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# Ecology of Sandalwood (*Santalum album* L.) at Lingmethang, Eastern Bhutan

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**Abstract**

A study was carried out at Lingmethang to find out the ecological requirement for the growth of Sandalwood (*Santalum album* L.) trees in Bhutan. It also aimed to determine the preferred hosts of Sandalwood in the study site and to map its habitat suitability in the country. Plot size of 20 x 20 $m^2$ for trees, 10 x 10 $m^2$ for shrubs, and 5 x 5 $m^2$ for regenerations and herbs were used. Soil samples were collected by digging soil to 25-30 cm depth from each plot. PC-ORD software was used for finding the relation of the variable with seedling abundance. A total of 19 tree species under 14 families and 40 undergrowth species under 24 families were recorded in the areas where Sandalwood is growing naturally. *Mallotus philippensis* and *Albizia sikkimensis* were the co-dominant tree species with chirpine as the dominant tree. *Chromolaena odorata* (Asteraceae) was the most preferred host species of the Sandalwood seedlings followed by *Murraya koenigii*. Mature Sandalwood tree was found parasitizing on *Desmodium* sp. (Fabaceae). Slope was one of the most determinant factors for the growth of Sandalwood ($r = .951$, $p < .05$), but rainfall had greater influence even though negative ($r = -.943$, $p < .05$) in the valley. Soil Nitrogen did not have much effect on the seedling abundance but mature trees prefered Fabaceae as hosts. A total of 16 dzongkhags are suitable for plantation of Sandalwood. Among these, Zhemgang Dzongkhag has the maximum potential area (469.62 $km^2$) and Punakha Dzongkhag has the least (2.88 $km^2$).

**Keywords:** Bhutan, ecology, hemi-parasitic, host, Sandalwood, *Santalum album,* suitability map

## Introduction

*Santalum album* L. (Sandalwood) is a commercially and culturally important plant species belonging to the family Santalaceae and the genus *Santalum*. There are around 18 Sandalwood species of genus *Santalum* (Baldovini *et al.*, 2011). Among various *Santalum* species, Indian Sandalwood (*S. album*), which is also sometimes referred as east Indian Sandalwood, stands out for its highly valued oil and aromatic wood (Arunkumar *et al.*, 2016). However, there is lack of knowledge on the ecology and the distribution of this commercially valued species due to inadequate research (Subasinghe, 2013). Due to hemi-parasitic nature, finding suitable host species

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is a limitation in establishment of Sandalwood plantations (Silva *et al.*, 2016). In India, the area under Sandalwood is decreasing fast due to illegal collection and its difficulty in planattion establishment (Rocha *et al.*, 2014).

In Bhutan, the Sandalwood is known by the local name "*Tsenden Karp"* which is described as a woody plant that grows up to 10-12 m high. It was planted around a Research Centre at *Lingmethang*, Mongar (Wangchuk and Samten, 2009), which has escaped and established in the surrounding areas.

Due to high value of oil and timber, research in *Santalum album* has gained over the years (Jain *et al.*, 1998). In Bhutan, it has its cultural and religious significance as it is used for various purposes including in formulation of traditional medicine. Due to over harvesting in its natural habitat in India, it is listed as Vulnerable by the International Union for Conservation of Nature (IUCN) and is placed in Appendix II of CITES.

Owing to the immense value and its declining population in its natural habitats, opportunity for plantation of Sandalwood to satisfy its demand is huge (Jones, 2008). Considering its successful natural establishment at Lingmethang, this study aimed to identify the local host species and enumerate environmental factors supporting its natural population in the study area. The contributing factors are used to generate a habitat suitability map for growing Sandalwood in the country. This will provide opportunity for the farming communities to plant Sandalwood and benefit economically.

## Materials and Methods

*Study area*

Lingmethang is in eastern Bhutan at 27.264°N, 91.153°E. It is located in Mongar District, particularly to the west and close to the town of *Gyalpozhing*. It is one of the hottest places in Bhutan. The focus area is primarily covered by broadleaved and chirpine forest. It falls under *Saling gewog* which has an area of 479.5 km$^2$ with a population of 3,727 individuals (1,879 males and 1,849 females) consisting of 355 households (Mongar Dzongkhag Administration, 2019). The temperature in the study can vary between 15 to 30 degrees Celsius (59-86 degrees Fahrenheit). In the central part of the country, which consists of temperate and deciduous forests, the climate is more seasonal with warm summers and cool-dry winters (Bhutan Travels, 2019).

