Maling Bamboo (*Yushania Maling)* Overdominance Alters Forest Structure and Composition in Khangchendzonga Landscape, Eastern Himalaya

Kailash Gaira
G.B. Pant Institute of Himalayan Environment and Development
Aseesh Pandey (draseeshpandey@gmail.com)
G.B. Pant Institute of Himalayan Environment and Development
Sheila Sinha
G.B. Pant Institute of Himalayan Environment and Development
Hemant Badola
G.B. Pant Institute of Himalayan Environment and Development
Jhony Lepcha
G.B. Pant Institute of Himalayan Environment and Development
Pitamber P. Dhyani
G.B. Pant Institute of Himalayan Environment and Development
Nakul Chettri
International Centre for Integrated Mountain Development

Research Article

Keywords: Yushania maling, Eastern Himalaya, Forest composition, Generalized Additive Model, Singalila National Park

Posted Date: October 26th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-989148/v1

Version of Record: A version of this preprint was published at Scientific Reports on March 16th, 2022. See the published version at https://doi.org/10.1038/s41598-022-08483-8.

Abstract

The Khangchendzonga Landscape (KL), a part of 'Himalayan Biodiversity Hotspot', is known for its unique biodiversity. In recent years the KL experiencing threats to biodiversity due to biological overdominance of native species such as Maling bamboo (*Yushania maling*). In the present study, we investigated the impacts of the overdominance of *Y. maling* on the forest composition of Singalila National Park (SNP), Eastern Himalaya, India. Elevational habitats 2400 to 3400 m asl were surveyed by laying 69 (10m x 10m) forest plots including 51 bamboo plots and 18 non-bamboo plots. Bamboo plots showed significantly ($p<0.05$) low species richness and density in both shrub and herb layers which further manifested the low seedling density. Generalized Additive Model (GAM) estimated a significant ($p<0.0001$) decline in species richness and density with increasing bamboo density in SNP. Our study projects the overdominance of *Y. maling* has a significant negative impact on forest structure and composition. Therefore, management of invasiveness of *Y. maling* is essential through its optimized removal and utilization in handicrafts to create ecological and economic benefits. Further long-term studies assessing the impacts of *Y. maling* overdominance on forest ecosystems and soil dynamics are recommended.

Introduction

Biodiversity provides numerous essential services to society; the survival and socio-economic activities of people largely depend upon various natural resources. Forests, hitherto, are considered to provide renewable resources and ecosystem services that support life on the planet [1–3]. However, invasion of invasive alien species [4–6] and over expansion/dominance of native plant species[7–9] alter the composition and structures of natural forests, which mostly manifested by the loss of biodiversity at the global scale[10]. Besides, an overabundance of native herbaceous species can appear as dominant element in the forest ecosystem[11,12]. That may disturb the composition and dynamics of the forest ecosystem adversely. However, some studies revealed that the expansion of bamboo has altered the overall forest composition and dynamics in many areas [6,13,14,15].

Bamboo, the fastest growing plant also referred as 'green gold', offers incredible economic, cultural and ecological benefits. Owing to its cheap and plentiful availability, bamboo is also known as 'poor man's timber'[16] and especially used as a substitute of the wood[17] and as food product in numerous cases for human[18–20] and wildlife[21,22]. Communities extensively use bamboos, for various household purposes such as supporting poles, flooring, frames, partitions, ceiling, walls, thatching, tying, roofing, making doors and windows frames, etc. [23,24]. Various traditional items and modern decorative are crafted from bamboos. Worldwide, they represented by about 1400 species and 107 genera, consisted 79 genera representing 1200 species of woody bamboo, and 28 genera representing 180 species of herbaceous bamboo[6]. India stands second largest diversity center for bamboos after China[25] and possess over 8.96 million ha of bamboo, occupying 12.8% of the total forest cover (Planning Commission, 2005). Over 84 bamboo species are found in Northeastern Himalaya (India) alone[19,26]. Bamboo inhabits a wide range of ecosystems along sea level to 4000 m asl. and often questioned for its contribution in population dynamics in plant communities[15]. The uncontrolled expansion/ invasion/overdominance of bamboo in Eastern Asia has led to the formation of ‘bamboo forests’[27,28] that can remodel the entire structure and composition of the native forests. Similarly, in parts of India, bamboo overdominance is a concern. A native reed bamboo (*Ochlandra travancorica*) has threatened 20.8% of evergreen forests in Western Ghats, similarly *Yushania maling*, a native bamboo species has become alarmingly invasive in Darjeeling Himalaya[29].

Yushania maling (Gamble) R.B. Majumdar & Karthik. previously known as *Arundinaria maling* Gamble (Family: Poaceae; Sub family: Bambusoideae), is a native bamboo species of temperate zones in eastern Himalaya, having a wide elevation range c.a.1800 to 3600 m [29,30]. Recent MaxEnt, GARP based remote sensing studies in parts of Eastern Himalaya, India indicated its gregarious colonization in the temperate coniferous and temperate broadleaf forests[29].This plant generally grows in clumps (sympodial growth habit) and attains a height upto 2.5-3m. However, unlike regular clumping bamboos, it develops wider spreading rhizomes, which makes it an invasive semi-running bamboo, which ultimately expected to excludenative species by outgrowing them[31,29].Due to its invasive nature *Y. maling* has become a threat to protect areas where native species are conserved.

Keeping above in view, we conducted the study in bamboo rich protected area, Singalila National Park (SNP) in Khangchendzonga Landscape (KL), Indian eastern Himalaya. We studied, whether invasiveness of *Y. maling* has any significant effect on the forest composition in SNP? Therefore, our study in SNP focused to: i) compare species (trees, shrubs and herbs) composition in bamboo and non-bamboo plots, and ii) estimate the changes in forest composition (species richness and density) due to overdominance of native bamboo species *Y. maling*.

