BJNRD (2014), 1(1): 1-10

Bhutan Journal of Natural Resources & Development

Article

www.bjnrd.org

Open Access

ISSN 2409–2797 (Print)
ISSN 2409–5273 (Online)

doi: http://dx.doi.org/10.17102/cnr.2014.01

Structure and Composition of the Natural Sal (*Shorea robusta* Gaertner f.) Forest, Gomtu, Southern Bhutan

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Abstract

Scattered pockets of natural hill Sal forest in the southern foothills of Bhutan are the only remnant forests important for protection and conservation in southernmost Bhutan. The ecological study of Sal forest in Gomtu is the first of its kind in Bhutan and is aimed at enhancing future management and conservation programmes. We wanted to understand the floristic composition, diversity, and structural traits of this forest type in detail. A total of nine plots were sampled along the altitudinal gradients; trees and epiphytic vegetation were enumerated in all the plots. A total of 91 tree species belonging to 38 families were recorded (51 trees, 30 shrubs, 7 woody climbers and 3 palm species). Floristically, two major life-forms were exhibited; deciduous forest in the upper elevations mainly dominated by *Shorea robusta* and evergreen broad-leaved forest at the lower elevations. The entire study area was demarcated into three different forest types using cluster analysis; a *Shorea* dominant one on the ridge top, a *Schima* dominant one with *Shorea* at the lower altitudes, and a riparian one at the lowest altitude. The *Shorea* dominated type showed relatively low diversity and species richness compared to the other two types. The total basal area of *Shorea robusta* was 86,786.5 cm^2/3,200 m^2 while the stem density was 123 stem/3,200 m^2. The basal area increased from 2,146.2 cm^2/400 m^2 to 18,926.0 cm^2/400 m^2 while stem density increased from 3 stems/400 m^2 to 32 stems/400 m^2 with increasing altitude. However, the maximum estimated tree height decreased from 41.3 to 22.4 m approaching ridge tops. The study provided clear evidence that the most suitable range for the hill Sal forest was from a high altitude of 600 metre above sea level down to 527 m on northwest-facing ridge slopes.

Key words: Natural hill Sal forest, floristic composition, diversity, structure

Introduction

Tropical rain forest is absent in the Bhutan Himalaya, yet there are several tropical genera and species along the foothills contiguous with natural Sal forest. *Shorea robusta* Gaertner f., in the Dipterocarpaceae family, is commonly known as Sal in India, Nepal and Bhutan. It is a light-demanding and deciduous tree (from February to March) and grows up to 45 m tall, frequently forming a nearly mono-specific canopy (Champion and Seth, 1968; Stainton, 1972; Ohsawa, 1983; Rautiainen and Souheimo, 1997; Pandey and Shukla, 2001). Sal thrives in a wide range of well drained soils (Champion and Seth, 1968; Stainton, 1972; Dinerstein, 1979; Banerjee *et al.*, 1992) and requires high temperatures with substantial rain during the monsoon and a dry period of about 4 months (Tewari, 1995; Rahman *et al.*, 2010). According to Kawakita (in Numata ed., 1983), the suitable Warmth Index (WI) for *Shorea* zone is 165 – 240. The natural Sal forest is distributed in the Southeast Asia and mostly prevalent along the foothills of the Himalaya in India, Nepal, Bhutan, Bangladesh, and South China (Rautiainen and Suoheimo, 1997; Rautiainen, 1999; Sapkota, 2009; Chitale and Behera, 2012). According to Tewari (1995), the total coverage of the Sal forest amounts to about 11.16 m/ha.

In Nepal and India, Sal is considered to be one of the most valuable tree species. It is used for constructions and is the main source of fuel wood for the people of Terai (Timilsina *et al.*, 2007). Sal leaves are valuable fodder and used for making

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Received, Aug. 2014. Accepted, Sept. 2014

disposable plates (Jackson, 1994). Tannin and gum are collected from the bark, and oil is extracted from its seeds (Chitale and Behera, 2012). Thus, Sal forests are among the most heavily utilised and disturbed forest types in Southeast Asia (Sapkota *et al.*, 2009). However, in Bhutan, it is the least studied forest type, hence limited information on its habitat is available. Southernmost Bhutan may be the last natural refuge for *S. robusta* in an era of climate change. Elsewhere, human disturbances are major threats to the sustainability of the Sal forest, and in our study area, conspicuous mining activities present a serious threat. Therefore, protection and conservation of the natural Sal forest of Bhutan are absolutely critical. The findings of this study could be useful for future management and conservation efforts.

