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Relationship between Maling bamboo (*Yushania maling*) invasion and decrease of plant species diversity in the Eastern Himalayan temperate forest

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Abstract

Temperate forests of the Eastern Himalayan region are undergoing a noticeable transformation due to invasion and over-dominance by indigenous *Yushania maling*, Maling bamboo. In the present study, the impact of invasion of Maling bamboo on forest species composition in the Senchal Wildlife Sanctuary located in Darjeeling district of West Bengal, India was investigated, using a comparative approach. Ten plots each from Maling and non-Maling habitats at 10 sites were sampled using the nested quadrat method. Maling-infested plots showed lower species richness and diversity compared to non-Maling plots. The Maling-infested plots harboured 119 species compared to 165 species in non-Maling plots. Across habitat and vegetation strata, diversity indices such as Shannon-Weiner, Menhinick, Simpson, and evenness consistently indicated lower diversity in Maling-dominated habitats accompanied by higher dominance scores. Significantly lower shrub and herb species diversity were observed in Maling plots, along with elevated shrub density and moderately lower tree density as compared to non-Maling plots. The sapling species diversity and density were significantly lower in Maling plots, along with moderately reduced seedling density. The average Maling culm density was 1232.8 per 0.04 ha. These results underscore the adverse impact of Maling bamboo over-dominance on species composition of shrub, herbs, sapling and seedlings, and the density of trees, shrubs, saplings and seedlings within the temperate forests. Potential management strategies for the native species are discussed.

Key words: Eastern Himalayan forest, forest species composition, Maling bamboo over-dominance, seedling and sapling composition, Senchal wildlife.
Abbreviations: GAM, Generalized Additive Model.

Introduction

Forests are essential natural resources required for people's survival and socio-economic activities. They support various forms of life on the planet, providing direct benefit and ecosystem services (Badola, Aitken 2010; Isabell et al. 2017; Linders et al. 2019). Biological invasion is considered the second greatest threat to biodiversity after habitat loss (Buckley, Roughgarden 2004; Zhan, Chen 2011). Invasion by alien species (Mack et al. 2000; Gooden et al. 2009; Sundaram et al. 2012; Neena et al. 2013; Shackelton et al. 2017; Nath et al. 2019; Huges et. al. 2020) and dominance by indigenous species (Okutomi et al. 1996; Gooden et al. 2009; Tomimatsu et al. 2011; Lima et al. 2012; Tao et al. 2012; Xu et al. 2020; Rai and Singh 2020; Gaira et al. 2022) have altered forest structure and species composition. Invasion or dominance by one species modifies the natural ecosystem, thereby adversely affecting floral and faunal diversity, productivity, and hydrological cycle (Lima et al. 2012; Kudo et al. 2017; Chen et al. 2022). The rapid expansion of runner bamboo has become a major global concern due to its invasive nature (Tylor et al. 2004; Montti et al. 2011; Roy et al. 2016; Srivastava et al. 2018; Xu et al. 2020). Bamboo dominance has been recognized globally for its impact on tree recruitment, especially in the form of seedlings and saplings (Gratzer et al. 1999; Larpkern et al. 2011) as it reduces resources available for other species (Griscom, Ashton 2003; Montii et al. 2011).

Bamboos are large woody grasses belonging to the family Poaceae. They are known for being one of the fastest-growing plants that are found in a broad range of climates, including tropical, sub-tropical, and warm temperate ecoregions of the world. Globally, bamboos are represented by 1400 species under 107 genera (Xu et al. 2020). In India, there are 148 bamboo species under 29 genera (Sharma, Chongtham 2015) making it the second-highest bamboo diversity country after China. Bamboo is found throughout the country, covering 15 million ha, which contributes to

20.9% of India's total forest and tree cover (ISFR 2021). The northeastern states of India are the center of bamboo diversity, accounting for more than 60% (90 species), with high endemism (41 species).

Bamboos are one of the most versatile plant groups, serving various socio-economic and environmental roles (Gupta, Kumar 2008; Sarmah et al. 2020). Owing to its numerous and varied uses they are often referred to as 'Green Gold' (ISFR 2021). Bamboo has thousands of uses and is commonly found in everyday products. It provides structural materials for construction (Razal et al. 2012; Chaowana 2013; Sebastian et al. 2016; Poonia et al. 2021). It is extensively used for building houses for flooring, making house frames, roofing, walls, etc. (Tamang et al. 2013; Mohammad et al. 2015). Moreover, bamboo significantly contributes to the livelihood of forest dwellers and rural communities (Frith 2008; Sharma et al. 2018), with an estimated 2 million people in India depending on bamboo for their livelihood (ISFR 2021). Bamboo is used to craft utility items such as mats, fishing rods, baskets, bows and arrows, and making furniture (Kumar 2009; Tamang et al. 2013). Additionally, bamboo crafts and decorative items (Phukan 2018) add to the rural economy by providing livelihood and employment opportunities. Furthermore, the pulp and paper industry heavily relies on bamboo as a resource to meet industrial demand (Tambe et al. 2019). Young shoots of various bamboo species are used as a food source (Tamang et al. 2013; Nongdam, Tikendra 2014; Cassi, Punzalan 2015; Mohammad et al. 2015; Kumar et al. 2016) and also serves as vital component of wildlife diets (Pradhan et al. 2001; Sharma et al. 2014).

The Himalayan region in India is one of the world's most biodiverse landscapes. It is recognized as one of the 36 global biodiversity hotspots and is a crisis ecoregion (Brooke et al. 2006). Its remarkable diverse ecosystem comprises various forest types (Champion, Seth 1968; Rai, 2006; Bhatt et al. 2020), which evolved over an extensive long period of time. The interplay of climatic conditions, altitudinal variations, physiography, soil types played a crucial role in shaping the Himalayan ecosystem following the collision of the Eurasian and Gondwana plates (Gansser 1964; Sharma et al. 2017). These Himalayan forests play a vital role in climate regulation, carbon sequestration, soil retention, and the provision of various ecological services. Additionally, the rivers originating in the Himalayas are inextricably linked with millions of people living downstream (Saha et al. 2016; Negi et al. 2018).

The temperate zone of Darjeeling Himalaya (India) is experiencing a high level of dominance and landscape homogenization caused by *Yushania maling* (Gamble) R.B. Majumdar & Karthik, a bamboo species of indigenous origin locally known as Maling. This leptomorphic bamboo species proliferates through underground rhizomes (Chao, Renvoize 1989) and typically attains a height of 2.5 to 3.5 m. It has been spreading rapidly throughout the Eastern Himalayan region (Rai 2006, Rai, Rai 2017; Roy et al. 2016; Gaira et al. 2022) at elevation between 1800 and 3600 m above sea level. The clonal vegetative rhizome of Maling bamboo is believed to contribute to its invasiveness, as it can withstand varied climatic conditions and efficiently utilize resources (Okutomi et al. 1996; Xu et al. 2020). Consequently, it is forming impenetrable shrub and understory canopy in the temperate forests of the Eastern Himalayas. A recent investigation by Gaira et al. (2022) in the Kanchandzonga Landscape revealed extensive over-dominance of Maling bamboo in the Singalila National Park. Additionally, Roy et al. (2016) utilized species niche modeling and MaxEnt to predict critical forest patches in Darjeeling Hills as potential areas of invasion. Moreover, ensemble the modeling approach (Srivastava et al. 2018) predicted a potential increase in Maling habitat in the Hills of Darjeeling, posing a threat to local biodiversity.

The rapid proliferation of Maling bamboo is perceived as one of the major threats to the local biodiversity in the temperate region of Eastern Himalaya, where native species are conserved. There are also concerns about its potential spread to other areas where Maling is absent (Roy et al. 2016; Srivastava et al. 2018), which could affect biodiversity and essential ecosystem services such as provisioning, regulating, supporting, and cultural services. These impacts, in turn, would affect the well-being of people living in Eastern Himalaya. The dominance of Maling bamboo can also have wider implication on human health, food security, livelihoods and the regional economy. Understanding the impact of Maling's over-dominance on local biodiversity and overall ecological and socio-economic implication is crucial. Therefore, we conducted a study to assess the effects of Maling bamboo on species composition, forest structure and regeneration status of tree species in the Senchal Wildlife Sanctuary. Additionally, we also propose management strategies to mitigate the negative effects and promote overall ecosystem improvement in the region.