*Study design*

Purposive sampling was done in the Sandalwood established stands to collect data for host plants due to its confined distribution. Plot size of 20 x 20 m$^2$ for trees, 10 x 10 m$^2$ for shrubs, and 5 x 5 m$^2$ for regenerations and herbs were used following Seran *et al.* (2018) and Kacholi (2014).

Climatic and edaphic data were collected to analyze the ecological factors from all the plots. Mean annual temperature and annual precipitations were computed using Dorji *et al.* (2016). Soil samples were collected by digging soil to 25-30 cm depth from each plot (Clay *et al.*, 2002). A depth of 30 cm was dug around the Sandalwood trees and saplings to find the host association following Rocha *et al.* (2014). Primary, secondary and tertiary roots were examined to find the host association.

*Specimen identification*

The unidentified plant specimens from the field were taken to the National Biodiversity Centre at Serbithang to compare with the herbarium collections. Specimens that were identified untill their families were identified using Grierson and Long (1983-2001) (Flora of Bhutan).

*Vegetation analysis*

Cluster analysis was conducted based on slope with dominant forest types using PC-ORD (Dorji and Gurung, 2017). For NMS (Nonmetric Multidimensional Scaling) ordinations, two data matrices were used; one containing relative abundance of the Sandalwood regeneration data and the second containing environmental variables including mean annual temperature, mean annual rainfall, slope, aspect and soil data (pH, N, P, K moisture content and organic carbon). NMS ordination was performed for the Sandalwood regeneration status based on its relative abundance in each plot as the main matrix data and the environmental variables as the second matrix which were subsequently correlated and overlaid on the NMS axes. The distance measure used was Sorensen (Bray-Curtis). The "auto-pilot" and "medium" options were selected. This analysis used a series of repeated computations (iterations) to adjust the position of entities (plots) in ordination space including 400 randomisation to measure Sorensen distance and Monte Carlo test to check ordination stress. Pearson's correlation (*r*) was used to see the strength of correlation of variables between axes following Rowland *et al.* (2009).

*Dominant species*

Species association or correlation among species was determined to understand the influence of biotic factors enabling the growth of Sandalwood in the region. In order to calculate the most dominant associated tree species with the Sandalwood, Important Value Index (IVI) analysis was carried out using the following formulae based on Mishra *et al.* (2008).

IVI = Relative Dominance + Relative Density + Relative Frequency .

Associated co-dominant species was calculated using the modified formula developed by Ohsawa (1984).

$$d = \frac{1}{N}\{\Sigma\,(\chi i - \chi')2 \;+\; \Sigma\,\chi j\;2\,\}$$

Where χi is the actual percent share (relative basal area is adopted here) of the top species (T), i.e., in the top dominant in the one-dominant model, or the two top dominants in the two-dominant model and so on; χ' is the ideal percent share based on the model as mentioned above, χj is the percent share of the remaining species (*U*) and *N* is the total number of species.

*Soil data analysis*

For soild data analysis, the variables included were soil organic material, Nitrogen, Phosphorus, Potassium, soil reaction (pH), and soil moisture content.

*Suitable areas for Sandalwood plantation*

Based on the ecological data, suitable Sandalwood plantation sites were mapped across the country with the help of Q-GIS. Field data such as slope, precipitation, temperature and elevation in combination with Bhutan's Land Use and Land Cover data of 2010 through a simple model builder were used.

## Results and Discussion

*Tree species composition*

A total of 19 tree species was recorded from 15 plots. Based on the lifeform of the trees recorded in the plots, the Sandalwood habitats in the study region were divided into two major liefeforms. The evergreen lifeform comprised of *Santalum album, Persea* sp.*, Mallotus philippensis, Pinus roxburghii, Mangifera sylvatica, Citrus reticulata, Zyziphus mauritiana, Aegle marmelos, Rhus paniculata,* and *Syzygium* belonging to eight families and the deciduous trees consisted of *Albizia sikkimensis, Flueggea virosa, Sapium insigne, Zanthoxylum armatum, Wrightia arborea, Morus* sp.*, Phyllanthus emblica, Bombax ceiba,* and *Desmodium* sp. belonging to seven families.