Results

Along the Gorkhey-Phalut transect (2400m to 3600m asl) in SNP, KL (India),we observed three major vegetation types, viz. temperate broad-leaved forest, temperate coniferous broad-leaved forest, and subalpine vegetation, in general. Wherein, the *Quercus lineata, Quercus thomsoniana* and *Quercus lamellosa* with *Symplocos sp.*, *Eurya sp.* and *Rhododendron arboreum*, were dominant between 2400 m and 2800 m asl, whereas, *Rhododendron arboreum* in association with *Vitex heterophylla* dominated from 3000 m to 3100 m asl. Different species of *Rhododendron* were observed in association with *Abies densa* from 3200m to 3400m asl, while scrubs of *Rhododendron lepidotum* and shrubberies of *Gaultheria* spp. were dominated in the subalpine vegetation at above 3400m asl. In addition, we observed *Aconogonum molle*, *Rubus* spp., *Berberis* spp., and *Osbekia* spp. as dominant shrubs and species of *Carex, Plantago, Anaphalis, Swertia, Polygonum*, and *Impetians* as dominant herbs. Along the transect, the shoots of *Y. maling* (bamboo) were observed with high frequency (mean density = 300±33 per $100m^2$) upto 3400 m asl across the transect; wherein, as such no prominent distinction of the species availability was observed among bamboo and non-bamboo plots.

To understand the species composition along elevation, the GAM estimated a significant ($p< 0.001$) increase in species richness for shrubs (β = 0.0013; SE=0.0006), herbs (β = 0.0017; SE= 0.0008) and tree seedlings (β = 0.0066; SE= 0.0005) along elevation, whereas a significant ($p< 0.001$) decrease indicated for tree saplings (β= -0.0017; SE= 0.001). However, tree layer richness was seemingly unaffected along elevation (Table 1). A significant ($p< 0.001$) increase in species density for trees (β = 0.005; SE= 0.001), shrubs (β = 0.011; SE= 0.002), herbs (β = 0.650; SE= 0.017), and tree seedlings (β = 0.195; SE= 0.006) was estimated along the elevation. However, a significant decline ($p <0.001$) was estimated in species density for tree saplings (β=-0.019; SE= 0.002) and bamboo (*Y. maling*) culms (β= -0.33; SE= 0.003) along the elevation.

We compared the species composition, i.e. species richness and density between bamboo and non-bamboo plots (Table 2). Our results showed significantly ($p<0.0001$) low species richness of shrubs (1.39±0.14) and herbs (3.80±0.39) in the bamboo plots as compared to non-bamboo plots (4.22±0.48 shrubs and 6.44±0.67 herbs) respectively. Similarly, we observed significant ($p<0.01$) low average density of shrubs (14.27±2.60 individual) and herbs (1710.78±328.4825 individual) in bamboo plots as compared to non-bamboo plots (79.11±22.82 shrubs and 3936.11±912.77herbs) respectively. We found significantly lower ($p<0.0001$) tree seedlings' richness (1.00±0.16) in bamboo plots than those in non-bamboo plots (2.67±0.21) (Table 3). We also observed lower tree seedlings' density (130.39±24.70 individual/100m^2) in bamboo plots than non-bamboo plots (444.44±41.60 individual/ 100m^2).

Concerning the bamboo shoot density across the plots, we estimated the changes in species richness for trees, shrubs, and herbs (Table 4). Our results projected significantly ($p<0.0001$) declining trends for shrubs (β= -0.0026; SE = 0.0005; R^2 = 53.61) and a non significant decline for herbs (Fig. 2) with increasing bamboo density. Similarly, the density indicated declining trends significantly ($p<0.001$) for shrubs (β= -0.029; SE= 0.0013; R^2 = 43.94) and herbs (β= -1.956; SE= 0.013; R^2 = 57.03) (Fig. 3). The model predicted a significant decrease in the richness of shrubs (2-3 species) with an increase of 1000 shoots of bamboo per 100 m^2 area (Table 4). Also, the model projected significant decline in species density with increasing 1000 shoots of bamboo for shrubs (28-30 individual) and herbs (1943-1969 individual) per 100m^2 area. Nevertheless, we did not observe the trends for a change in the species richness of trees and herbs, and density of trees ($p>0.05$), which indicates recent overdominance of *Y. maling* in the area.

The GAMs projected the species richness and density of tree saplings and seedlings along with the bamboo (shoot) density (Table 5). GAM showed a non-significant decline in the species richness of tree saplings (β= -0.0024; SE = 0.0002; R^2 = 22.70) and a significant ($p<0.00001$) decline seedlings (β= -0.0014; SE = 0.0002; R^2 = 45.57) (Fig. 4). Similarly, the density of tree saplings (β= -0.024; SE = 0.0007; R^2 = 23.41) and seedlings (β= -0.143; SE = 0.002; R^2 = 55.92) were observed decreasing significantly ($p<0.0001$) with increasing density of bamboo (shoots) (Fig. 5). Our model predicted a decrease in tree seedlings (1-2 species) richness with an increase of 1000 shoots of bamboo per 100 m^2. Similarly, tree saplings (23-25 individual) and seedlings (141-145 individual) density were projected as decrease with an increase of 1000 shoots of bamboo per 100 m^2.

Discussion

In our study in SNP, the plots invaded by bamboo (*Y. maling*) showed the low species richness and density of the shrubs, herbs, and tree seedlings as compared to the non-bamboo plots. These results indicate that the abundance of bamboo restricts the richness and density of the shrubs and herbs species and hinders tree regeneration in the forests. A supportive study on the expansion of dwarf bamboo in Japan[9] showed the negative relationship between bamboo density and herb species richness. Also, studies have suggested altering forest structure and dynamics, revealing lower density of trees and lower species diversity, by the overabundance of bamboo in Brazilian Atlantic forest[15]. Such evidences signify that the high degree of bamboo dominance over a long period may effectively alters the forest composition and structures.