Materials and methods

Study area

Senchal Wildlife Sanctuary, which is located in the Eastern Himalaya, in the state of West Bengal, India, harbours rich biodiversity and unique ecological features. Originally established as a game reserve by the British in 1915 and recognized as a Wildlife Sanctuary in 1976, it has since become one of the oldest sanctuaries in India safeguarding the regional biodiversity. The sanctuary is geographically located between 26°56′ to 27°00′ N latitude and 88°18′ to 88°20′ E longitude, about 10 km south-east of Darjeeling town (Fig. 1). Nestled on the southern ridge of Singalila range, the sanctuary covers an area of 38.6 km^2 with an elevation ranging from 1500 to 2600 m above sea level. The sanctuary primarily falls within the temperate eco-climatic zone, which is characterized by wet temperate forests and

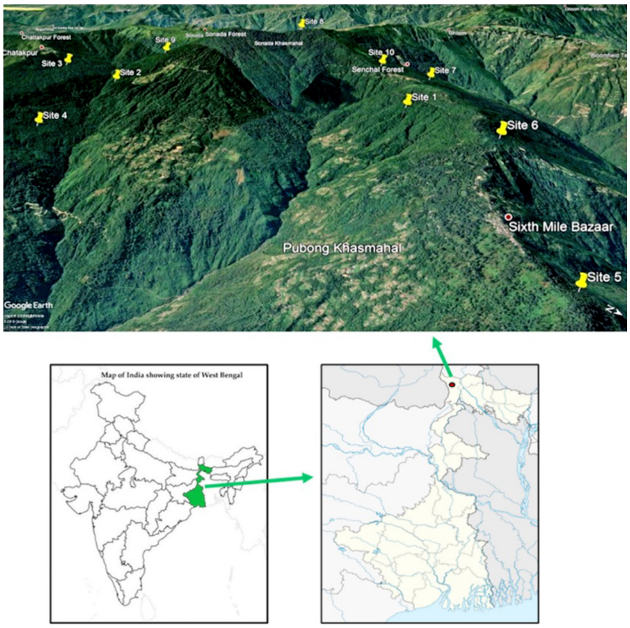

Fig. 1. Map showing location and sampling sites in Senchal Wildlife Sanctuary (source: Google Earth).

temperate broad-leaved forests (Champion, Seth 1968; Rai 2006). Notably, the forests face varying degrees of over-dominance by Maling bamboo, sometimes displaying gregarious nature, particularly in regions like Tiger Hill and Chatakpur forest beats. Remarkably, the Maling bamboo invades open spaces and also thrives and grows luxuriantly inside the forest as an understory canopy. The sanctuary is home to a variety of mammals, birds, and diverse flora, many of which are endemic and threatened. The sanctuary is a major watershed that provides drinking water for Darjeeling town and a host of other ecological services.

Data sampling

A reconnaissance survey along the Tiger Hill-Chatakpur ridge in the south and 3rd Mile- 6th Mile ridge in the east was performed, covering the sanctuary to identify the Maling-infested and non-Maling habitats. Geographical coordinates of the identified habitats were recorded using a hand-held Garmin 76 S GPS. For quantitative assessment of the floristic composition and community structure, 20 plots were randomly selected, with 10 plots each for Maling-infested and non-Maling habitats (Table 1). The nested quadrat method was adopted (Rai 2006; Roy et al. 2008) to study different vegetation layers, viz. trees, shrubs, herbs, and new recruits (seedlings and saplings). Tree species were studied within a 400 m^2 (20 × 20 m) plot, and within this area, two 25 m^2 (5 × 5 m) subplots were laid diagonally to study shrubs, saplings, and Maling bamboo. For herbaceous species and seedlings, five 1 m^2 (1 × 1 m) plots were used, positioned at the four corners and one at the center of the 400 m^2 plot to optimize data quality. Trees with a girth above 15 cm at breast height were recorded as trees, saplings were with a girth size of ≥10 to ≤15 cm and seedlings with collar girth ≤ 10 cm. A measuring tape was used to measure the circumference of the trees. To assess vegetation density and Maling bamboo density (shoots and culms) the number of individuals per unit area of each sample plots were counted.

Plant species were identified using regional flora: Flora of Bhutan, Vol. I & II (Grierson, Long 1983 – 2001), Flora of Eastern Himalaya Vol. 1 & 2 (Hara 1966; Hara 1971). Any unidentified species were matched with herbarium specimens at the Llyod Botanical Garden herbarium, Darjeeling and North Bengal University herbarium, Siliguri. Authentication of nomenclature of plant species was done following The Plant List online database. Initial analysis was done in MS Excel and various diversity indices (Shannon-Weiner's index, Menhinick's index, Simpson's index, evenness index, and dominance were computed using PAleontological STatistics (PAST) 4.13 software. For statistical analysis, the recorded data were subjected to an independent sample *t*-test for comparing the mean of species composition and density of trees, shrubs, herbs, and seedlings and saplings of tree species between Maling and non-Maling plots.

Table 1. Information on the study sites with geographical coordinates and status of forest

Type	No.	Site	Place	Coordinates	Altitude (m above sea level)	Quadrats studied
Non-Maling sites	1	Site 1	3rd Mile	27°00′52.10″ N, 88°18′08.89″ E	2043	2
	2	Site 2	Rambi	26°58′45.64″ N, 88°18′36.59″ E	1992	2
	3	Site 3	Upper Chatakpur	26°58′19.10″ N, 88°18′41.09″ E	2157	2
	4	Site 4	Rampuria	26°58′51.54″ N, 88°19′24.46″ E	1731	2
	5	Site 5	6th Mile	27°02′02.93″ N, 88°19′42.77″ E	1947	2
Maling infested sites	6	Site 6	Naya Busty	27°01′30.68″ N, 88°18′32.30″ E	2097	2
	7	Site 7	3rd Mile	27°00′44.99″ N, 88°17′21.62″ E	2043	2
	8	Site 8	Tiger Hill	26°59′34.43″ N, 88°17′13.25″ E	2534	2
	9	Site 9	Rambi	26°58′49.29″ N, 88° 5′05.69″ E	2246	2
	10	Site 10	Gaddi Khana	27°00′23.79″ N, 88°17′25.87″ E	2244	2

Results

A comprehensive plant study across 20 plots at 10 different sites was conducted in the Senchal Wildlife Sanctuary, in Eastern Himalaya in the state of West Bengal, India (Table 1). Five sites were chosen for Maling bamboo dominance and another five were used as a control (without Maling). Within each site two sampling plots were used. In the Maling habitats, 4494 individuals of plants belonging to 119 species were sampled. Among these, there were 27 tree species with total 189 individuals, 32 species of shrubs with total 2551 individuals (including 1541 Maling bamboo individuals), and 76 herb species with total 1754 individuals including 10 species of seedlings and 12 species of saplings (Appendix 1). In the non-Maling habitat 2256 individuals belonging to total 165 species were sampled, which included 34 tree species with total 254 individuals, 56 shrubs with total 398 individuals, and 127 species of herbs with total 1604 individuals) including 16 species of seedlings and 21 species of saplings (Appendix 2). Species diversity between the two habitats were compared (Table 2). Notably, the Maling plots showed a lower number of taxa, with 119 species belonging to 85 genera in 53 families, as compared to non-Maling plots that exhibited 165 species, 120 genera and 67 families. There was a noticeable decrease in the species abundance across vegetation strata in the Maling-infested sites. In the Maling plots the dominant genera in tree layer were Lithocarpus pachyphylla and Rhododendron grande, while the shrub layer was dominated by Yushania maling with an average density of 1232.8 individuals per 0.04 ha. The herb layer showed abundance of *Peracarpa carnosa, Smilax rigida, Fragaria nubicola, Persicaria chinensis, Acogonon molle* etc. In contrast, the non-Maling plots was dominated by *Lithocarpus pachyphylla* and *Quercus oxydon* in the tree layer. The shrub layer contained abundant *Smilax rigida, Viburnum erubescens, Dichroa febrifuga* etc., and the herbaceous layer showed high occurrence of *Oplismenus burmanii, Peracarpa carnosa, Cyperus* sp., *Ophiopogon intermedius, Elatostema* sp. etc. The dominant families differed between the two habitats, with Asteraceae and Rosaceae being the dominant families in Maling plots, while Rosaceae, Urticaceae, Lauraceae, and Asteraceae were dominant families in non-Maling plots.