*Undergrowth composition*

Undergrowth cover was classified under six life forms which included herbs, shrubs, grasses, climbers, ferns and sub-shrubs. A total of 40 undergrowth species under 24 families were recorded. P1 was dominated by *Justicia adhatoda* (shrub), P2, P3, P4, P5, P6, P9, P10 and P12 were dominated by *Chromolaena odorata* (shrub), P7 by *Rhus paniculata* (shrub), P8, P13 and P15 by *Murraya koenigii* (shrub),

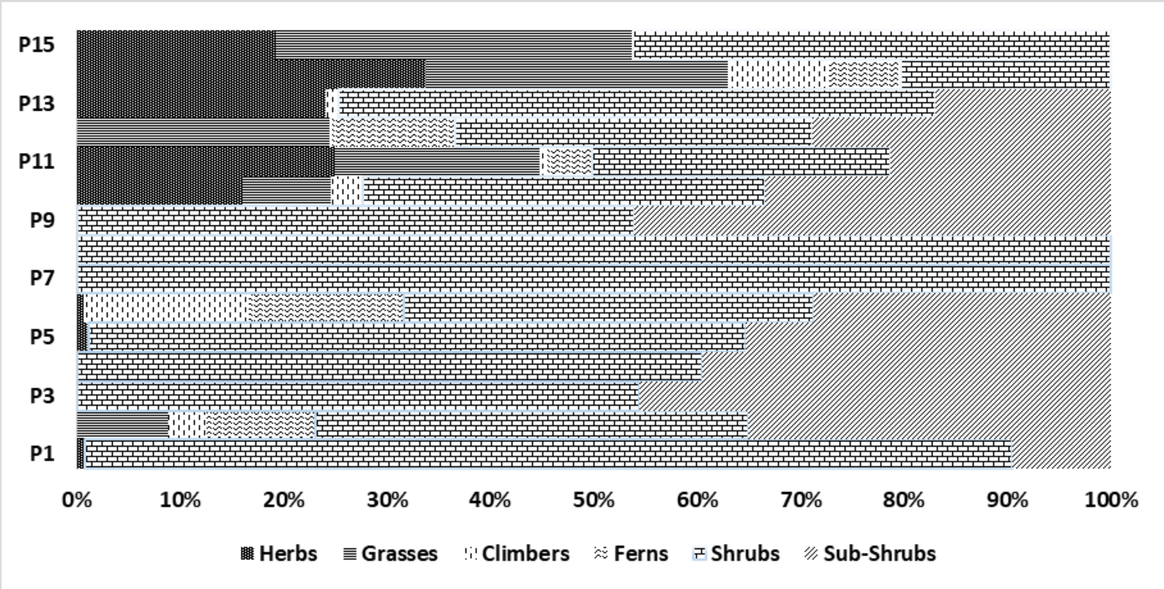


**Figure 1**: Undergrowth vegetation composition

P11 by (*Alternanthera sessilis*) herb and P14 with grass (*Oplismenus* sp.) (Figure 1). *C. odorata* is an invasive species and occupies barren areas at lower altitude.

*Co-dominant tree species*

With the help of Important Value Index (IVI) the dominant species of trees were calculated. Out of 19 associated tree species recorded, the top most tree species with the highest value of IVI after *Santalum album* was selected as the most co-dominant tree species. *Pinus roxburghii* was the most co-dominant associated tree species in the Sandalwood established forest (Table 1) which is predominant with dry soil as mentioned by Singh and Singh (2011) and Padmanabha (2003). Although Nurochman *et al.* (2018) reported that *Syzygium cumuni* has a strong association with Sandalwood in Indonesia, it was not the case in this study, which had the least IVI value of 2.73 among the 19 species. The girth data from the incidental distribution of Sandalwood outside the plantation sites were compared with the girth of Sandalwood trees found inside the plantation sites.

A Mann-Whitney test compared the tree girths of sandalwood from the two sites. No

**Table 1:** Important Value Index (IVI)

| Species | Total number of | Relative | Relative | Relative | IVI |
|---|---|---|---|---|---|
| *Santalum album* | 71 | 47.973 | 29.412 | 17.906 | 95.29 |
| *Pinus roxburghii* | 17 | 11.486 | 7.843 | 18.243 | 37.57 |
| *Mallotus philippensis* | 18 | 12.162 | 9.804 | 14.109 | 36.08 |
| *Albizia sikkimensis* | 13 | 8.784 | 13.725 | 11.445 | 33.95 |
| *Zyziphus mauritiana* | 1 | 0.676 | 1.961 | 0.221 | 2.86 |
| *Zanthoxylum armatum* | 1 | 0.676 | 1.961 | 0.217 | 2.85 |
| *Syzygium cumini* | 1 | 0.676 | 1.961 | 0.095 | 2.73 |

Note: Qs is the number of quadrats

significant difference in the results of the tree girth was found ($U$ = 14, $p$ > .05). The tree girth of sandalwood outside the planation sites averaged 6.25 cm and those inside the plantations averaged 10 cm.