Our analysis of the effect of the bamboo overdominance on the forest composition in SNP and the results drawn from GAM vividly estimated the significant decline in the richness of shrubs and herbs and further predicted that, with increasing 1000 shoots of bamboo per 100 m^2, there would be an adverse change in the species richness of shrubs (2-3 species). Also, changes in the richness of tree seedlings, (1-2 species) were estimated with 1000 shoots of bamboo. Similarly, disadvantageous changes of density of shrubs (28-30 individual) and herbs (1943-1969 individual), tree saplings (23-25 individual) and tree seedlings (141-145 individual) were estimated with increasing the 1000 shoots of bamboo in 100m^2 area significantly. The GAMs predictions indicate that the abundance of bamboo has negatively influenced the richness of shrubs, herbs and tree saplings and tree seedlings. Concurrently, the density of shrubs, herbs, tree saplings and tree seedlings in SNP, as the physical and physiological stresses of bamboo, may cause the reduction of the tree seedlings' richness[15]. Further, it is suggested that the dominance of bamboo reduces the tree regeneration and the undergrowth vegetation, and their thick layer of litter affects the tree seedling regeneration negatively causing alternations in the plant community composition and species diversity[32]. Another supportive study from Southwest China suggested that the high density of bamboo *Fargesia nitida* greatly decrease understory species richness especially shrubs[33] (Tao et al. 2012). However, the expansion of a dominant native species may threaten other native forest species and enables invasion of non-native species in herbs and shrubs layers[7].

The rapid overdominance of bamboo species (*Y. maling*) in SNP has consequently indicated the alteration in forest composition when compared with non-bamboo plots. Here, we recorded the widespread extension of bamboo reaching upto 3300 m asl, which is commonly observed in the Temperate broadleaved forests, and expanded across the Temperate Coniferous broad-leaved forests. We observed excellent bamboo growth under tree species like *Quercus* spp., *Rhododendron* spp., *Eurya* spp., *Symploccus* spp., *Vitex heterophyllum* and *Abies densa* accompanying various shrub species because of its tremendous adaptability and excellent resource use (light) capability in different habitats[34]. They expand through their rhizomes and survive over several decades in many forest types and thus have raised concerns about the regeneration of tree seedlings and the diversity of shrubberies and herbaceous species[13, 35,36,37]. Consequently, some studies have suggested controlling and managing the invasion of bamboos by applying moderate grazing. That can control forest structures to some extent thereby reducing the density and height of the bamboos and creating favourable conditions for the regeneration of other species[35,38,39].

Additionally, our results reveal a positive alteration in species richness of shrubs, herbs, and tree seedlings and in density of tree, shrubs, herbs and tree seedlings while, negative change in tree saplings richness and density of tree saplings and bamboo (stems). Previous study from similar region resulted negative correlation between species richness of woody species and elevation[40] however, contradictory results as adverse change in species richness along the elevation emerged from the mountains of China[41]. The change in species richness and density may be due to difference in climatic, physiographic and edaphic factors [2,42].

In general, bamboos offer major ecosystem services, providing livelihood opportunities and supplying food resources to humans and wild fauna. These uses are wide-ranging, like tender shoots eaten as vegetable, the leaves for fodder to cattle and as important food to the wild animals especially for the endangered animal Red panda (*Ailurus fulgens*) [21,22] and the Himalayan black Bear (*Selenarctos thibetanus*) in SNP. The bamboo seeds and young shoots are the good food resources for wild herbivores[43,44]. Also, the species offers various uses in constructive purposes, linking directly to the livelihood of the forest fringe communities. Simultaneously, bamboo may provide opportunities for carbon farming and carbon trading[16,45] and supports the increasing organic matters in soil[46]. Nonetheless, as per the National Park rule and regulations, the community people around SNP are restricted to use bamboo and other resources for the commercial purposes. The invasiveness of native bamboo species (*Y. maling*) in SNP might have resulted, due to, i) ban on grazing and shifting shepherd communities outside the park area, ii) restriction on harvesting bio-resources for the forest fringe communities, iii) global climate change, and iv) limited management measures, etc.

The management of bamboos by controlling their expansion in the areas of high bamboo density could be an appropriate forest restoration approach. It is understood that the bamboos have great potential for the rapid growth and forming complex dominant structures in the forests. The sustainable utilization of bamboos by the local communities would be suggestive especially in the PAs, not only in Darjeeling Himalaya but also in the entire eastern Himalayan forests. Such uses of bamboos can be encouraged, in order to, i) limit its uncontrolled extension further inside the forests, ii) decrease extraction pressure in other forest wood species, iii) revitalize the local bamboo-based traditional handicrafts and linking with livelihood alternatives and iv) remove bamboo clumps form affected areas, which can be used as a planting material in waste land restoration purpose. Besides, the growing ecotourism in the region demands the supply of various ethnic products for which the bamboo resources become the best option as an alternative livelihood. The bamboo should be used in such a way that the negative impacts of its current expansion on the other species could be limited.

Based on the information gathered from our case study from Khangchendzonga Landscape-India, appropriate management plans need to be developed, focusing on its sustainable harvesting system and identifying the threshold levels of extraction for conservation and sustainable utilization approaches. Furthermore, we suggest in-depth further studies on, i) bamboo-based forest community structures and dynamics, ii) changing the intensity of bamboos community growth with respect to climate change, iii) monitoring ecological resilience with respect to the bamboos plantation and cultivation, and iv) integrating mechanism of sustainable utilization of bamboo by the communities around PAs.

Methods

Study Site

The Khangchendzonga Landscape (KL) [26°21'40.49" and 28°7'51.25" E latitude and 87°30'30.67" and 90°24'31.18" N longitude], delineated in January 2014, extends from the southern stretch of Mount Khangchendzonga (8,586 m asl) and spreads over varied ecological zones in eastern Nepal, Sikkim and northern West Bengal in India and western Bhutan. The Landscape covers the significant region of Eastern Himalaya from 40 m asl upto 8,586 m asl [47]. Covering spatial area of 14,126.36 km^2, the Indian part of KL includes 17 protected areas (PAs), of which four PAs have transboundary settings with neighbouring countries. Our study site, Singalila National Park (SNP), covers an area of 79 km^2, extending within 27°13' 15" N and 22°1'46" N latitude and 83°1'91" to 38°7'54"E longitude. SNP lies in transboundary with Nepal and India, and its northern part borders with Barsey Rhododendron Sanctuary of Sikkim. The study site represents sub-tropical to sub-alpine eco-climatic zones (2200m to 3668m asl) along the trekking corridor from the Gorkhey forest village to Phalut (Fig. 1). The diversified eco-climatic ranges provide various broad habitats and numerous microhabitats harboring the inclusive floral and faunal diversity. A prior permission to conduct this study was taken from the Department of Forests, West Bengal and all rules and regulations of protected areas (National Park) were followed during the study.