Table 2. Taxonomic diversity and species occurrence in different vegetation strata in Maling-infested and Maling-free plots in Senchal Wildlife Sanctuary

Type	Parameter	Maling infested plots (*n* = 10)	Non-Maling plots (*n* = 10)
Taxonomic diversity	Family	53	67
	Genus	85	120
	Species	119	165
Species occurrence	Tree	27	34
	Shrub	32	56
	Herb	76	127
	Sapling	12	21
	Seedling	10	16

Various diversity indices were compared between the bamboo-infested and non-infested sites. All diversity parameters in Maling plots tended to have lower values when compared to non-Maling plots. The diversity drivers in Maling plots were 2.852 for the Shanon-Weiner index, 1.897 for the Mehninick index, 0.828 for the Simpson index, 0.143 for the evenness index and 0.172 for dominance, as compared to 4.542 for the Shanon-Weiner index, 3.611 for the Menhinick index, 0.981 for the Simpson index, 0.452 evenness index) and 0.019 for dominance for non-Maling plots.

Similarly, diversity indices for different vegetation strata were compared between two habitats (Table 3). The Shannon-Weiner index for trees (H' = 2.392), shrubs (H' = 1.542), and herbs (H' = 3.277) for Maling plots were comparatively lower than the non-Maling plots: trees (H' = 3.063), shrub (H' = 3.201) and herbs (H'= 4.077), indicating reduced diversity in the Maling-infested areas. A similar trend for the Menhinick index was observed in Maling plots: trees (1.964), shrubs (0.634), and herbs (1.815) as compared to non-Maling plots – 2.133 (trees), 1.956 (shrubs), and 3.056 (herbs). Simpson's index ($1–D$) was also lower in Maling-infested sites (0.847 for trees, 0.604 for shrubs, and 0.933 for herbs) in comparison to non-Maling plots (0.942 for trees, 0.936 for shrubs and 0.973 for herbs). Similarly, the Evenness index (e^H/S), a measure of species distribution, was significantly lower: 0.405 for

Table 3. Diversity indices for different vegetation layers in Senchal Wildlife Sanctuary

Index	Maling plots (*n* = 10)				Non-Maling plots (*n* = 10)			
	Tree	Shrub	Herb	Habitat	Tree	Shrub	Herb	Habitat
Number of taxa	27	32	76	121	34	56	126	190
Number of individuals	189	2551	1754	4483	254	820	1700	2769
Shannon (H')	2.392	1.542	3.277	2.852	3.063	3.201	4.077	4.452
Menhinick index (I*Mn*)	1.964	0.634	1.815	1.807	2.133	1.956	3.056	3.611
Simpson ($1–D$)	0.847	0.604	0.933	0.828	0.942	0.936	0.973	0.981
Evenness (e^H/S)	0.405	0.146	0.349	0.143	0.629	0.439	0.468	0.452
Dominance (D)	0.153	0.396	0.067	0.172	0.058	0.064	0.027	0.019

Table 4. Vegetation parameters compared between Maling infested and non-Maling plots using a t-test for independent samples assuming unequal variance

Type	Parameter	Mean ± SE	Variance	Mean ± SE	Variance	*t*-value	*p*-value
		Maling plots		Non-Maling plots			
Species composition	Tree	7.2 ± 1.1	11.5	7.5 ± 0.9	8.1	0.2145	0.4164
	Shrub	8.5 ± 0.6	3.61	11.7 ± 1.0	10.01	2.742	0.007
	Herb	16.2 ± 1.7	29.5	22.3 ± 2.6	69.12	1.94	0.035
Species density	Tree	18.9 ± 2.1	42.77	25.4 ± 3.3	111.15	1.657	0.059
	Shrub	1652 ± 189	716500	318 ± 432	48583.41	6.82	0.0001
	Herb	12384 ± 1159	6.71E+07	12832 ± 928	4.31E+07	−0.301764	0.38

trees, 0.146 for shrubs, and 0.349 for herbs in Maling plots, whereas in non-Maling plots, it was 0.629 for trees, 0.439 for shrubs, 0.468 for herbs. Additionally, the dominance (*D*) scores were significantly higher for all vegetation strata in the Maling plots: 0.153 for trees, 0.396 for shrubs, 0.067 for herbs; compared to non-Maling plots, where the scores were 0.058 for trees, 0.064 for shrubs, and 0.027 for herbs) These diversity indices figures suggest that the invasion and over-dominance by a particular species had the potential to impact species diversity, species richness, and evenness.

Species composition and species density between the Maling and the non-Maling plots were evaluated using the *t*-test for independent samples assuming unequal variance (Table 4). The results showed a significant (p = 0.007) reduction in shrub species richness (8.5 ± 0.06) and herb species richness (16.2 ± 1.72; $p = 0.035$) in the Maling plots compared to non-Maling plots (11.7 ± 1.0 for shrubs, and 22.3 ± 2.6 for herbs). However, there was no significant difference in tree species richness ($p = 0.4164$) between the two habitats, with 7.2 ± 1.1 species in Maling plots and 7.5 ± 0.9 species in non-Maling plots. Regarding density, a significant ($p = 0.0001$) increase in average shrub density (1652 ± 189) was observed in Maling plots compared to non-Maling plots (318 ± 432). There was a non-significant ($p = 0.059$) decrease of tree density (18.9 ± 2.1 in Maling plots and 25.4 ± 3.3 in non-Maling plots). Surprisingly, there was no significant difference ($p = 0.38$) in herb density between the two habitats (12384 ± 1159 for Maling plots and 12832 ± 928 for non-Maling plots). A decreasing trend in the species richness of trees ($R^2 = 0.19$), shrubs ($R^2 = 0.11$) and herbs ($R^2 = 0.001$) in non-Maling plots with increasing Maling bamboo density was observed (Table 6). Similarly, a decreasing trend in density of trees ($R^2 = 0.01$), shrubs ($R^2 = 0.07$), and herbs ($R^2 = 0.10$) was observed in the non-Maling plots with increasing bamboo density. However, the tightness of the association was low and variable for different parameters.

Tree recruitment at the Maling and non-Maling sites by counting the number of seedlings and saplings was analyzed (Table 5). In total, 749 individuals of saplings and seedlings, representing 36 tree species were encountered. The tree recruitment, in terms of both species occurrence and density of seedlings and saplings, was comparatively lower in the Maling plots. Of the 27 tree species encountered, Maling plots showed 12 species of saplings (with 198 individuals) and 10 species of seedlings (with 117 individuals). In contrast, the non-Maling plots exhibited higher tree recruitment, with 21 species of saplings (267 individuals) and 16 species of seedlings (167 individuals) of the 32 tree species encountered. The most abundant species in the Maling plots were *Viburnum erubescens* (with 91 individuals) followed by *Symplocos glomerata* (with 49 individuals). On the other hand, non-Maling plots were dominated by *Symplocos glomerata* (92 individuals) and *Pieris formosa* (72 individuals), while Eurya acuminata, and *Eurya caudata* (with 42 and 41 individuals respectively) were common (Appendix 3).

