 0.25)).

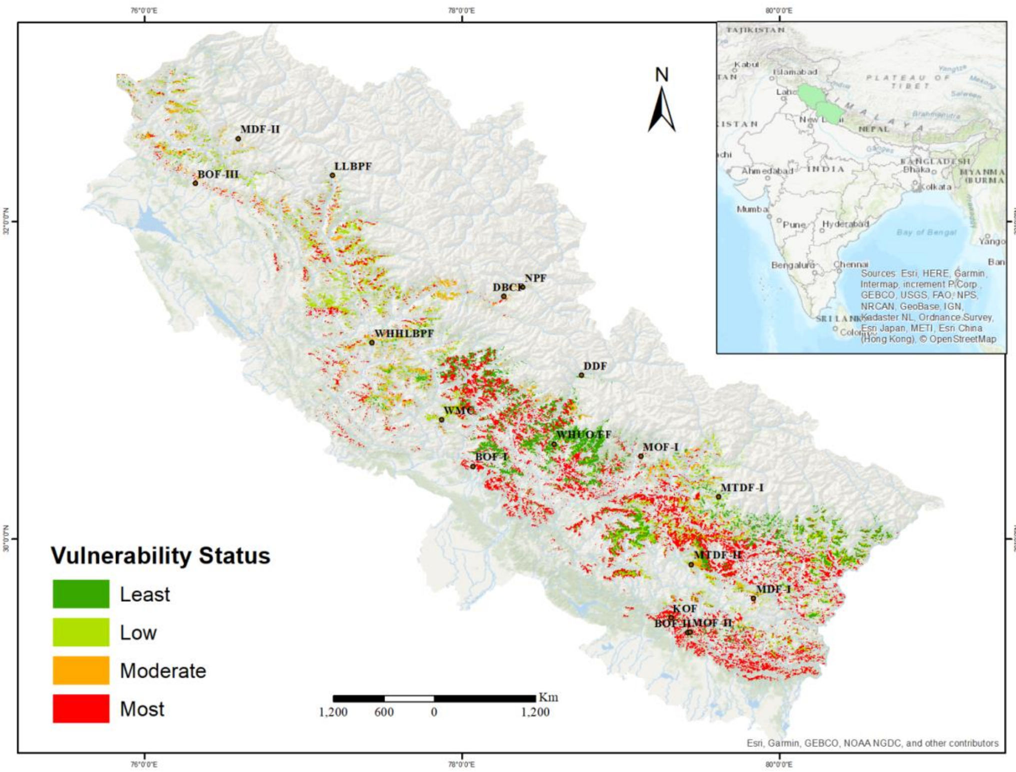

Figure 2. Vulnerability status of the selected forests.

Out of 17 sub-forest types, five were assessed as least vulnerable whereas the remaining 12 were uniformly distributed against the three higher vulnerability classes i.e., low, moderate and most as per the vulnerability classification approach mentioned in the method section. Though a varied distribution of vulnerability status of the forests with respect to elevation range was observed, Fisher's Exact test results point towards non-association between the two i.e., elevation and vulnerability status were independent to each other (Table 3).

Table 3. Association between vulnerability status with elevation range and exposure level.

Category	Vulnerability Status				Total
Elevation Range	**Least**	**Low**	**Moderate**	**Most**	
High (above 2500 m)	1	1	1	1	4
Middle (between 2000–2500 m)	3	0	3	2	8
Lower (below 2000 m)	1	3	0	1	5
Total	5	4	4	4	17
Fisher's Exact Test = 6.74 (0.33)					
Exposure Level	**Least**	**Low**	**Moderate**	**Most**	**Total**
Least	0	0	3	2	5
Low	2	0	1	1	4
Moderate	1	2	0	1	4
High	2	2	0	0	4
Total	5	4	4	4	17
Fisher's Exact Test = 11.59 (0.14)					

4. Discussion

The proposed vulnerability analysis method depicted the vulnerability status of the various sub-groups of temperate forest types on relative basis. The indices were based on the various contextual taxonomical indices, representing species richness, abundances and thereby the species composition. "Species richness of the forests signifies resource availability and increase with spatial heterogeneity and conservation practices [45,46]. However, causes of biodiversity loss are mainly anthropogenic involving over-harvesting, pollution, habitat change and climate change [47]". The study region has huge anthropogenic disturbances [48–51], moreover, changes in climate as temperature and rainfall patterns are also observed in the region [2,4].

The lower values of basal area in Dry Broadleaved and Coniferous forest, Kalpa might be due to trees with low diameter classes as well as anthropogenic disturbances as forest vegetation of Himalayas is severely affected by anthropogenic disturbances such as logging, uncontrolled grazing, lopping for firewood and fodder, and litter removal [52]. Tree with high basal area signifies the high performance of the species in specific environmental conditions, and reduced basal area suggests either the chance occurrence of a species or the occurrence of biotic disturbances in the past [53]. Accumulation of biomass and total basal area might decrease with altitude because of several factors such as low air and soil temperatures, short growing season, increased exposure to wind, and reduced nutrient supply [54]. Low species richness in the forests indicated that these sites have low resources and low spatial heterogeneity thereby restricting the establishment of other species. In contrast, the sites with more number of species and high density have high richness and in general high basal area i.e., the resource availability and heterogeneity within the forests were high therefore facilitating the establishment of other species. Forest community diversity is generally influenced by the stability or evolution time of the forest resulting in heterogeneity of micro and macro environment which affects the diversity of the community [55].