*Associated co-dominant tree species*

Sandalwood was the most dominant tree species, followed by *Mallotus philippensis* as the first co-dominant associated tree species in Sandalwood forest as shown in Table 2. A similar finding was recorded in the Floral Diversity of the Indian Sandalwood, Marayoor Sandal Provenance of Kerela, written by Sundararaj and Sharma (2010). Fabaceae is one of the most preferred host family of plants for Sandalwood growth as reported by Radomiljac (1998). Barbour (2008) also reported *Sesbania formosa* (Fabaceae) as the primary host for the Sandalwood in Australia. With *Albizia sikkimensis* as the next co-dominant tree species in the study sites, which belongs to family Fabaceae, the finding is similar to the previous studies mentioned above.

*Undergrowth dominance*

Undergrowth species dominance analysis was done with the help of PC-ORD software following Rosabal *et al.* (2010) to determine the most dominant undergrowth species. *Chromolaena odorata* stands out top followed by *Murraya koenigii, Oplismenus* sp., *Rhus paniculata, Desmodium* sp., *Alternanthera sesillis, Adiantum philipense, Justisia adhatoda, Strobilanthes* sp. and *Creptolepis* sp.

*Hosts of Sandalwood*

Within the 15 plots, 22 random attempts were made to dig the regenerations and the Sandalwood trees to confirm the most suitable hosts in the area. Sandalwood seedlings were found parasitizing on *Chromolaena odorata* (12) followed by *Murraya koenigii* (5). Whereas in Sri Lanka its primary host is *Trithonia diversifolia* (Tennakoon and Cameron, 2006) belonging to family Asteraceae, which is absent in the study area. A matured Sandalwood tree was observed to be parasitizing on the roots of *Desmodium* sp. (1). Least encountered host was *Paederia foetida* (1) (Table 3). In an experiment carried out by Radomiljac (1998), *Alteranthera nana* (Amaratheceae) and *Senna formosa* (Fabaceae) were identified as the most effective hosts both of which are absent in the study area.

Parasitizing *Desmodium* sp. by a mature Sandalwood tree indicates potential supply of nitrogen by the host as Sandalwood with age requires more nitrogen. Barbour (2008) reported that as the Sandalwood tree ages, there is an increasing demand for nitrogenous compounds which the Fabaceae family can provide. Therefore, considering the parasitizing nature of seedlings and mature Sandalwood trees, vegetation composition may play an important role in the germination of the Sandalwood seedlings.

The formation of haustorium was more or less confined to younger roots (Figure 2). They arise from external layers of rootlets, unlike lateral rootlets, which are formed deep in hosts' tissues as noted by Sathe and Chauhan (2003). Therefore, in this study, the primary hosts of seedlings were identified as *Chromolaena odorata* followed by *Murraya koenigii* based on their dominance. Although *C. odorata* is considered invasive in nature, Woodall and Robinson (2002) reported that parasitism of hosts by Sandalwood can weaken and cause the death of the host, particularly when it is at a young stage. So, growing Sandalwood trees could

**Table 2:** Associated co-dominant species

| Species | RBA | 100% | 50% | 33.33% | 25.00% | 20% |
|---|---|---|---|---|---|---|
| *Santalum album* | 30.28 | 4860.80 | 388.90 | 9.10 | 27.90 | 105.70 |
| *Pinus roxburghii* | 16.18 | 261.80 | 1143.70 | 293.00 | 77.80 | 14.60 |
| *Mallotus philippensis* | 13.44 | 180.60 | 180.60 | 394.40 | 133.60 | 43.00 |
| *Albizia sikkimensis* | 10.87 | 118.10 | 118.10 | 118.10 | 199.80 | 83.40 |

**Table 3:** Showing the dominant host plants for Sandalwood in the study site

| Species | Frequency | Relative Frequency | Remarks |
|---|---|---|---|
| *Chromolaena odorata* | 12 | 54.55 | |
| *Paederia foetida* | 1 | 4.55 | |
| *Murraya koenigii* | 5 | 22.73 | |
| *Desmodium* sp. | 1 | 4.55 | By mature tree |
| *Zanthoxylum armatum* | 3 | 13.64 | |
| **Total** | 22 | 100 | |

control invasive *C. odorata* in the area.