The data were extrapolated with estimation per 0.04 ha and subjected to statistical analysis. Significantly (p = 0.01) lower sapling species richness (2.2 ± 0.337) in Maling plots compared to (3.5 ± 0.432 in non-Maling plots) and a significantly ($p = 0.042$) lower sapling density in Maling

Table 5. Regeneration status compared between Maling infested and non-Maling plots using a *t*-test for independent samples assuming unequal variance

Type	Parameter	Mean ± SE	Variance	Mean ± SE	Variance	*t*-value	*p*-value
		Maling plots		Non-Maling plots			
Species composition	Sapling	2.2 ± 0.3	2.27	3.5 ± 0.4	3.73	−2.371	0.011
	Seedling	4.3 ± 0.4	1.34	4.8 ± 0.7	4.40	−0.660	0.260
Species density	Sapling	158.4 ± 23.2	10749	293.6 ± 71.2	101248.7	−1.81	0.042
	Seedling	187.3 ± 24.8	6146	267.2 ± 39.8	15818	−1.71	0.054
	Maling bamboo	1232 ± 131	347121	0		9.35	0.0001

Table 6. Relationship between Mailing bamboo density and diversity-related parameters in different forest plots

Parameter	Intercept	R^2
Tree species richness	y = –0.0007 x + 9.3065	0.0795
Shrub species richness	y = –0.0009 x + 4.7877	0.1111
Herb species richness	y = –0.0003 x + 23.098	0.0018
Tree density	y = –0.0028 x + 32.688	0.0938
Shrub density	y = –0.1008 x + 442.62	0.0725
Herb density	y = – 8.0609 x + 84912	0.1036
Sapling species	y = –0.0003 x + 3.8963	0.0096
Seedling species	y = –0.0009 x + 7.2176	0.2607
Sapling density	y = –0.1746 x + 508.81	0.1045
Seedling demsity	y = –0.0491 x + 393.53	0.198

Table 7. Average density per plot (individuals per 400 m^2) of different vegetation layers and basal area of trees in Maling-infested and Maling-free habitat in Senchal Wildlife Sanctuary

Parameter	Maling plots (*n* = 10)	Non-Maling plots (*n* = 10)
Tree density	18.9	25.4
Shrub density	1652	318.4
Herb density	12384	12832
Yushania maling culm density	1232.8	0
Tree basal area (m^2 per 400 m^2)	14.86	19.64

plots (158.4 ± 23.18) compared to non-Maling plots (293.6 ± 71.15) was found. No significant difference ($p = 0.26$) in seedling richness between the two habitats (4.3 ± 0.367 for Maling plots and 4.8 ± 0.663 for non-Maling plots) was observed, as well as non-significant ($p = 0.054$) lower seedling density in Maling plots (187.3 ± 24.79) compared to non-Maling plots (267.2). A decreasing trend in the species richness of saplings ($R^2 = 0.009$) and seedlings ($R^2 = 0.27$) in the non-Maling plots with increasing Maling bamboo density was found (Table 6). Similarly, there was a decreasing trend for density for saplings ($R^2 = 0.10$) and seedlings ($R^2 = 0.198$) in the non-Maling plots with increasing Maling bamboo density.

The density of various vegetation strata were estimated from the field data collected, including Maling bamboo. The average species density (number of individuals) and basal area of trees in 0.04 ha across different vegetation layers in Senchal Wildlife Sanctuary, focusing on two habitat types was compared (Table 7). A direct relationship between the abundance of Maling bamboo and a decrease in density and basal area for the tree layers was found. In the Maling plots, an average density of 18.9 trees with a basal area of 14.86 m^2 ha^{-1}, 1652 shrubs (1232.8 Maling individuals) and 12384 herbs was observed, compared to density of 25.4 trees with a basal area of 25.5 m^2 ha^{-1}, 318.4 shrubs, and 12832 herbs in the non-Maling plots. The significantly higher shrub density in the Maling plots was primarily due to the profuse bamboo growth with bamboo density of 1232.8. Interestingly, average density of other shrub species (excluding bamboo) was also found to be higher in the Maling plots (419.2) compared to the non-Maling. High density of shrubs could be attributed to the thick growth of Sarcocca hookeriana and Smilax rigida, which were found in high abundance in the bamboo-dominated habitat.

Discussion

In the present study in the Senchal Wildlife Sanctuary, Maling-infested (*Y. maling*) habitats showed lesser number of trees, shrubs, and herbs compared to non-Maling habitat. This was evident from lower scores in various diversity indices including the Shannon-Weiner's index, Simpson's index, Menhenick's index, evenness index, and higher dominance of trees, shrubs, and herbs as compared to non-Maling habitat. The species richness was lower in Maling plots. These results indicate that the abundance and over-dominance by Maling bamboo have significant impact on species richness and other diversity indexes. A supportive study in Singalila National Park (Gaira et al. 2022), of the same region showed a negative relationship between bamboo density and shrub, herb, and seedling richness. Bamboo dominance restricts the growth and establishment of shrubs, herbs, and new recruits in its vicinity (Tomimatsu et al. 2011). Similar observations were reported in other regions, where bamboo dominance led to reduced species richness and diversity (Larpkern et al. 2011; Lima et al. 2012; Tao et al. 2012; Kudo et al. 2017) leading to change in community structure. These findings emphasize an adverse ecological impact of bamboo dominance which can alter the forest structure and species composition over long term.

A significant reduction in species composition for shrubs and herbs observed in Maling plots compared to non-Maling plots, and a significant increase in the shrub density and weakly significant decrease in tree density was observed in Maling plots. No difference in tree species composition was observed in the study area between the two habitats. Similarly, there was no difference in density in herbs. An increased density in the shrubs was observed, which was due to 75% of the bamboo culms that constituted the shrub layer. Additionally, *Smilax rigida* and *Sarcocca hookeriana* also showed high concentration in some plots. Regression analysis showed a decreasing trend in the species richness and density in trees, shrubs, and herbs in the non-Maling plots with increasing Maling bamboo density. A Generalized Additive Model (GAM) estimated a significant decline in the species richness of shrubs and herbs in Singalila National Park (Gaira et al. 2022). Furthermore, their GAM predicted for every 1000 bamboo shoots, shrub species richness decreased by two to three species. These results indicate Maling over-dominance adversely impacts tree, shrub and herb species composition (species richness). It also impacts the tree density. This probably may be due to high mortality rate of saplings which could not reach adult stage due to hindrance by Maling over-dominance. A supportive study of high mortality rate of saplings due to over-dominance of bamboo in the Andean forests has been reported by Fedrique et al. (2017).

It was found that species diversity and density of tree seedlings and saplings significantly lower in the Maling-infested plots. While a small difference in seedling species richness between the two habitats was observed, which may be due to variation in sampling designs. Additionally, a decreasing trend was seen in species composition and density of seedlings and saplings in the non-Maling plots with increasing bamboo density. Reduced seedling and sapling may be due to physical and physiological stresses caused by bamboo over-dominance (Lima et al. 2012). The GAM estimates of Gaira et al. (2022) reported significant decline in species richness and density of saplings and seedlings with increasing density of bamboo. They predicted a decrease in 1 – 2 species of tree seedlings, with 141 to 145 individuals, and 23 to 25 individuals of saplings for every 1000 shoots of bamboo in 100 m^2. These results suggest that the aggressive growth of Maling bamboo in the Senchal Wildlife Sanctuary significantly affects tree recruitment, particularly the saplings. Moreover, high abundance of second and third-story trees alongside very few dominant first-storied species indicate a shift in species diversity. The significant difference in sapling occurrence within our study area may be an indication of high mortality of the seedlings not reaching the sapling stage. A similar supportive study was reported by Montii et al. (2011) in neotropical forests of Misiones. These findings highlight changing forest structure and dynamics influenced by bamboo dominance.

Analysis of the basal area of tree stands per hectare revealed relatively low volume and tree density in the Maling plots. Low basal area may be due to prevalence of medium sized trees and lesser number of individuals in the Maling plots. A supportive study carried out by Fedrique et al. (2017) revealed the bamboo dominated forests are more dynamic with small sized trees with low density and basal area in the Andean forests. A low mortality rate was observed for trees with intermediate size compared to larger trees in Southwestern China based on a 12 years study on bamboo dynamics (Tylor et al. 2004). The community structure and dynamics of forests are largely influenced by the interaction of forest canopy characteristics and understory canopy (Nakashizuka 1987; Griscom, Ashton 2003). The negative association between bamboo abundance and tree basal area suggest a lower biomass accumulation and lower carbon storage capacity.