Sampling design

The study was undertaken along the stretch of 2400 m asl to 3400 m asl (temperate to sub-alpine zone) in SNP, across the Gorkhey-Phalut trekking corridor. In the region below 2400 m, the bamboo growth was sparse due to the anthropogenic activity including the extent of agricultural fields and the use of bamboo for various purposes by the people of the fringe villages. Along this elevation, we randomly sampled 69 plots to assess the community structure of the vegetation (tree, shrub and herbaceous species) within the assemblage of *Y. maling*, as the major understory growth including both bamboo and non-bamboo areas. We adopted nested quadrat method for the study of species richness and density of trees, shrubs, herbs, tree saplings and tree seedlings within identified plots. We studied the tree species in 0.1 hactare (10m x10m) plots, within which 25m^2 (5m x 5m) plots exactly in the middle were selected to study shrubs, bamboos, and tree saplings. We laid two quadrats m^2 (1m x1m) each in the alternative corners of the major plot to study tree seedlings and other herbaceous species. We considered mature trees having the girth size ≥ 31cm (girth at breast height; 1.3cm above the ground level); the saplings having girth of ≤ 31cm to ≥10 cm, while we regarded seedlings having collar girth <10 cm at the height of 1cm from the ground level. In all the plots, we recorded total number and the respective diameters of each tree. To understand the bamboo density responses over other forest communities (trees, shrubs, herbs, including seedling and sapling of trees), we recorded it in each random plot. Out of 69 major 0.1 ha plots, 51 were recognized with the occurrence of bamboo species and 18 plots without any presence of *Y. maling*. For the quantitative measure of species richness (tree, shrub, herb, sapling, and seedling) was calculated as the number of species per unit area [48]. We measured the density (number of individuals per unit area) for tree, shrub, herb, tree sapling, and tree seedling, simultaneously with *Y. maling* density. For bamboo density, shoots/culms were counted from each sampled plot.

Statistical analysis

Realizing the asymmetrical data structure (Non-Normal), we transformed the recorded data into arcsine format and applied independent sample t-test for comparing the mean of diversity and density of the trees, shrubs, herbs, and seedlings and saplings of trees between bamboo and non-bamboo plots. Finally, we retransformed the analysed arcsine data presented in the tables for interpretation.

To deal with nonparametric statistical analysis, Generalized Additive Model (GAM) was considered exceedingly suitable for ecological studies[49,50]. The GAM is a semi-parametric extension of GLM[51] and deals with highly non-linear and non-normal relationships between the response and the set of explanatory variables[52]. GAM includes the estimation of smoothing terms in the additive model and general algorithm added in the model as partial residuals (i.e. R_j^{th} set of partial residuals).

$$R_{ji} = Y - S_0 - \sum_{h \neq j} S_k(X_k)$$

The partial residuals remove the effects of all the other variables from *Y* (depended variable i.e. richness and density of trees, shrubs, herbs, and saplings and seedlings of trees); therefore, the *Y* can be used to model the effects against X_j (density of bamboo- *Y. maling* for all studied plots including non-bamboo plots as zero quantitative value). However, due to ranging wider variability and inconsistence series of data, the variables under study were indicated non-normal and non-linear data structure.

Declarations

Authors declare no any competing interests to disclose related to the work submitted for publication.

Acknowledgements

We highly thank the Director of the Institute (NIHE) for providing necessary facilities and consistent supports. Also, we thank the Regional Head, Sikkim Regional Centre for consistent encouragement. We deeply appreciate the Directorate of Forest, West Bengal for providing permission to conduct this study and support during the field studies. We gratefully acknowledge the financial support from the International Centre for Integrated Mountain Development (ICIMOD), Nepal under Khangchendzonga Landscape Conservation and Development Initiative (KLCDI) programme.

Author’s Contribution

KSG, HKB designed the study, JL, SS, KSG, conducted filed exploration, KSG, SS, AP wrote the initial manuscript and analyzed the data, AP, NC reviewed and revised the manuscript draft, PPD provided support for the study.

References

1. Badola, H.K. & Aitken, S. Potential biological resources for poverty alleviation in Indian Himalaya. *Biodiver*. 11(3-4): 8-18 (2010).
2. Pandey, A., Badola, H. K., Rai, S., & Singh, S. P. Timberline structure and woody taxa regeneration towards treeline along latitudinal gradients in Khangchendzonga National Park, Eastern Himalaya. *PloS one*, 13(11), e0207762(2018).
3. Isbell, F., Gonzalez, A., Loreau, M., Cowles, J., Díaz, S., Hector, A., Mace, G.M., Wardle, D.A., et al. Linking the influence and dependence of people on biodiversity across scales. *Nature* doi:10.1038/nature22899 (2017).
4. Hansen, A.J., Neilson, R.P., Dale, V.H., Flather, C.H., Iverson, L.R., Currie, D.J., Shafer, S., Cook, R. & Bartlein, P.J. Global change in forests: Responses of species, communities, and biomes. Bio-Sciences 51:765–779 (2001).
5. Gooden, B., French, K.O. & Turner, P. Invasion and management of a woody plant, *Lantana camara* L., alters vegetation diversity within wet sclerophyll forest in southeastern Australia. *For Ecol Manag* 257 (3):960-967 (2009).
6. Xu, Q., Liang, C., Chen, J., Li, Y., Qin, H. & Fuhrmann, J.J. Rapid bamboo invasion (expansion) and its effects on biodiversity and soil processes. *Global Ecol Cons* https://doi.org/10.1016/j.gecco.2019.e00787 (2020).
7. Dhar, U., Rawal, R.S. & Samant, S.S. Structural diversity and representativeness of forest vegetation in a protected area of Kumaun Himalaya, India: implications for conservation. *Biodiver Cons* 6:1045-1062 (1997).
8. Mack, R.N., Simberloff, D., Mark, L.W., Evans, H., Clout, M. & Bazzaz, F.A. Biotic invasions: causes, epidemiology, global consequences, and control. *Ecol Application* 10(3):689-710 (2000).
9. Tomimatsu, H., Yamagishi, K., Tanaka, I., Sato, M., Kondo, R. & Konno, Y. Consequences of forest fragmentation in an understory plant community: extensive range expansion of native dwarf

bamboo. *Plant Species Biol* 26:3-12(2011).