*Environmental variable assessment*

Kendall's tau correlation was performed to analyse the soil factors influencing Sandalwood growth. The result showed that none of the six soil parameters had significant association with the growth of the Sandalwood in the study site (Table 4). However, a significant association of nitrogen was noted with soil moisture ($t$ = 0.65, $p < .01$) and soil carbon ($t$ = 0.65, $p < .01$). This indicates that soil moisture is a critical environmental factor that determines the soil nitrogen and carbon content.

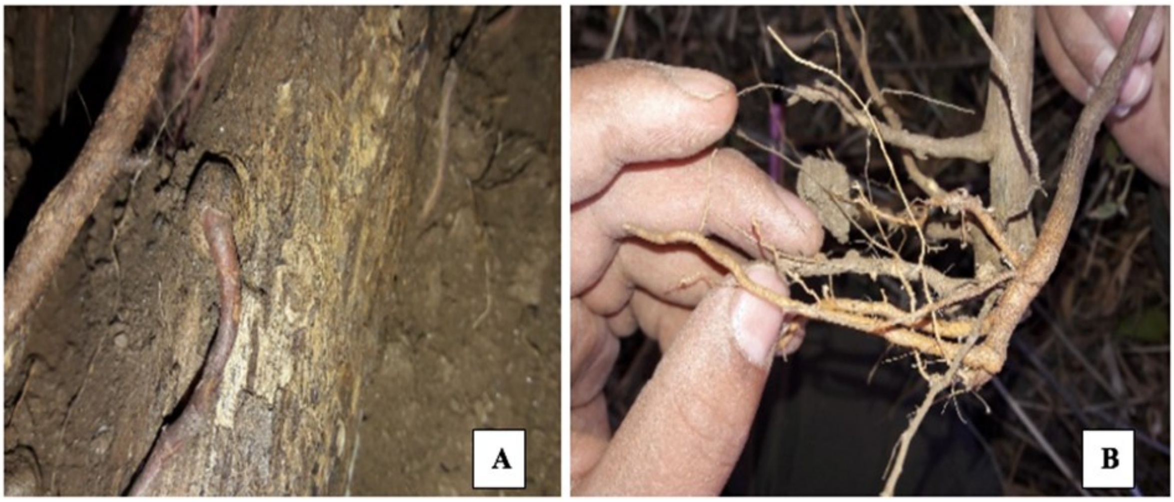


**Figure 2:** Haustorium nature of Sandalwood (A: seedling parasitizing on *Chromolaena odorata,* B: mature tree parasitizing on *Desmodium* sp.

**Table 4:** Kendall's tau correlation matrix

| Parameters | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1. Tree counts | 1 | | | | | | | |
| 2. Seedling counts | -.419* | 1 | | | | | | |
| 3. Soil pH | 0.221 | -0.367 | 1 | | | | | |
| 4. Soil (P) | 0.342 | -0.367 | -0.01 | 1 | | | | |
| 5. Soil (N) | 0.101 | -0.077 | 0.105 | 0.086 | 1 | | | |
| 6. Soil (K) | 0.161 | -0.077 | 0.352 | -0.086 | 0.257 | 1 | | |
| 7. Soil (moisture) | 0.133 | -0.296 | 0.107 | 0.34 | .651** | 0.185 | 1 | |
| 8. Organic C | 0.101 | -0.077 | 0.105 | 0.086 | 1 | 0.257 | .651** | 1 |

**Table 5:** Showing the result of the soil minerals

| | Soil pH | P(ppm) | N(%) | K(mg/kg) | Moisture (%) | C(%) |
|---|---|---|---|---|---|---|
| Lowest | 6.5 | 12 | 0.06 | 12.26 | 0.8 | 0.71 |
| Average | 7.29 | 38.19 | 0.1 | 325.94 | 2.48 | 1.16 |
| Highest | 8.36 | 60.4 | 0.23 | 690.17 | 9 | 2.71 |

*Soil nutrients*

Highest soil pH was recorded from Plot 11 (8.36) and lowest in Plot 15 (6.50 [Table 5]). Similarly, highest Phosphorus content was in Plot 5 (60.40) and the lowest in Plot 15 (12.00). Maximum nitrogen content was in Plots 7, 8, and 9 with lowest in Plot 13. Likewise, the highest potassium was recorded in Plot 13 and lowest in Plot 1. Similarly, organic carbon was highest in Plot 13 and lowest in Plot 9.