The average Maling bamboo culm density was 1232.8 individuals per 0.04 ha in Senchal Wildlife Sanctuary, which was comparable to 300 bamboo shoots per 100 m^2 reported by Gaira et al. (2022) in Singalila National Park, located in the same region. Interestingly, in the present study, *Smilax rigida* and *Sarcocca hookeriana*, were also observed in abundance in Maling plots, indicating their ability to thrive well in bamboo dominated habitat. Our observations revealed rhizomatous growth of Maling bamboo, with profuse fibrous roots spreading below the soil surface, which is mainly responsible for over-dominance overwhelming native vegetation. Moreover, Maling bamboo rapidly invades open spaces within the Wildlife Sanctuary, forming gregarious stands in areas like Tiger Hill and Chatakpur beats. It demonstrates excellent adaptability under the forest canopy of *Quercus* spp., laurels, conifers, *Rhododendron* spp. and other temperate tree species, as also noted by Gaira et al. (2022) in the same ecoregion. Similar observations were made by Okutomi et al. (1996) in Japan, and studies in broad-leaved forests in China (Song et al. 2017, Bai et al. 2016, Xu et al. 2020) where the invasive nature of bamboo was primarily attributed to its rhizomatous clonal growth habit. The study provides valuable insight into the impact of Maling bamboo on the forest ecosystem and its role in shaping forest structure and dynamics in the temperate forest ecosystem over the long term.

In the Senchal Wildlife Sanctuary, *Y. maling* has formed a thick shrub layer along the Tiger Hill ridge dominating nearly 770 ha of the forest area (Wildlife Division, unpublished report). Maling bamboo has been spreading continuously for several decades without any reports of die-back. Due to its long life-cycle and aggressive growth and changing climate, Maling has the potential to spread further into adjacent forests of the temperate region in the Eastern Himalayas (Roy et al. 2016; Srivastava et al. 2018), leading to serious disruption in ecological services. The impact is evident in the drying up of 14 out of 26 perennial natural springs that feed the Senchal Lake, resulting in water shortages in Darjeeling town (Rai, Rai 2017; Bhutia 2017). Moreover, the productivity of temperate cash crops, such as large cardamom, which heavily relies on bumblebee pollinators (Sharma et al. 2019), has sharply declined (Gudade et al. 2013; Tarafdar et al. 2018; Veenita et al. 2023), further confirming the degrading ecological services caused by Maling bamboo's dominance.

The uncontrolled expansion of the Maling may be attributed to existing wildlife protection policies of the Government, limited knowledge of reproductive biology and autecology of this indigenous bamboo species, and inadequate management measures. Effective management of aggressive species like Maling bamboo should encompass environmental, social and economic aspects. Studies on controlling and managing invasive species throughout India have emphasized utilizing resources for livelihood generation (Neena et al. 2013; Negi et al. 2019). Implementing policies for the sustainable harvest of Maling for utilization could be the most effective alternative for controlling further spread and promote forest restoration. This approach would not only revitalize bamboo-based handicrafts but also provide livelihood opportunities and alleviate poverty for forest dwellers and fringe communities. Additionally, by developing human resources on bamboo craftsmanship and promoting bamboo-based products like bamboo shoot pickles, utility items of daily use, and decorative pieces, the region can witness employment opportunities and foster bamboo-based entrepreneurship.

Based on the information from our study a well-thought long-term management plan needs to be developed focused on the sustainable harvesting principle. This will help in addressing the Maling bamboo problem at the same time alleviating poverty of the forest dwellers. We suggest thinning of Maling bamboo culms for income generation by the forest dwellers on a regular basis and sustained harvest of young shoots as a management practice to control further expansion. To complement the control and management of the *Y. maling* and forest restoration programme, revitalization of bamboo craftsmanship need to be promoted. The existing Forest Protection Committees have to be strengthened. Moreover, in-depth study on Maling bamboo distribution, its proliferation, comprehensive autecological study, and socio-economic aspects must be central to the management plan.

Conclusions

Over-dominance by Maling in Eastern Himalaya is increasingly becoming a threat to biodiversity. It is forming an effective biological barrier for the dispersal of other species particularly for the endemic and threatened species. The results clearly indicate its negative ecological impact on temperate forest ecosystem in terms of species occurrence, species diversity, density, and new recruitment of tree species. Changing forest structure and dynamics can have far-reaching long-term consequences in terms of ecological services. Sustainable utilization of marketable bamboo products will help in controlling the spread of the species at the same time help in poverty alleviation. A comprehensive autecological study is needed to draw up a proper management strategy. We also sincerely acknowledge the anonymous reviewers for their invaluable suggestions and inputs, which greatly improved the quality of our article.

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Appendix 1. Inventory data of Maling bamboo infested plots in Senchal Wildlife Sanctuary, West Bengal, India. Numbers indicate individuals of a species

No.	Name	Family	Tree	Shrub	Herb
1	*Acer campbellii* Hook.f. & Thoms. ex Hiern	Sapindaceae	4	–	2
2	*Acer sikkimense* Miq.	Sapindaceae	1	–	–
3	*Aconogonon molle* (D.Don) Hara	Polygonaceae	–	–	53
4	*Ainsliaea aptera* DC.	Asteraceae	–	–	28
5	*Ainsliaea latifolia* (D. Don) Sch. Bip.	Asteraceae	–	–	2
6	*Anaphalis busua* DC.	Asteraceae	–	–	7
7	*Anaphalis controta* Hook.f.	Asteraceae	–	–	2
8	*Anaphalis margaritacea* (L.) Bentham & Hook.f.	Asteraceae	–	–	3
9	*Anaphalis triplinervis* Sims ex. Clarke	Asteraceae	–	–	11
10	*Aralia leschenaultii* (DC.) J.Wen	Araliaceae	–	2	–
11	*Arisaema* sp.	Araceae	–	–	1
12	*Berberis nepalensis* Spreng.	Berberidaceae	–	–	2
13	*Berberis wallichiana* DC.	Berberidaceae	–	3	–
14	*Boehmeria* sp.	Urticaceae	–	–	88
15	*Brachystemma calycinum* D. Don	Caryophyllaceae	–	–	1
16	*Calanthe brevicornu* Lindl.	Orchidaceae	–	–	5
17	*Cautleya gracilis* (Smith) Dandy	Zingiberaceae	–	–	13
18	*Cautleya spicata* (Smith) Baker	Zingiberaceae	–	–	10