Materials and Method

The study area is located in Pagli *Geog* (block) (26^{0}49'N; 89^{0}12'E) under Samtse *Dzongkhag* (districts) bordered by Tading Geog to the east and Samtse Geog to the north and west, and the Indian state of West Bengal to the south (Figure 1B). The area receives a total annual rainfall of 4,000 mm with prevailing hot and wet summers and warm winters. A field survey was conducted on one of the ridge tops where *S. robusta* dominates and where human interference is minimal. The study area stretched from 517 m near Khanabarti River to 617 m at Khurkhurey Banjang near the Uttaray mining site.

The field work was conducted from December 2012 to January 2013. A total of nine plots were sampled along the altitudinal gradients with an altitudinal interval of 20 m between each plot (Figure 1C) and a plot size of 20 x 20 m was adopted. Field equipment consisted of a digital hypsometer, a compass, a clinometer, a hand-held GPS unit, a diameter tape, and a measuring tape. All trees occurring within the quadrat attaining a height greater than 1.3 m were measured. The diameter at breast height (DBH) was measured to determine the basal area (BA). Total tree height (H), height of the lowest living branch (HB), and height of the lowest living leaf (HL) were measured to determine height distribution.

Instant soil moisture content was measured along the altitudinal gradients in each plot using HydroSense (CD 620 + CS 620) (CAMPBELL SCIENTIFIC INC. Logan, Utah, USA) bearing 12 and 20 cm probes. Similarly, soil hardness was measured by push cone (Yamanaka's soil hardness tester, Kiya Seisakusho Ltd., Tokyo, Japan).

We calculated species basal area (BA cm^2) from DBH and then the relative proportion of each species relative to basal area, expressed as a percentage (RBA%). The RBA of each species were used as abundance measure of species in a community. The dominant species of the altitudinal plots were determined based on the dominance analysis

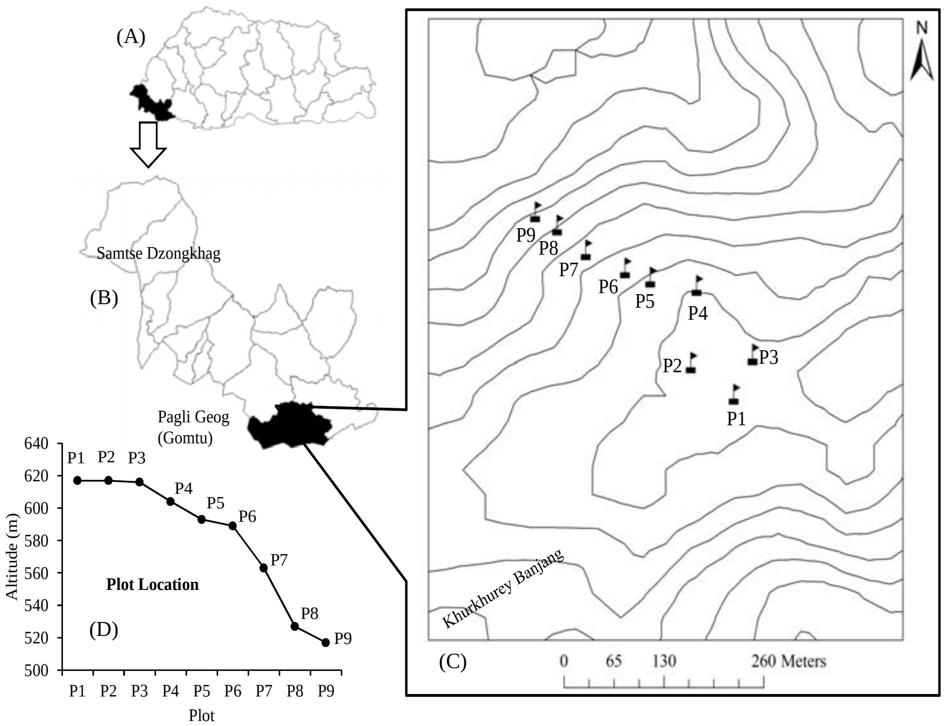

Figure 1. Location map of the study area: (A) Bhutan map indicating Dzongkhags, (B) Dzongkhag map indicating the Geog, (C) Topographical map (20 m interval) of the study area showing sampling plots with flags (P1 – P9), and (D) Vertical profile of the location of the plots along the altitudinal gradients