Soil moisture was highest in Plot 13 and lowest in Plot 15. In India, Rajan and Jayalakshmi (2017) reported the suitable range of soil moisture between 3.70-114.86 kg/$m^2$ and soil pH between 3.11-7.30 for the growth of Sandalwood. Comparatively, in the study area the soil pH ranged between 6.5 to 8.36, which is high but the soil moisture content was low. Low moisture content could be attributed to the time of study, which avoided monsoon season. Mishra *et al.* (2018) reported that the Sandalwood can grow in soil pH up to 9.0, but cannot grow in waterlogged sites.

*Climatic variables*

According to Rajan and Jayalakshmi (2017), the most suitable mean annual temperature,

**Table 6:** Suitable environmental variables for the growth of Sandalwood in the region

| | Altitude (m) | Mean annual temperature ($^0$C) | Mean annual rainfall (mm) |
|---|---|---|---|
| Minimum | 559 | 21.58 | 592.63 |
| Average | 699.93 | 22.23 | 950.43 |
| Maximum | 820 | 22.97 | 1516.75 |

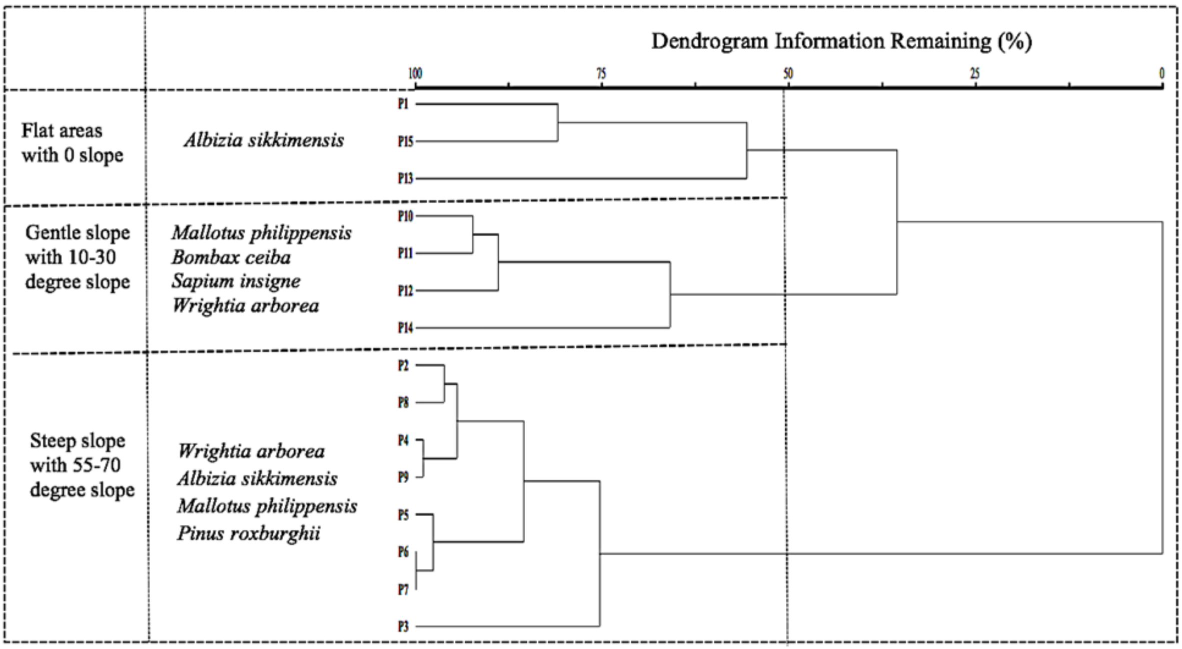


**Figure 3:** Cluster dendrogram based on the steepness of the areas and the dominant trees

altitude, mean annual rainfall ranges are 19.05-28.90 ºC, 451-1,951.36 m and 981.85-1,983.95 mm respectively in southern India. The study site had similar ranges of these variables which could be the reasons for successful establishment of Sandalwood seedlings.

The suitable slope for the growth of the Sandalwood in the region was recorded as $0^0$ to $70^0$ with an average slope of $40.67^0$ which is little steep that is helpful in avoiding waterlog condition (Table 6). Padmanabha (2003) reported that Sandalwood needs sloppy areas for good drainage. In this study, Sandalwoods were predominant in the south facing slopes.