10. Sala, O.E., Chapin III, S.F., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., et al. Global biodiversity scenarios for the year 2100. *Science* 287:1770 –1774(2000).
11. Royo, A.A., Carson, W.P. On the formation of dense understory layers in forests worldwide: consequences and implications for forest dynamics, biodiversity, and succession. *Canadian J For Res* 36:1345–1362 (2006).
12. Royo, A.A., Stout, S. L. & Pierson, T.G. Restoring forest herb communities through landscape-level deer herd reductions: is recovery limited by legacy effects? *Biol Cons* 143:2425–2434 (2010).
13. Taylor, A.H., Jinyan, H. & ShiQiang, Z. Canopy tree development and undergrowth bamboo dynamics in old-growth *Abies–Betula* forests in southwestern China: a 12-year study. *For Ecol Manag* 200(1): 347-360(2004).
14. Zhou, X., Chen, L. & Lin, Q. Effects of Chemical Foaming Agents on the Physico-Mechanical Properties and Rheological Behavior of Bamboo Powder-Polypropylene Foamed Composites. *Bio Resources* 7(2):2183-2198(2012).
15. R.A. Lima, D.C. Rother, A.E. Muler, I.F. Lepsch, R.R. Rodrigues Bamboo overabundance alters forest structure and dynamics in the Atlantic Forest hotspot *Biol Conserv* 147 32-39(2012)
16. Tariyal, K. Bamboo as a successful carbon sequestration substrate in Uttarakhand: A brief analysis. *Int J Curr Adv Res* 5(4): 736-738(2016).
17. Badoni, A.K., Badola, H. K. & Sharma, S.P. Inter-disciplinary approach towards environmental management: A case study with wild bamboos in Garhwal Himalayas, In: Prakash R (Ed), Editor. Advances in Forestry Research in India, Vol. III, Intl. Book Distrib., Dehradun. pp 261-280 (1989).
18. Bahadur, K.N. Bamboos in the service of man. *Biol Contemp J* 1(2):69-72(1974).
19. Tomar, J.M.S., Hore, D.K. & Annadurai, A. Bamboos and their conservation in North-East India. *Indian For* 135(6): 817-824(2009).
20. Kumar, P.S., Kumari, K.U., Devi, M.P., Choudhary, V.K. & Sangeetha, A. Bamboo shoot as a source of nutraceuticals and bioactive compounds: a review. *Indian J Nat Pro Res* 8(1):32-46 (2016).
21. Pradhan, S., Saha, G.K. & Khan, J.A. Ecology of the red panda *Ailurus fulgens* in the Singhalila National Park, Darjeeling, India. *Biol Cons* 98(1):11-18(2001).
22. Dorji, S., Vernes, K. & Rajaratnam. Habitat correlates of the Red Panda in the temperate forests of Bhutan. *PLoS ONE*610:1-11 (2011).
23. Mohan Ram, H.Y. & Tandon, R. Bamboos and Rattans– From Riches to Rags. *Proc Nat Sci Acad India* 63(3):245-267(1997).
24. Sharma, R., Wahono, J. & Baral, H. Bamboo as an alternative bioenergy crop and powerful ally for land restoration in Indonesia. *Sustainability* 10:4367 (2018).
25. Seethalakshmi, K.K. & Kumar, M.S.M. Bamboos of India: A Compendium. Bamboo Information Center, India, Kerala Forest Research Institute, Peechi and International Network for Bamboo and

Ratten, Beijing (1998).

26. Sarmah, A., Thomas, S., Goswami, M., Haridashan, K., Borthakur, S.K. Rattan and bamboo flora of North-East India in a conservation perspective. In: Arunachalan A, Khan ML, (Eds). Sustainable Management of Forests. International Book Distributors, Dehradun, India. pp 37–45 (2000).
27. Taylor, A.H. & Zisheng, Q. Culm dynamics and dry matter production of bamboos in the Wolong and Tangjiahe giant panda reserves, Sichuan, China. *J Applied Ecol* 24:419–433(1987).
28. Okutomi, K., Shinoda, S. & Fukuda, H. Causal analysis of the invasion of broadleaved forest by bamboo in Japan. *J Vegetation Sci* 7:723–728(1996).
29. Srivastava, V., Griess, V.C. & Padalia, H. Mapping invasion potential using ensemble modelling. A case study on *Yushania maling* in the Darjeeling Himalayas. *Ecol Model* 385:35-44 (2018).
30. Roy, A., Bhattacharya, S., Ramprakash, M. & Kumar, A.S. Modelling critical patches of connectivity for invasive Maling bamboo (*Yushania maling*) in Darjeeling Himalayas using graph theoretic approach. *Ecol Model* 329:77-85 (2016).
31. Stapleton, C.M.A. The morphology of woody bamboos. LinneanSocietySymposium Series 19. Academic Press Limited, pp. 251–268 (1997).
32. Larpkern, P., Mor, S.R. & Totland, Q. Bamboo dominance reduces tree regeneration in a disturbed tropical forest. *Oecologia* 165(1):161-168 (2011).
33. Tao, J.P., Shi, X.P. & Wang, Y.J. Effects of different bamboo densities on understory species diversity and trees regeneration in an *Abiesfaxonian*a forest, Southwest China. *Scientific Res Essays* 7:660-668(2012).
34. Wang, W., Franklin, S.B., Ren, Y. & Ouellette, J.R. Growth of bamboo *Fargesiaqinlingensis* and regeneration of trees in a mixed hardwood-conifer forest in the Qinling Mountains, China. *For Ecol Manag* 234(1-3): 107-115(2006).
35. Gratzer, G., Rai, P.B. & Glatzel, G. The influence of the bamboo *Yushaniamicrophylla* on regeneration of *Abies densa* in central Bhutan. *Canadian J For Res* 29:1518-1527 (1999).
36. Takahashi, K., Uemura, S., Suzuki, J.I. & Hara, T. Effect of understory dwarf bamboo on soil water and the growth of overstory trees in a dense secondary *Betula ermanii* forest, northern Japan. *Ecol Res* 18(6):767-774 (2003).
37. Ito, H. & Hino, T. Effects of deer, mice and dwarf bamboo on the emergence, survival and growth of *Abieshomolepis* (Piceaceae) seedlings. *Ecol Res* 19 (2):217-223(2004).
38. Tenzin, K. & Rinzin. Impact of livestock grazing on the regeneration of some major species of plants in conifer forest. RNR-RC, Jakar, Bumthang, Bhutan (2003).
39. Darabant, A., Rai, P.B., Tenzin, K., Roder, W. & Gratzer, G. Cattle grazing facilitates tree regeneration in a conifer forest with palatable bamboo understory. *For Ecol Manag* 252(1-3): 73-83(2007).
40. Sinha, S., Badola, H.K., Chhetri, B., Gaira, K.S., Lepcha, J. & Dhyani, P.P. Effect of altitude and climate in shaping the forest compositions of Singalila National Park in Khangchendzonga Landscape, Eastern Himalaya, India. *J Asia-Pacific Biodiver*11(2): 267-275(2018).