Continued

Appendix 1. *Continued*

No.	Name	Family	Tree	Shrub	Herb
19	*Celtis tetrandra* Roxb.	Cannabaceae	4	–	–
20	*Cerastium glomeratum* Thuillier	Caryophyllaceae	–	–	16
21	*Cinnamomum impressinervium* Meisn.	Lauraceae	2	–	–
22	*Clinopodium umbrosum (Bieberstein)* Koch	Lamiaceae	–	–	3
23	*Crawfurdia speciosa* Wall.	Gentianaceae	–	–	5
24	*Cyperus* sp.	Cyperaceae	–	–	18
25	*Daphne papyracea* Wall. ex G.Don	Thymelaeaceae	5	18	–
26	*Daphne bholua* Buck.-Ham. ex D.Don	Thymelaeaceae	2	24	64
27	*Daphne bholua* D.Don var. *glacialis* (W.W Sm. & Cave) Burtt	Thymelaeaceae	–	1	–
28	*Didymocarpus podocarpus* C.B. Clarke	Gesneriaceae	–	–	4
29	*Dimetia scandens* (Roxb.) R.J. Wang	Rubiaceae	–	–	1
30	*Elatostema hookerianum* Wedd.	Urticaceae	–	–	7
31	*Erigeron karvinskianus* DC.	Asteraceae	–	–	25
32	*Euonymus echinatus* Wall.	Celastraceae	–	–	15
33	*Euonymus tingens* Wall.	Celastraceae	1	–	–
34	*Eurya acuminata* DC.	Pentaphylacaceae	3	19	4
35	*Eurya cavinervis* Vesque	Pentaphylacaceae	–	6	–
36	*Eurya crassifolia* (D.Don) Kobuski	Pentaphylacaceae	1	–	–
37	Fern	Fern	–	–	28
38	*Fragaria nubicola* Lindl. ex Lacaita	Rosaceae	–	–	106
39	*Galium cryptanthum* Hemsl.	Caryophyllaceae	–	–	5
40	*Galium elegans* Wall.	Caryophyllaceae	–	–	5
41	*Gamblea ciliata* C.B.Clarke	Araliaceae	–	2	4
42	*Garuga floribunda* Decne.	Burseraceae	1	–	–
43	*Gaultheria nummularioides* D. Don	Ericaceae	–	–	17
44	*Gentiana pedicellata* (D. Don) Griseb.	Gentianaceae	–	–	15
45	*Geranium nepalense* Sweet	Gerianaceae	–	–	2
46	*Globba hookeri* C.B. Clarke ex Baker	Zingiberaceae	–	–	22
47	*Globba racemosa* Smith	Zingiberaceae	–	–	1
48	*Helwingia himalaica* Hook.f. & Thomson ex C.B. Clarke	Helwingiaceae	–	1	–
49	*Hemiphragma heterophyllum* Wall.	Scrophulariaceae	–	–	18
50	*Hydrangea febrifuga* (Lour.) Y.De Smet & C. Granados	Hydrangeaceae	–	17	–
51	*Hydrangea* sp.	Hydrangeaceae	–	–	1
52	*Hypericum choisianum* Wall. ex N. Robson	Hypericaceae	–	–	1
53	*Impatiens stenantha* Hook.f.	Balsaminaceae	–	–	1
54	*Ligustrum confusum* Decne.	Oleaceae	1	–	–
55	*Lindera assamica* (Meisn.) Kurz	Lauraceae	1	–	–
56	*Lindera pulcherrima* (Nees) Benth. ex Hook.f.	Lauraceae	2	–	–
57	*Lithocarpus pachyphyllus* Rehder	Fagaceae	51	–	1
58	*Litsea kingii* Hook.f.	Lauraceae	4	–	–
59	*Lobelia montana* Reinw. ex Blume	Campanulaceae	–	–	16
60	*Lonicera tomentella* Hook.f. & Thomson	Caprifoliaceae	–	–	7
61	*Machilus odoratissimus* Nees	Lauraceae	2	–	–
62	*Magnolia campbellii* Hook. f. & Thomson	Magnoliaceae	5	–	–
63	*Magnolia pterocarpa* Roxb.	Magnoliaceae	1	–	–
64	*Mahonia nepaulensis* DC.	Berberidaceae	–	1	–
65	*Maianthemum oleraceum* (Baker) LaFrankie	Asparagaceae	–	–	1
66	*Melanoseris brunoniana* (Wall. ex DC.) N.Kilian & Ze H.Wang	Asteraceae	–	–	7
67	*Melastoma malabathricum* subsp. *normale* (D. Don) Karst. Mey.	Melastomataceae	–	2	–
68	*Myriactis nepalensis* Less.	Asteraceae	–	–	5
69	*Ophiopogon intermedius* D. Don	Asparagaceae	–	–	57
70	*Ophiorrhiza rugosa* Wall.	Rubiaceae	–	–	3
71	*Ophiorrhiza treutleri* Hook.f.	Rubiaceae	–	–	13
72	*Oplismenus burmanni* (Retz.) P. Beauv.	Poaceae	–	–	8
73	*Oxalis acetosella* L.	Oxalidaceae	–	–	49

Continued

Appendix 1. *Continued*

No.	Name	Family	Tree	Shrub	Herb
74	*Oxyspora paniculata* DC.	Melastomataceae	–	4	–
75	*Paris polyphylla* Smith	Melanthiaceae	–	–	3
76	*Peracarpa carnosa* Hook. f. & Thomson	Campanulaceae	–	–	304
77	*Persea clarkeana* King ex Hook.f.	Lauraceae	2	–	–
78	*Persicaria chinensis* (L.) H.Gross	Polygonaceae	–	–	138
79	*Pieris formosa* (Wall.) D.Don	Ericaceae	–	3	–
80	*Pilea scripta* (Buch.-Ham. ex D. Don) Wedd.	Urticaceae	–	113	–
81	*Piper sylvaticum* Roxb.	Piperaceae	–	–	1
82	*Plagiogyria pycnophylla* (Kuntze) Mett.	Plagiogyriaceae	–	–	83
83	*Polystichum lentum* (D.Don) T.Moore	Polypodiaceae	–	–	12
84	*Prunella vulgaris* L.	Labiatae	–	–	25
85	*Quercus glauca* Thunb.	Fagaceae	15	–	–
86	*Quercus thomsoniana* A.DC.	Fagaceae	17	–	–
87	*Rhododendron grande* Wight	Ericaceae	46	2	–
88	*Rhododendron griffithianum* Wight	Ericaceae	1	–	–
89	*Rubia manjith* Roxb. ex Flem.	Rubiaceae	–	–	2
90	*Rubia wallichiana* Decne.	Rubiaceae	–	–	14
91	*Rubus buergeri* Miq.	Rosaceae	–	19	–
92	*Rubus calycinus* Wall.	Rosaceae	–	–	30
93	*Rubus elliptcus* Smith	Rosaceae	–	4	–
94	*Rubus lineatus* Reinw. ex Blume	Rosaceae	–	1	–
95	*Rubus paniculatus* Smith	Rosaceae	–	19	–
96	*Rubus sikkimensis* Hook.f.	Rosaceae	–	–	3
97	*Rubus thomsonii* Focke	Rosaceae	–	20	–
98	*Rubus wardii* Merr.	Rosaceae	–	3	–
99	*Salix daltoniana* Andersson	Salicaceae	1	–	–
100	*Sarcococca hookeriana* Baill.	Buxaceae	–	134	4
101	*Scutellaria violacea* B. Heyne ex Bentham	Labiatae	–	–	7
102	*Senecio scandens* Buch.–Ham. ex D.Don	Asteraceae	–	–	1
103	*Setaria plicata* (Lam.) T. Cooke	Poaceae	–	–	5
104	*Smilax lanceifolia* Roxb.	Smilacaceae	–	24	1
105	*Smilax minuta* S.C. Chen	Smilacaceae	–	398	103
106	*Smilax minutiflora* A.DC.	Smilacaceae	–	6	6
107	*Streptolirion volubile* Edgew.	Commelinaceae	–	–	4
108	*Swertia bimaculata* (Siebold & Zucc.) Hook.f. & Thomson ex C.B. Clarke	Gentianaceae	–	–	2
109	*Symplocos caudata* Wall. & G. Don	Symplocaceae	–	20	–
110	*Symplocos glomerata* King ex C.B. Clarke	Symplocaceae	8	49	–
111	*Symplocos phyllocalyx* C.B. Clarke	Symplocaceae	–	2	–
112	*Symplocos theifolia* D. Don	Symplocaceae	7	–	–
113	*Tetradium fraxinifolium* (Hook.) T.G.Hartley	Rutaceae	1	–	–
114	*Tetrastigma serrulatum* (Roxb.) Planch.	Vitaceae	–	–	10
115	*Viburnum erubescens* Wall. ex DC.	Thymelaeaceae	–	91	–
116	*Viola hookeriana* Kunth	Violaceae	–	–	8
117	*Viola pilosa* Blume	Violaceae	–	–	7
118	*Yushania maling* (Gamble) R.B Majumdar & Karthik	Poaceae	–	1541	195
119	*Zanthoxylum rhetsa* (Roxb.) DC.	Rutaceae	–	2	3
	Total 4494		189	2551	1754

Appendix 2. Inventory data of Maling bamboo free plots in Senchal Wildlife Sanctuary, West Bengal, India. Numbers indicate individuals of a species

No.	Name	Family	Trees	Shrubs	Herbs
1	*Acer campbellii* Hook.f. & Thoms. ex Hiern	Sapindaceae	6	–	–
2	*Achyranthes bidentata* Blume	Amaranthaceae	–	–	24
3	*Aconogonon molle* (D.Don) Hara	Polygonaceae	–	–	4