*Cluster analysis using slope*

Sandalwood sites were classified into three broad clusters based on slope percent. A Mann-Whitney test using the incidental data showed no significant difference ($U$ = 14, $p$ > .05) in the girth of the Sandalwood growing in these sites. In plots with $0^0$ slope, the only dominant tree species was *Albizia sikkimensis*. This was replaced by *Mallotus*, *Bombax*, *Sapium* and *Wrightia* in the gentle slope. At higher slope

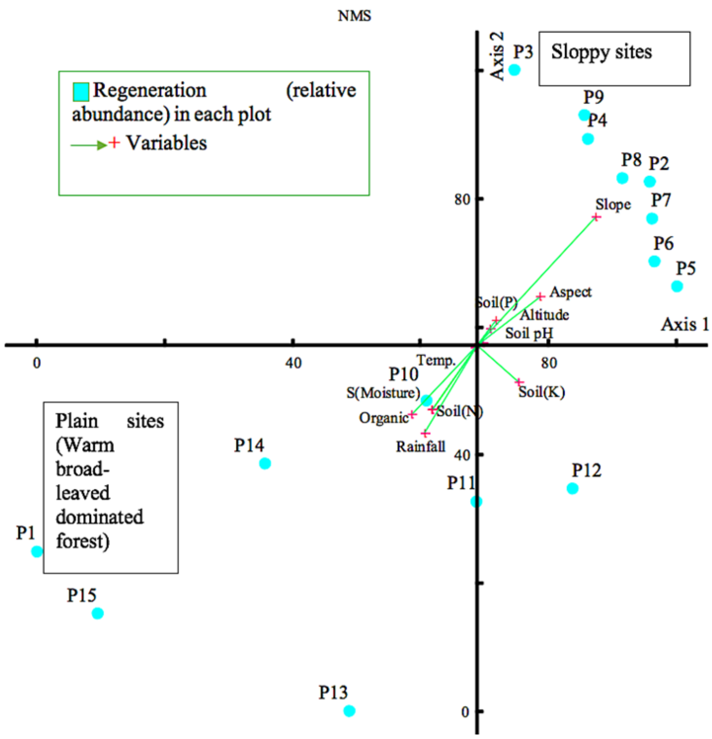


**Figure 4:** Non-metric Multidimensional Scaling

*Pinus roxburghii* sarted to feature as one of the dominant species as shown in Figure 3.

*Ordination using Non-metric Multidimensional Scaling (NMS)*

In Figure 4, Axis 1 is mostly associated with slope, Phosphorus, altitude and soil pH. The plots associated with Axis 1 had higher slope with *Pinus roxburghii* as one of the dominant species. Whereas Axis 2 was associated with temperature, precipitation, Nitrogen, Organic carbon and soil moisture. The research plots in this group predominantly had broadleaved species.

Based on the Ordination Axes (Table 7) showing the Pearson and Kendall tau correlations, slope had the maximum influence ($r$ = .951, $t$ = 0.811) on the relative abundance of Sandalwood regeneration (P2, P3, P4, P5, P6, P7, P8 and P9). Effect of Phosphorus, Potassium and pH was negligible on the seedlings of Sandalwood. In this study, slope was important factor for the growth of Sandalwood as reported by Padmanabha (2003) and other adaphic factors had almost no effect on the growth as noted by Viswanath *et al.* (2009).

*Relationship between DBH and height*

There was significant relationship between the height and the DBH of the Sandalwood, $r$ = .643, $p$ < .01. This could be because of young regeneration growth of Sandalwood trees in the sites. There were not many matured trees ready for harvest.

*Suitable Sandalwood plantation sites in Bhutan*

Since the range of temperature and altitude was very small in the study site, some variables used in this

**Table 7:** Pearson and Kendall Correlations with Ordination Axes $N = 15$

| **Axis** | **1** | | | **2** | | |
|---|---|---|---|---|---|---|
| | *r* | $r^2$ | *tau* | *r* | $r^2$ | *tau* |
| Slope (Deg) | 0.951 | 0.904 | 0.811 | 0.872 | 0.76 | 0.551 |
| Altitude (m) | 0.82 | 0.672 | 0.721 | 0.638 | 0.408 | 0.375 |
| Temperature (Deg) | -0.826 | 0.683 | -0.721 | -0.635 | 0.403 | -0.375 |
| Soil (K) | -0.366 | 0.134 | -0.333 | 0.363 | 0.132 | 0.371 |
| Soil pH | 0.114 | 0.013 | 0.86 | 0.378 | 0.143 | 0.295 |
| Soil (P) | 0.331 | 0.109 | 0.219 | 0.258 | 0.066 | 0.2 |
| Soil (N) | -0.728 | 0.531 | -0.604 | -0.511 | 0.262 | -0.342 |
| Soil (moisture) | -0.569 | 0.323 | -0.254 | -0.341 | 0.116 | -0.117 |
| Precipitation (mm) | -0.943 | 0.89 | -0.79 | -0.893 | 0.797 | -0.505 |
| Organic C | -0.721 | 0.52 | -0.581 | -0.503 | 0.253 | -0.257 |