41. Zhang, W., Huang, D., Wang, R., Liu, J. & Du, N. Altitudinal Patterns of Species Diversity and Phylogenetic Diversity across Temperate Mountain Forests of Northern China. *PLoS ONE* 11(7): e0159995. doi:10.1371/journal.pone.0159995 (2016).
42. Sharma, C.M., Mishra, A.K., Tiwari, O.P., Krishna, R., Rana, Y.S. Effect of altitudinal gradients on forest structure and composition on ridge tops in Garhwal Himalaya. *Energ Ecol Environ* (2017) 2(6):404–417. DOI 10.1007/s40974-017-0067-6(2016)
43. Silveira, M. Ecological aspects of bamboo-dominated forests in southwestern Amazonia: an ethnoscience perspective. *Ecotropica* 5:213-216 (1999).
44. Franklin, D.C. Vegetation phenology and growth of a facultatively deciduous bamboo in a monsoonal climate. *Biotropica* 37:343-350 (2005).
45. Nath, A.N., Lal, R. & Das, A.K. Managing woody bamboos for carbon farming and carbon trading. *Global Ecol Con*s 3:654–663(2015).
46. Venkatesh, M.S., Bhatt, B.P., Kumar, K., Majumdar, B. & Singh, K. Soil properties as influenced by some important edible bamboo species in the North Eastern Himalayan region. *Indian J Bamboo Rattan* 4(3): 221-230 (2005).
47. ICIMOD, WCD, GBPNIHESD, RECAST Kangchenjunga landscape feasibility assessment report. ICIMOD Working Paper 2017/9. Kathmandu: ICIMOD (2017).
48. de Bello, F., Leps, J. & Sebastia, M.T. Variations in species and functional plant diversity along climatic and grazing gradients. *Ecograph* 29: 801-810(2006).
49. Hastie, T.J. & Tibshirani, R.J. Generalized additive models. Chapman and Hall, New York (1990).
50. Guisan, A., Edwards, T.C. Jr. & Hastie, T. Generalized linear and generalized additive models in studies of species distributions: setting the scene. *Ecol Model* 157:89–100(2002).
51. McCullagh, P. & Nelder, J.A. Generalized linear models, 2nd edn. Chapman and Hall, London (1989)
52. Gaira, K.S., Dhar, U. & Belwal, O.K. Potential of herbarium records to sequence phenological pattern: a case study of *Aconitum heterophyllum* in the Himalaya. *Biodiver Cons* 20:2201–2210 (2011).

Tables

Due to technical limitations, tables are only available as a download in the Supplemental Files section.