(Ohsawa, 1984). Shannon and Wienner Diversity Index (H[I]) was calculated by using the RBA data. The preliminary data were processed using pivot-table of Microsoft Excel 2010 and species composition was compiled. Cluster analysis was performed using PC-ORD version 5.1 to determine the Sal forest type. SPSS Ver. 16 was used for correlation test.

The meteorological data maintained by the Penden Cement Authority Limited (PCAL), Gomtu from 1980 – 2011 was used for analysis. Using pivot-table in Microsoft Excel 2010, the climate data was processed to means and totals on a daily, monthly and yearly basis to determine various thermal indices. A warmth Index (WI) was calculated by using Kira's (1977) method while the Aridity Index (AI) was determined by using Martonne's (1926) method. Potential Evapotranspiration Ratio was calculated using Holdridge's (1967) method. The Precipitation Intensity was determined as; PI = PPT/n, where n = number of rainy days > 1 mm.

Results and Discussion

Climatic condition

The mean annual precipitation at Gomtu at 290 m was 4,109 mm, occurring mainly during the monsoon season (June – September). The maximum precipitation was in July (Figure 2A) with an average total of 1,072.2 mm, while an average number of rainy days (rainfall > 1 mm) in a year was 146 with a precipitation intensity of 28 mm. The mean annual temperature was 25.01 ^{0}C with the warmest mean and coldest mean temperature of 30.1 ^{0}C (August) and 17.9 ^{0}C (January) respectively (Table 1). The temperature increased gradually from the month of mid – February to August and dropped gradually in September with the end of the monsoon (Figure 2B) showing significant positive correlation between rainfall and temperature, $r = .97$, $p < .05$.

However, the air relative humidity (RH) showed a strong positive correlation with temperature during the monsoon, $r = .63$, $p < .05$, revealing a clear contrast with the inner dry valleys (Wangda, 2003), indicating an absence of mountain and valley wind circulation (Eguchi and Wangda, 2011).

The warmth index (WI) of 238.9 indicated suitable available heat energy for the *Shorea* zone (WI: 165 – 240) according to Kawakita in Numata (1983). The potential evapotranspiration ratio (PER) was 0.4, indicating a wet forest type and similarly, the aridity index was also determined. The result clarified the prevalence of a special microclimate suitable for the Sal forest ecosystem. It requires relatively higher mean annual temperature and higher rainfall particularly during the rainy season with dry periods

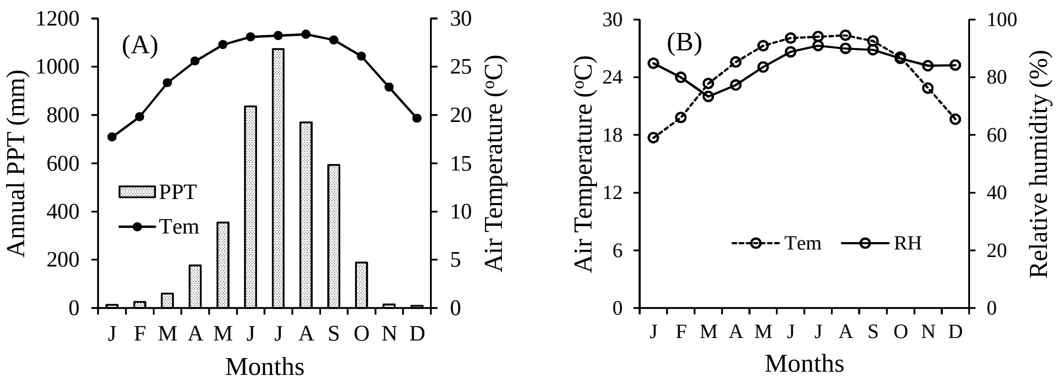

Figure 2. Climatic condition: (A) Mean monthly rainfall & temperature and (B) Mean monthly temperature. PPT = Total Precipitation, Tem = Air Temperature, RH = Relative Humidity