study are based on previous study findings from India. The range of mean annual temperature (MAT) and altitude was within the range studied by Rajan and Jayalakshmi (2017) therefore, MAT and the altitude data of this study was used along with other determinant variables.

There are 16 districts in Bhutan where Sandalwood plantations can be carried out (Figure 5). Zhemgang Dzongkhag has the highest suitable area of 469.62 $km^2$ of land where the species can be planted. Among these Dzongkhag, Punakha Dzongkhag had the least suitable area of 2.88 $km^2$ of land suitable for the plantation. If Sandalwood plantation can be taken up by farming communities in these potential areas, the plantations may provide additional income for the rural people.

## Conclusions

The study assessed the host species and ecological factors supporting Sandalwood growth in Bhutan. A total of 19 tree species with *Pinus roxburghii* as the most dominant species followed by *Mallotus philippensis* and *Albizia sikkimensis* were recorded. *Syzygium cumini* had a weak association with the Sandalwood growth. Sandalwood seedlings established well in the slopy areas which escaped from the plantation sites. There was no significant difference in the girth of Sandalwood trees growing in the natural and plantation sites ($p$ = .068).

Although this research could find only one host species of a mature Sandalwood tree, there could be more host species which require further study. *Chromolaena odorata* was the most preferred host species of Sandalwood seedlings, so plantation of useful Sandalwood trees could help controlling invasive *C. odorata* in Bhutan. A map showing potential areas for growing Sandalwood showed that local communities from 16 Dzongkhags could benefit economically from Sandalwood plantations.

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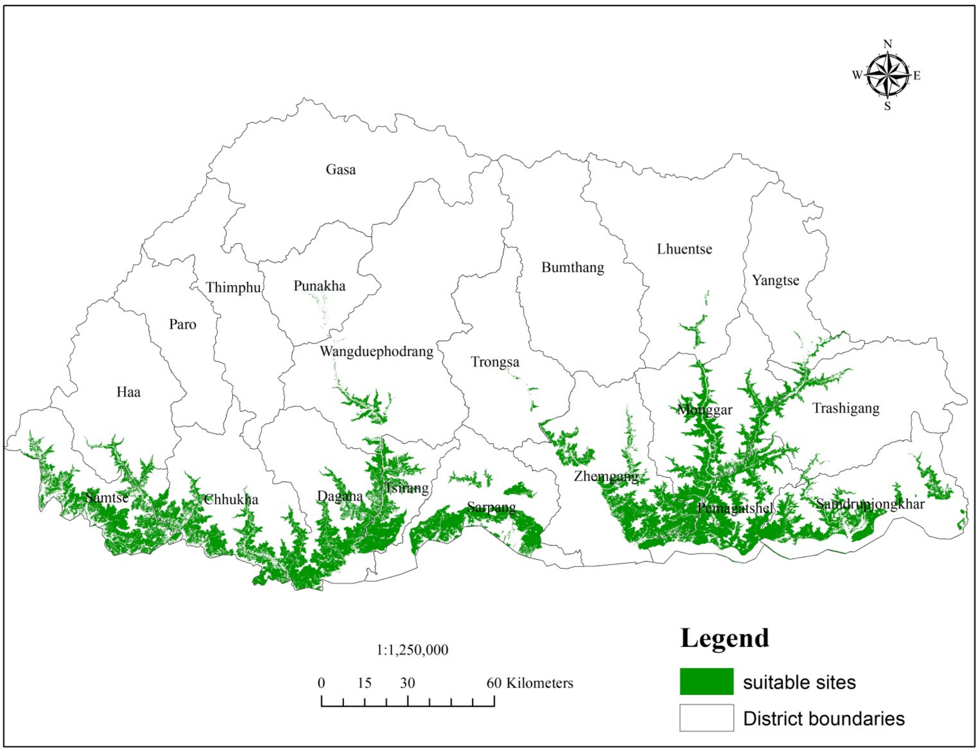


**Figure 5:** Map showing potentials areas to grow Sandalwood

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