The least vulnerability in the forests of the Moru Oak forest, Deorital; West Himalayan Upper Oak/Fir forest, Maid; Kharsu Oak forest, Kunjkharak; Moist Temperate Deciduous forest, Dunagiri and Moru Oak forest, Kilbury were attributed to high diversity with high density and more number of species. More number of species and high diversity may be strengthened and made the internal ecosystem stable leading to a resilient ecosystem to the changes. The low vulnerability of the forests of Ban Oak forest, Mcleodganj; Moist Deodar forest, Jageshwar; Ban Oak forests, Binog; Western Mixed Coniferous forest, Chakrata were primarily due to low degradation and low anthropogenic disturbances besides high density along with more number of species with the high basal area. Forests with high basal area signify the high performance of the species of the forests in specific environmental conditions thereby attributing better adaptation of the species [53]. The moderate vulnerability to the forests of the Dry Deodar forest, Harshil; Low-Level Blue Pine forest, Manali; West Himalayan High Level Blue Pine forest, Narkanda and Moist Temperate Deciduous forest, Sutol was attributed to high anthropogenic pressure with relatively low density and less number of species i.e., dominated by one species on those forest patches. The most vulnerability in the forests of Dry Broadleaved and Coniferous forest, Kalpa; Ban Oak forests, Pangot; Moist Deodar forest, Dalhousie and Neoza Pine forest, Akpa were attributed to low diversity with low density i.e., sparsely distributed of single dominated species with low maturity thus low adaptability to change [56]. Moreover, the fragmentation patches also contribute to increased vulnerability as the movement of species and genes within a landscape are restricted [57], thereby the ability of forests ecosystems to maintain identity and function as the climate shifts are restricted [20]. The low basal area indicates a low occurrence of a species or biotic disturbances or both [53] thereby making the forests more vulnerable. The resilience of vulnerable forests may be increased by promoting the species and genetic diversity through the plantation of multiple use trees in a changing climate [58]. The diversity of forest community indicates the stability or evolution of the forest under the micro and macro environment heterogeneity of the forests [59] thereby facilitating for adaptation. Moreover, the attributable causes of the changes in the forests in Himalayan region are due to high dependency of the people on the forests [60]. The low vulnerability in Moru Oak forest, Deoriatal and Ban Oak forest, Binog was also due to the low external pressure in these forests being protected areas (Figure 2).

Changes in the temperature and rainfall pattern in the Himalayan temperate forests (Supplementary Materials Table S3) may be the factors, suggesting the changing pattern of species composition, distribution and structure of the forest. Moreover, shifting from a very dense forest to a moderate and open forest (Supplementary Materials Table S4) and decreasing forest area (Supplementary Materials Table S5) reflects the degradation as well as deforestation in Uttarakhand and Himachal Pradesh. Ban oak forest was designated as one of the most degraded deforested and vulnerable forests in the present study, comparable to that of the FSI report (Supplementary Materials Table S5). Forest degradation changes species composition, physico-chemical properties of soil and micro-climate of the forests community [61,62]. The finding of the present paper supports that climatic as well as anthropogenic factors are making the internal ecosystem weak and causing irreversible damage to Himalaya temperate forests and also making them vulnerable to the different stressors.

The selected temperate forests occur in a wide range of local physiographic landforms of Himalaya i.e., from rocky slopes to rolling planes. The present evaluation noted differential vulnerabilities among the selected forests. Moreover, the variability within each vulnerability status of the temperate forests was not governed by the various levels of elevation i.e., altitude of the occurrences of the forests and by the various level of exposure to climate. This might be due to the fact that forests are biological units, and various climatic and biological factors, interact in a complex way, and may counter the impacts of the altitude and exposure level i.e., species adjustments, nativeness of species, maturity and plasticity of the species may be coping with the changes and adjusting themselves for their survival. Besides, the forests adapted to the respective sites as per the availability of the resources matching with the growth of the individuals, composition and structure of the forests. The understanding of variation in habitat conditions of trees in temperate forests and their adaptation may support improved management strategies and conservation of forests over diverse habitats.

The applied vulnerability index may be used for assessing the vulnerability of forests against the changes in climate using taxonomical indices. The estimation of taxonomical indices is easy and based on actual field data about species in the forest. The actual data about the species abundance are capable of portraying the actual performance of the species occurrences, which forms the basis of the comparison of vulnerability.

5. Conclusions

The present paper highlights the vulnerability status of different temperate forests of Uttarakhand and Himachal Pradesh, India based on field measurements on the composition and distribution of species in the forests. The analysis confirms that the vulnerability of the temperate forests varies with respect to the climatic condition of the sites and variations in vulnerability status remain similar across the altitude and exposure level i.e., changes within the vulnerability levels were insignificant with elevation and climate.

The paper proposes a method for evaluation of vulnerability based on primary data on the species abundance and occurrences thereby providing support for vulnerability assessment as per the actual realisation of the exposure to the forest ecosystem.

Based on vulnerability scale, Neoza Pine forest; Akpa; Moist Deodar Forest; Dalhousie; Ban Oak Forest, Pangot and Dry Broadleaved and Coniferous Forest, Kalpa was prone to change in species composition and hence affect ecosystem functioning and services of these forest communities in the future if appropriate measures would not be implemented.

The information from the analysis raises an urgent call to stakeholders for sustainable conservation and management of the forest. Overall the changes may be addressed by managing the forests through adequate protection by reducing anthropogenic pressures and supplementing supportive programs for forest improvement in terms of species density and composition.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f13060848/s1. Supplementary Table S1: Details of selected Forest Type Group in Uttarakhand and Himachal Pradesh; Supplementary Table S2: Site description of selected Forest Type Group in Uttarakhand and Himachal Pradesh; Supplementary Table S3: Spatio-temporal details of climatic parameters of study sites; Supplementary Table S4: Forest cover of Uttarakhand and Himachal Pradesh (at 1000–3000 m amsl elevation); and Supplementary Table S5: Change in forest area under different temperate forest types of Uttarakhand and Himachal Pradesh.

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