Continued

Appendix 2. *Continued*

No.	Name	Family	Trees	Shrubs	Herbs
4	*Actinodaphne longipes* Kosterm.	Lauraceae	6	–	–
5	*Actinodaphne sikkimensis* Meisn.	Lauraceae	–	10	–
6	*Ainsliaea aptera* DC.	Asteraceae	–	–	70
7	*Ajuga lobata* D.Don	Lamiaceae	–	–	51
8	*Aletris gracilis* Rendle	Nartheciaceae	–	–	45
9	*Anaphalis controta* Hook.f.	Asteraceae	–	–	8
10	*Anaphalis margaritacea* (L.) Bentham & Hook.f.	Asteraceae	–	–	13
11	*Anthogonium gracile* Wall.	Orchidaceae	–	–	3
12	*Aralia leschenaultii* (DC.) J.Wen	Araliaceae	–	1	–
13	*Arisaema* sp.	Araceae	–	–	1
14	*Astilbe rivularis* Buch.–Ham.	Saxifragaceae	–	–	3
15	*Balanophora* sp.	Balanophoraceae	–	–	1
16	*Begonia picta* Smith	Begoniaceae	–	–	2
17	*Blechnum orientale* L.	Blechnaceae	–	–	1
18	*Calanthe brevicornu* Lindl.	Orchidaceae	–	–	1
19	*Carex teres* Boott	Cyperaceae	–	–	8
20	*Castanopsis hystrix* A.DC.	Fagaceae	4	–	–
21	*Cautleya spicata* (Smith) Baker	Zingiberaceae	–	–	10
22	*Cerastium glomeratum* Thuillier	Caryophyllaceae	–	–	21
23	*Chamabainia cuspidata* Wight	Urticaceae	–	–	12
24	*Cinnamomum impressinervium* Meisn.	Lauraceae	6	–	–
25	*Clematis buchanania* DC.	Ranunculaceae	–	–	2
26	*Clematis montana* Buch.-Ham. ex DC.	Ranunculaceae	–	–	1
27	*Codonopsis inflata* Hook.f. & Thomson	Campanulaceae	–	–	1
28	*Commelina paludosa* Blume	Commelinaceae	–	–	8
29	*Commelina suffruticosa* Blume	Commelinaceae	–	–	4
30	*Crawfurdia speciosa* Wall.	Gentianaceae	–	–	1
31	*Cryptomeria japonica* (Thunb. ex L.) D.Don	Cupressaceae	19	–	–
32	*Curculigo orchioides* Gaertn.	Hypoxidaceae	–	–	10
33	*Cyperus* sp.	Cyperaceae	–	–	94
34	*Didymocarpus pulcher* C.B. Clarke	Gesneriaceae	–	–	5
35	*Drymaria cordata* Willd. ex Schult.	Caryophyllaceae	–	–	8
36	*Dryopteris* sp.	Dryopteridaceae	–	–	2
37	*Duchesnea indica* (Andrews) Teschem.	Rosaceae	–	–	17
38	*Duhaldea eupatorioides* (DC.) Anderb.	Asteraceae	–	–	2
39	*Elatostema dissectum* Wedd.	Urticaceae	–	–	14
40	*Elatostema hookerianum* Wedd.	Urticaceae	–	–	20
41	*Elatostema lineolatum* Wight	Urticaceae	–	–	5
42	*Elatostema obtusum* Wedd.	Urticaceae	–	–	2
43	*Elatostema* sp.	Urticaceae	–	–	86
44	*Elsholtzia* sp.	Labiateae	–	–	2
45	*Epilobium* sp.	Onagraceae	–	–	1
46	*Euonymus echinatus* Wall.	Celastraceae	–	–	25
47	*Eupatorium adenophorum* (Spreng.) R.M.King & H. Rob.	Asteraceae	–	–	9
48	*Eurya acuminata* DC.	Pentaphylacaceae	20	42	–
49	*Eurya cavinervis* Vesque	Pentaphylacaceae	11	10	–
50	*Eurya crassifolia* (D. Don) Kobuski	Pentaphylacaceae	1	–	–
51	*Exbucklandia populnea* (R.Br. ex Griff.) R.W.Br.	Hamamelidaceae	1	–	–
52	Fern	Fern	–	–	29
53	*Ficus semicordata* Buch.–Ham. ex Smith	Moraceae	–	–	2
54	*Fragaria nubicola* Lindl. ex Lacaita	Rosaceae	–	–	1
55	*Fragaria rubiginusa* Lacaita	Rosaceae	–	–	3
56	*Galium elegans* Wall.	Rubiaceae	–	–	4
57	*Galium hirtiflorum* Req. ex DC.	Rubiaceae	–	–	4
58	*Gaultheria nummularioides* D.Don	Ericaceae	–	–	11

Continued

Appendix 2. *Continued*

No.	Name	Family	Trees	Shrubs	Herbs
59	*Gentiana pedicellata* (D.Don) Griseb.	Gentianaceae	–	–	11
60	*Geranium nepalense* Sweet	Geraniaceae	–	–	2
61	*Girardinia diversifolia* (Link) Friis	Urticaceae	–	–	1
62	*Globba racemosa* Smith	Zingiberaceae	–	–	32
63	*Hedera nepalensis* K.Koch	Araliaceae	–	–	4
64	*Hemidesmus indicus* (L.) R.Br. ex Schult.	Apocynaceae	–	–	9
65	*Hydrangea febrifuga* (Lour.) Y.De Smet & C. Granados	Hydrangeaceae	–	–	2
66	*Hypericum hookerianum* Wight & Arn.	Hypericaceae	–	–	1
67	*Ilex dipyrena* Wall.	Aquifoliaceae	1	2	–
68	*Ilex kingiana* Cockerell	Aquifoliaceae	2	5	–
69	*Impatiens* sp.	Balsaminaceae	–	–	6
70	*Jasminum dispermum* Wall.	Oleaceae	–	–	3
71	*Lindera pulcherrima* (Nees) Benth. ex Hook.f.	Lauraceae	–	4	–
72	*Lipparis* sp.	Orchidaceae	–	–	1
73	*Lithocarpus pachyphyllus* Rehder	Fagaceae	14	4	–
74	*Litsea elongata* (Nees) Hook.f.	Lauraceae	2	4	–
75	*Litsea lancifolia* (Roxb. ex Nees) Fern.-Vill.	Lauraceae	1	–	–
76	*Loxostigma griffithii* (Wight) C.B.Clarke	Gesneriaceae	–	–	6
77	*Lycopodium cernuum* L.	Lycopodiaceae	–	–	1
78	*Lycopodium clavatum* L.	Lycopodiaceae	–	–	3
79	*Lyonia ovalifolia* (Wall.) Drude	Ericaceae	2	–	–
80	*Lysimachia japonica* Thunb.	Primulaceae	–	–	6
81	*Machilus edulis* King ex Hook.f.	Lauraceae	1	–	–
82	*Maesa chisia* D.Don	Myrsinaceae	3	8	–
83	*Mahonia nepaulensis* DC.	Berberidaceae	–	2	–
84	*Maianthemum oleraceum* (Baker) LaFrankie	Asparagaceae	–	–	9
85	*Maianthemum purpureum* (Wall.) LaFrankie	Asparagaceae	–	–	10
86	*Malaxis* sp.	Orchidaceae	–	–	3
87	*Melanoseris brunoniana* (Wall. ex DC.) N.Kilian & Ze H.Wang	Asteraceae	–	–	2
88	*Monotropa uniflora* L.	Ericaceae	–	–	6
89	*Myriactis nepalensis* Less.	Asteraceae	–	–	2
90	*Natsiatum herpeticum* Buch.–Ham. ex Arn.	Menispermiaceae	–	–	5
91	*Neocinnamomum caudatum* (Nees) Merr.	Lauraceae	1	–	–
92	*Neolitsea calcicola* Z.R.Xu	Lauraceae	1	–	–
93	*Neolitsea foliosa* (Nees) Gamble	Lauraceae	1	–	–
94	*Ophiopogon intermedius* D.Don	Asparagaceae	–	–	78
95	*Ophiorrhiza rugosa* Wall.	Rubiaceae	–	–	1
96	*Oplismenus burmanni* (Retz.) P.Beauv.	Poaceae	–	–	143
97	*Oxalis acetocella* L.	Oxalidaceae	–	–	3
98	*Paris polyphylla* Smith	Melanthiaceae	–	–	2
99	*Parthenocissus* sp.	Vitaceae	–	–	1
100	*Peperomia tetraphylla* Hook. & Arn.	Piperaceae	–	–	1
101	*Peracarpa carnosa* Hook. f. & Thomson	Campanulaceae	–	–	60
102	*Persicaria chinensis* (L.) H. Gross	Polygonaceae	–	–	34
103	*Phlomoides hamosa* (Benth.) Mathiesen	Labiateae	–	–	12
104	*Pieris formosa* (Wall.) D.Don	Ericaceae	1	72	–
105	*Pilea bracteosa* Wedd.	Urticaceae	–	–	12
106	*Pilea scripta* (Buch.-Ham. ex D.Don) Wedd.	Urticaceae	–	–	43
107	*Piper sylvaticum* Roxb.	Piperaceae	–	–	8
108	*Plagiogyra pycnophylla* (Kuntze) Mett.	Plagiogyraceae	–	–	15
109	*Polystichum lentum* (D. Don) T.Moore	Polypodiaceae	–	–	11
110	*Prunus napaulensis* (Ser.) Steud.	Rosaceae	–	1	–
111	*Pteridium* sp.	Pteridaceae	–	–	3
112	*Pteris biaurita* L.	Pteridaceae	–	–	24
113	*Quercus glauca* Thunb.	Fagaceae	6	–	–