Figures

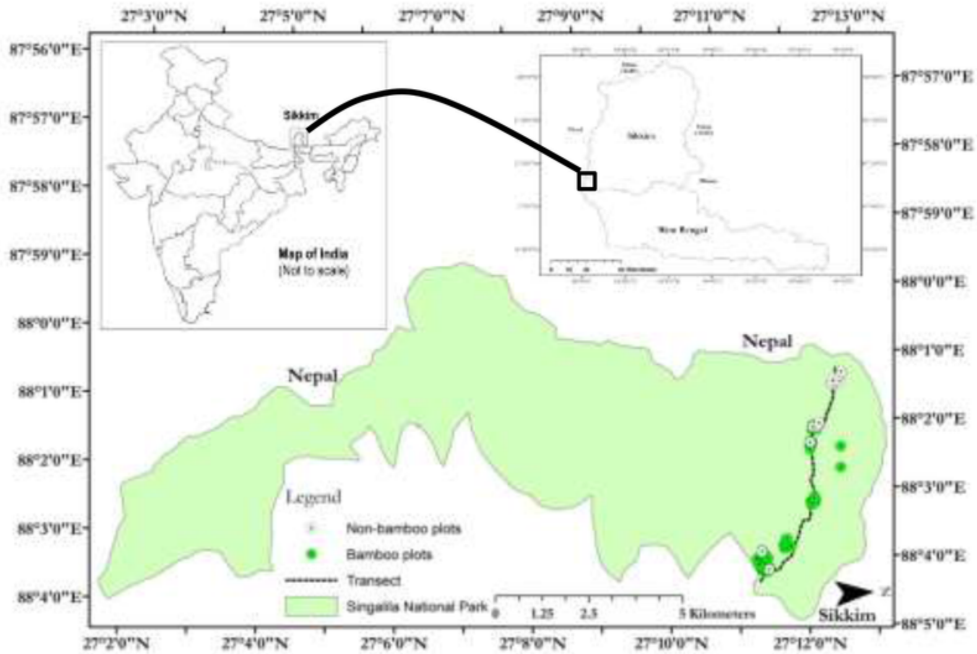

Fig. 1

Figure 1

Transect study and location map of SNP under KL-India

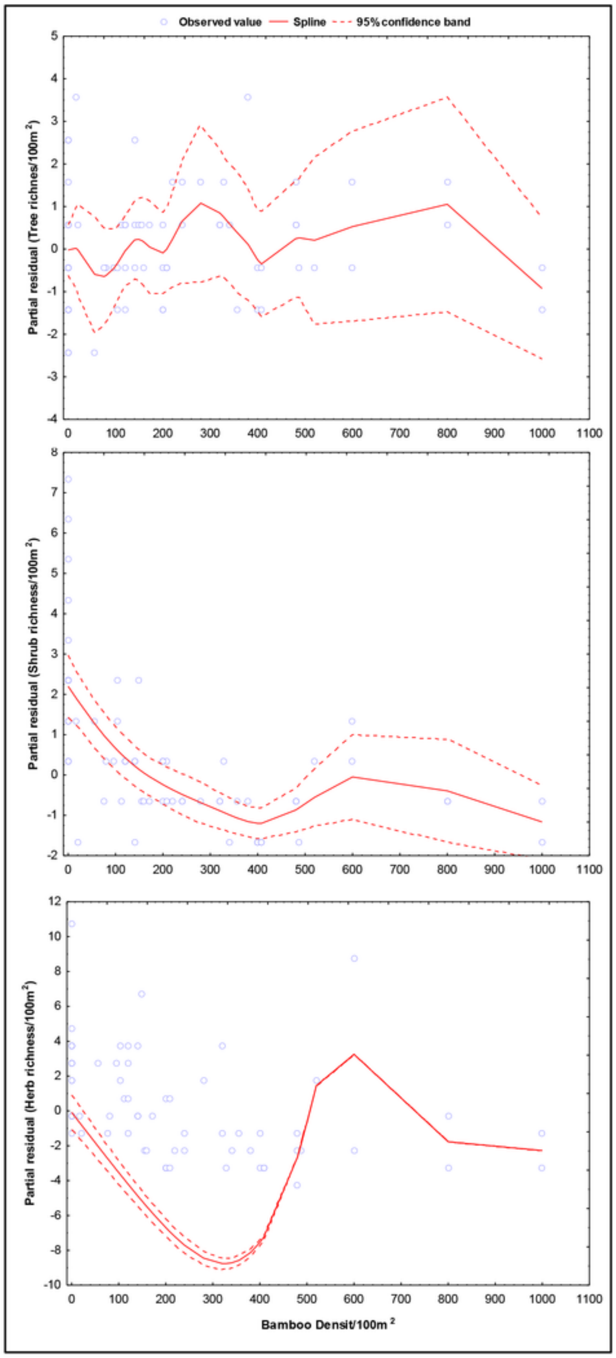

Fig. 2

Figure 2

Predicted changes in species richness of trees, shrubs and herbs with respect to increasing density of bamboo. The significance of the smooth best fit model generalized the changing slope as GAM coefficient (β), standard error (SE) and coefficient of determinant (R2).

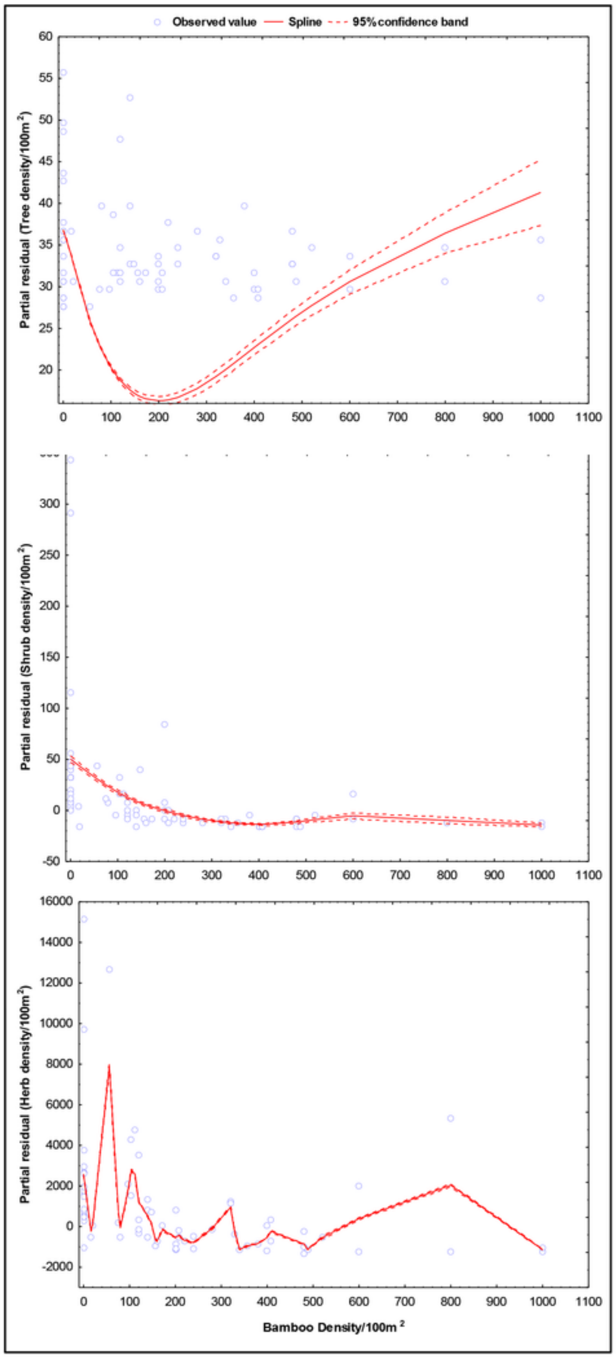

Fig. 3

Figure 3

Predicted changes in density of trees, shrubs and herbs with respect to increasing density of bamboo. The significance of the smooth best fit model generalized the changing slope as GAM coefficient (β), standard error (SE) and coefficient of determinant (R2).