Table 1. Comparison of Thermal indices of the study area (outer humid wet foot-hills) with Bajo, Wangdue (inner dry valley system; Wangda, 2003)

Location	Altitude (m)	AMT (^{o}C)	WMT (^{o}C)	CMT (^{o}C)	ART (^{o}C)	PPT (mm)	PER	AI	WI
PCAL, Gomtu	290	25.01	30.10	17.88	12.22	4109.00	0.36	117.37	238.87
Bajo, Wangdue	1200	18.30	29.00	3.20	25.80	583.50	1.85	20.60	159.50

Note: PCAL = Penden Cement Authority Limited, AMT = Annual Mean Temperature, WMT = Warmest mean Temperature, CMT = Coldest Mean Temperature, ART = Annual Range of Temperature, PPT = Total Precipitation, AI = Aridity Index, WI = Warmth Index, PER = Potential Evapotranspiration Ratio of not less than 4 months (Tewari, 1995; Rahman *et al.*, 2010).

Environmental attributes

An instant measurement of soil moisture content was measured using the digital Hydro-sense having 12 cm probe during the field survey (January 2013). The data showed low soil moisture content (SMC) and soil hardness (SH) ranging from 5 – 7% and 2.5 – 8.5 kg/cm^2 respectively, indicating a dry season and the lowest trampling effect. There was a significant negative correlation (Figure 3A) of SMC along the altitudinal gradients, $r = -.78$, $p < .01$ which supports the findings of Wangda (2003) and Wangda *et al.* (2010). Soil hardness indicated a low association, $r = .38$, $p < .01$. Spearman's rho correlation was tested to evaluate the association of these environmental attributes against slope and aspect. The result revealed a correlation between aspect and soil moisture content, $r = .86$, $p < .01$, indicating high moisture towards the northern aspect and the result from Wangda *et al.* (2010) revealed the same.

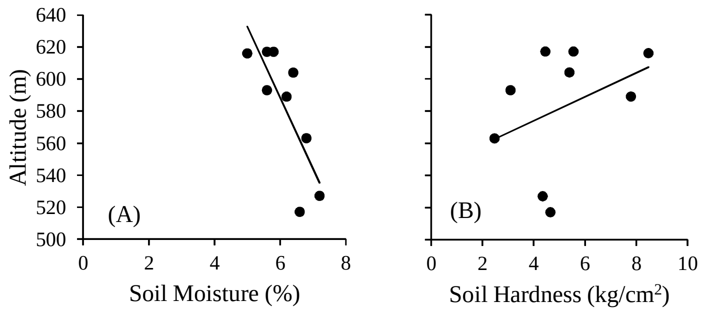

Figure 3. Environmental attributes: (A) soil moisture content & (B) soil hardness

Floristic composition of major life forms

A total of 91 species belonging to 38 families were recorded in the Hill Sal forest, of which 51 were trees, 30 shrubs, 7 woody climbers, and 3 palm species. All the forest trees (Table 2) were classified into two major life-forms of evergreen and deciduous broad-leaved forest (Figure 4). The result clarified the dominance of deciduous tree species in the mid and upper altitudes while the lower ones were dominated by evergreen species.

The deciduous forest was dominated by Dipterocarpaceae (*Shorea robusta*), Sterculiaceae (*Sterculia villosa*) and Apocynaceae (*Holarrhena pubescens*) while the evergreen forest was dominated by Theaceae (*Schima wallichii* and *Eurya acuminata*), Lauraceae (*Persea glaucenscens, P. odoratissima, Litsea salicifolia* var. *polyneura*), Rutaceae (*Acronychia pedunculata*), Euphorbiaceae (*Sapium baccatum*), Flacourtiaceae (*Casearea graveolens*), Meliaceae (*Aphanamixis polystachya*), Myrtaceae (*Syzygium cumini* and *S. ramosissimum*) and Annonaceae (*Polyalthia simiarum*).