Continued

Appendix 2. *Continued*

No.	Name	Family	Trees	Shrubs	Herbs
114	*Quercus lamellosa* Smith	Fagaceae	7	–	–
115	*Quercus lanata* Smith	Fagaceae	22	–	–
116	*Quercus oxyodon* Miq.	Fagaceae	23	–	–
117	*Quercus semiserrata* Roxb.	Fagaceae	4	–	–
118	*Quercus thomsoniana* A.DC.	Fagaceae	2	–	–
119	*Remusatia pumila* (D.Don) H.Li & A.Hay	Araceae	–	–	5
120	*Remusatia vivipara* (Roxb.) Schott	Araceae	–	–	3
121	*Rhododendron arboreum* Smith	Ericaceae	17	4	–
122	*Rhododendron grande* Wight	Ericaceae	1	–	–
123	*Rhododendron griffithianum* Wight	Ericaceae	–	1	–
124	*Rubia manjith* Roxb. ex Flem.	Rubiaceae	–	–	10
125	*Rubia wallichiana* Decne.	Rubiaceae	–	–	4
126	*Rubus buergeri* Miq.	Rosaceae	–	–	2
127	*Rubus calycinus* Wall.	Rosaceae	–	–	28
128	*Rubus paniculatus* Smith	Rosaceae	–	–	2
129	*Rubus thomsonii* Focke	Rosaceae	–	–	1
130	*Sanicula elata* Buch.-Ham. ex D.Don	Umbelliferae	–	–	3
131	*Scutellaria violacea* B.Heyne ex Benth.	Labiateae	–	–	33
132	*Scutellaria violacea* var. *sikkimensis* Hook.f.	Labiateae	–	–	4
133	*Senecio scandens* Buch.-Ham. ex D.Don	Asteraceae	–	–	1
134	*Setaria plicata* (Lam.) T. Cooke	Poaceae	–	–	15
135	*Smilax elegans* Wall.	Smilacaceae	–	–	6
136	*Smilax lanceifolia* Roxb.	Smilacaceae	–	–	4
137	*Smilax minuta* S.C. Chen	Smilacaceae	–	–	34
138	*Smilax minutiflora* A.DC	Smilacaceae	–	–	7
139	*Solanum macracanthum* A.Rich.	Solanaceae	–	–	3
140	*Stauntonia latifolia* (Wall.) R.Br.	Lardizabalaceae	–	–	2
141	*Stellaria sikkimensis* Hook.f.	Caryophyllaceae	–	–	4
142	*Streptolirion volubile* Edgew.	Commelinaceae	–	–	4
143	*Strobilanthes divaricata* (Nees) T.Anderson	Acanthaceae	–	–	41
144	*Strobilanthes* sp.	Acanthaceae	–	–	37
145	*Swertia nervosa* (G.Don) Wall. ex C.B.Clarke	Gentianaceae	–	–	1
146	*Symplocos caudata* Wall. ex G.Don	Symplocaceae	21	41	–
147	*Symplocos glomerata* King ex C.B.Clarke	Symplocaceae	10	92	1
148	*Symplocos lucida* Siebold & Zucc.	Symplocaceae	11	11	–
149	*Symplocos phyllocalyx* C.B.Clarke	Symplocaceae	–	3	–
150	*Symplocos theifolia* D.Don	Symplocaceae	21	–	–
151	*Synotis wallichii* (DC.) C.Jeffrey & Y.L.Chen	Asteraceae	–	–	5
152	*Tetradium fraxinifolium* (Hook.) T.G.Hartley	Rutaceae	–	15	–
153	*Tetrastigma serrulatum* (Roxb.) Planch.	Vitaceae	–	–	27
154	*Tetrastigma* sp.	Vitaceae	–	–	4
155	*Thelypteris nudata* (Roxb.) C.V.Morton	Thelypteridaceae	–	–	14
156	*Thunbergia coccinea* Wall. ex D.Don	Acanthaceae	–	–	2
157	*Thunbergia lutea* T.Anderson	Acanthaceae	–	–	6
158	*Trifolium repens* L.	Leguminosae	–	–	
159	*Tupistra clarkei* Hook.f.	Asparagaceae	–	–	39
160	*Viburnum erubescens* Wall.ex DC.	Thymelaeaceae	–	–	8
161	*Viola hamiltoniana* D.Don	Violaceae	7	35	1
162	*Viola hookeriana* Kunth	Violaceae	–	–	7
163	*Viola pilosa* Blume	Violaceae	–	–	18
164	*Viola* sp.	Violaceae	–	–	39
165	*Yushania maling* (Gamble) R.B Majumdar & Karthik	Poaceae	–	–	30
	Total 2214		165	367	1682

Appendix 3. Comparative species composition of regeneration potential (number of new recruits per 0.04 ha) in Maling bamboo infested and Maling bamboo free plots in Senchal Wildlife Sanctuary, West Bengal, India

No.	Species	Maling plots (*n* = 10)		Non-Maling plots (*n* = 10)	
		Saplings	Seedlings	Saplings	Seedlings
1	*Acer campbellii* Hook.f. & Thoms. ex Hiern	–	4	–	–
2	*Actinodaphne longipes* Kosterm.	–	–	–	6
3	*Actinodaphne sikkimensis* Meisn.	–	–	10	–
4	*Aralia leschenaultii* (DC.) J.Wen	2	–	1	–
5	*Castanopsis hystrix* A.DC.	–	–	–	4
6	*Cinnamomum impressinervium* Meisn.	–	2	–	6
7	*Cryptomeria japonica* (Thunb. ex L.) D.Don	–	–	–	19
8	*Eurya acuminata* DC.	19	3	42	20
9	*Eurya cavinervis* Vesque	6	–	10	–
10	*Eurya crassifolia* (D.Don) Kobuski	–	1	–	–
11	*Exbucklandia populnea* (R.Br. ex Griff.) R.W.Br.	–	–	–	1
12	*Gamblea ciliata* C.B.Clarke	2	6	–	–
13	*Helwingia himalaica* Hook.f. & Thomson ex C.B.Clarke	1	–	–	–
14	*Ilex dipyrena* Wall.	–	–	2	–
15	*Ilex kingiana* Cockerell	–	–	5	2
16	*Lindera pulcherrima* (Nees) Benth. ex Hook.f.	–	–	4	–
17	*Lithocarpus pachyphyllus* Rehder	–	51	4	14
18	*Litsea elongata* (Nees) Hook.f.	–	–	4	–
19	*Lyonia ovalifolia* (Wall.) Drude	–	–	–	2
20	*Maesa chisia* D.Don	–	–	8	–
21	*Mahonia nepaulensis* DC.	1	–	2	–
22	*Pieris formosa* (Wall.) D.Don	3	–	72	1
23	*Prunus napaulensis* (Ser.) Steud.	–	–	1	–
24	*Quercus glauca* Thunb.	–	18	–	–
25	*Quercus oxyodon* Miq.	–	–	–	23
26	*Quercus thomsoniana* A.DC.	–	17	–	–
27	*Rhododendron arboreum* Smith	–	–	4	17
28	*Rhododendron grande* Wight	2		–	–
29	*Rhododendron griffithianum* Wight	–	–	1	–
30	*Symplocos caudata* Wall. ex G.Don	20	–	41	21
31	*Symplocos glomerata* King ex C.B.Clarke	49	8	92	8
32	*Symplocos lucida* Siebold & Zucc.	–	–	11	–
33	*Symplocos phyllocalyx* C.B.Clarke	2	–	3	–
34	*Symplocos theifolia* D.Don	–	7	–	16
35	*Tetradium fraxinifolium* (Hook.) T.G.Hartley	–	–	15	–
36	*Viburnum erubescens* Wall.ex DC.	91	–	35	7

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