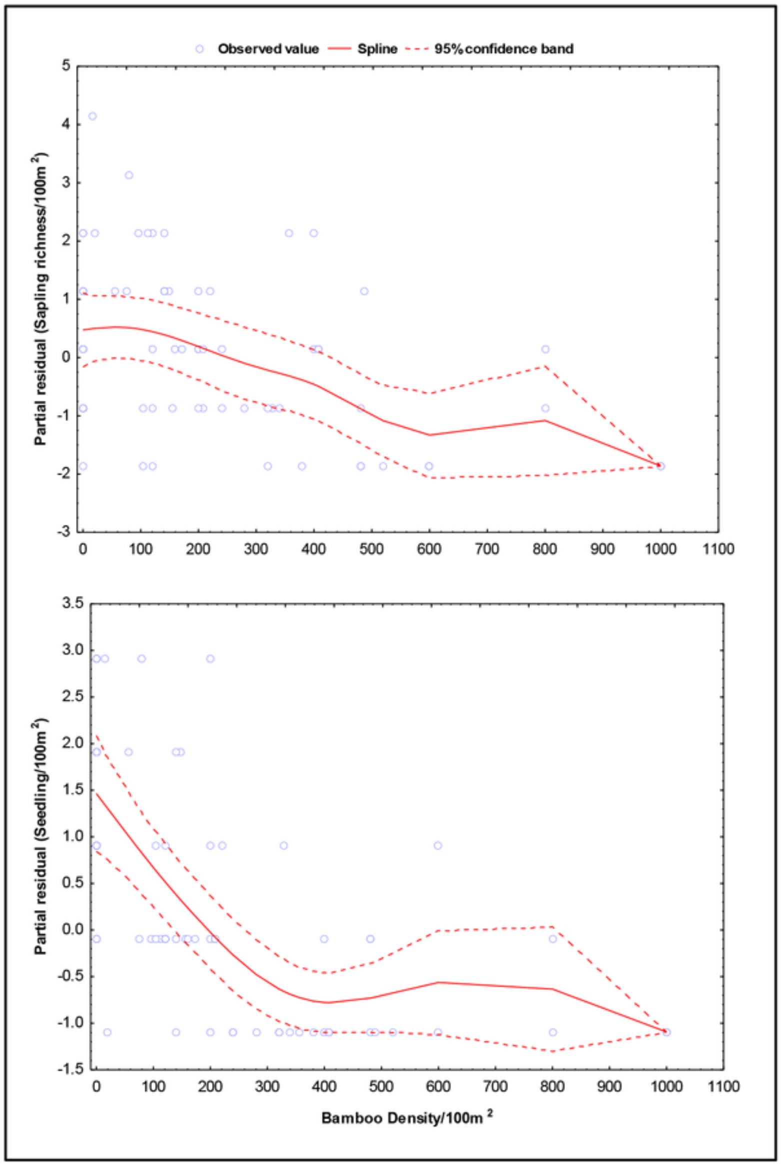

Fig. 4

Figure 4

Predicted changes in species richness of tree sapling and seedlings with respect to increasing density of bamboo. The significance of the smooth best fit model generalized the changing slope as GAM coefficient (β), standard error (SE) and coefficient of determinant (R2).

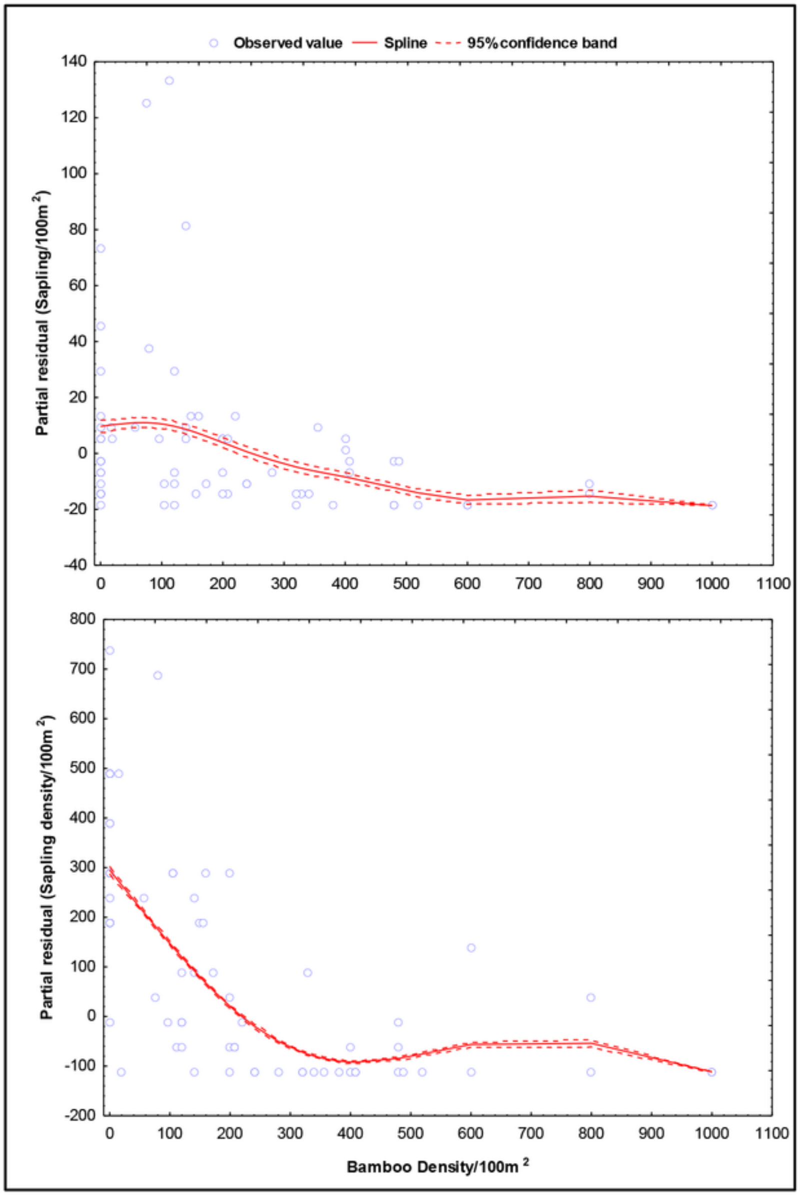

Fig. 5

Figure 5

Predicted changes in density of tree sapling and seedlings with respect to increasing density of bamboo. The significance of the smooth best fit model generalized the changing slope as GAM coefficient (β), standard error (SE) coefficient of determinant (R2).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table.pdf