The floristic composition of tree species in the Sal forest was slightly different compared to the hill Sal forests of Nepal. However, the presence of *Lagerstroemia parviflora* and *Terminalia alata* was recorded outside the plots of *Shorea* dominated forest in the same area. In the present study, the common associations of *S. robusta* were *Schima wallichii, Sterculia villosa, H. pubescens, A. pedunculata, Terminalia bellirica, Syzigium cumini, S. ramosissimum, P. glaucenscens, P. odoratissima, P. simiarum, A. polystachya, L. salicifolia* var. *polyneura* respectively. The difference in species composition between the two regions could be due to the degree and influence of human disturbances as reported in several studies in Nepal. The present study site was located in a natural and minimally disturbed forest.

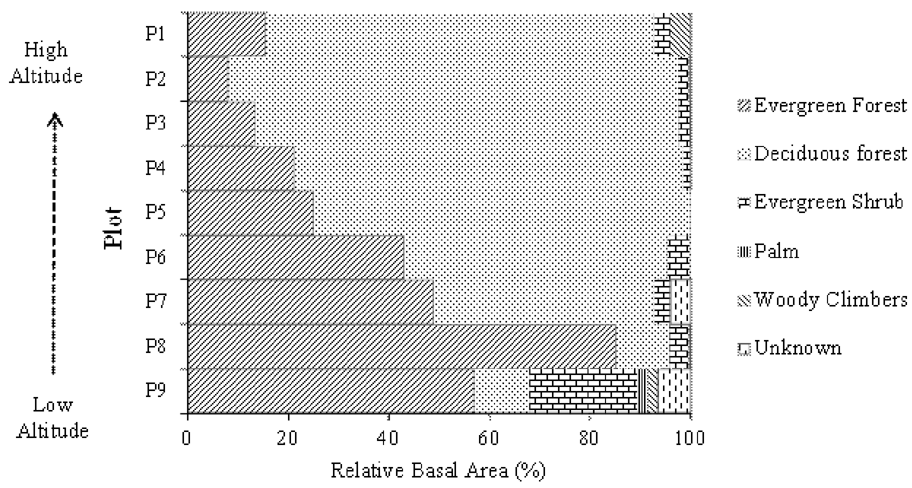

Figure 4. Altitudinal distribution of major life-forms in the Hill Sal forest

Classification of the Hill Sal forest

The cluster analysis was carried out using a similarity index. The result revealed three forest types; viz, two *Shorea* forest types (I. *Shorea* dominated type and II. *Schima* dominated with *Shorea* type) and a riparian forest type classified arbitrarily at 50% similarity threshold (Figure 5).

Table 2. Floristic composition of all the tree species in the Hill Sal forest along the altitudinal gradients and the plot information: P represents plot, TBA indicates total basal area (cm^2). RBA stands for relative basal area and dominant species were represented by shaded colour.

Plot Number	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**Total**
Altitude (m)	617	617	616	604	593	589	563	527	517	
Aspect (Degree)	SE150	SW240	NEE60	NNW290	N0	NNW290	NNW290	NW300	NW310	
Inclination (Degree)	43	50	56	13	22	30	20	24	50	
Plot size (m^2)	400	400	400	400	400	400	400	400	400	
Total Basal Area/Plot	12574.0	15265.5	22650.9	25329.6	13831.6	15903.6	21614.8	20086.2	12711.2	159967.4
Max. Ht. (m)	22.4	26.7	27.3	39	27.7	27.7	41.3	34.8	21.9	
Max. DBH (cm)	48.8	52	88.5	72	59.3	49	64.3	75.5	47.5	
Species Richness (N)/Plot	29	28	25	14	26	25	30	25	42	
Diversity (H')	1.63	0.7	0.8	0.7	1.0	1.4	1.8	1.7	2.8	
Eveness (J')	0.3	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.5	
No. of Dominants/Plot	3	1	1	1	1	2	2	4	12	
Stem Density/Plot	140	154	127	102	130	147	150	131	119	1200
Relative Basal Area (%)	**RBA**	**RBA**	**RBA**	**RBA**	**RBA**	**RBA**	**RBA**	**RBA**	**RBA**	**TBA**
Evergreen trees										
Terminalia bellirica	5.6				3.7					1219.1
Albizia lebbeck	5.6	0.0								710.0
Persea glaucenscens	1.8	2.9	0.9	0.6	1.3	6.0	4.5	5.5	0.1	4251.2
Polyalthia simiarum	0.9	0.1		0.1	0.2		0.0		0.0	196.8
Persea odoratissima	0.8	0.4	0.3	0.1	0.6	0.7	0.8			611.7
Acronychia pedunculata	0.3		0.6	2.7	3.5	2.0	3.4	8.4	10.7	5467.0
Aphanamixis polystachya	0.2	0.0	0.0	0.0	0.0	0.0		0.1		49.9
Litsea salicifolia var. *polyneura*	0.2	0.0	0.4	0.0	0.0	0.2	0.1	0.1		192.6
Syzygium cumini	0.1	0.1			0.0			2.4		508.7
Syzygium ramosissimum	0.1	0.0	0.0		2.1	0.4	0.2	0.0	0.1	449.0
Albezia sp.	0.0									0.2
Schima wallichii		4.4	8.7	21.2	9.4	31.8	32.5	53.2	2.6	32422.0
Dalbergia sericea		0.0			0.1					17.1
Canthium glabrum		0.0				0.0	0.0			4.2
Acer oblongum		0.0			0.0					2.3
Castanopsis tribuloides			2.3					3.1		1135.3
Michelia champaca			0.0							5.3
Sapindus sp.				0.2	0.1					66.4
Actinodaphne obovata						0.8			0.4	189.0
Styrax serrulatus						0.7				118.8
Phoebe lanceolata						0.2	0.0		3.8	520.2
Beilschmiedia sp.						0.1	0.0	0.1	0.1	37.9
Casearea graveolens							5.1	0.4	13.9	2939.8
Stereospermum colais							1.3			289.5
Syzygium operculatum							0.8	2.3		633.5
Ficus elastica							0.0			5.3
Aglaia korthalsii							0.0	0.0		4.6
Sapium baccatum								9.7		1947.8
Pterospermum acerifolium								0.0	0.0	1.9
Protium sp.									13.9	1772.1
Pandanus furcatus									6.2	793.8
Lithocarpus fenestratus									3.9	498.8
Antidesma acuminatum									1.0	128.7
Litsea sp.									0.0	2.9
Macaranga denticulata									0.0	2.5
Litsea monopetala									0.0	2.3
Archidendron clypearia									0.0	2.0
Sub-total	**15.5**	**8.1**	**13.3**	**25.0**	**21.1**	**43.0**	**48.9**	**85.2**	**56.9**	**57200.0**

Table 2. (Cont.)

Plot Number	P1	P2	P3	P4	P5	P6	P7	P8	P9	Total
Deciduous trees										
Shorea robusta	56.8	86.0	82.2	74.7	76.2	51.1	37.8	10.7		86786.5
Sterculia villosa	10.8									1352.7
Holarrhena pubescens	9.1	3.2	0.9	0.2	0.8	1.2	0.5			2288.7
Zanthoxylum myriacanthum	0.3		0.2	0.0	0.3					129.3
Chukrasia tabularis	0.1									18.9
Wrightia arborea	0.1		0.1							21.0
Engelhardia spicata		0.2								33.2
Rhus chinensis			1.0							227.0
Tetrameles nudiflora							5.4			1170.2
Betula alnoides var. *cylindrostachya*									**8.7**	1104.5
Dillenia pentagyna									2.3	295.6
Sub-total	**77.2**	**89.4**	**84.2**	**74.9**	**77.4**	**52.4**	**43.7**	**10.7**	**11.0**	**93427.3**
Shrubs										
Glochidion sp.	1.5	1.1	1.4	0.1	0.3	1.4		0.4		1054.0
Tabernaemontana divaricata	0.8	0.8	0.2	0.0	0.9	1.3	0.6	1.2	0.6	1044.3
Croton caudatus	0.6	0.0	0.1		0.1	0.0	0.0			122.6
Murraya koenigii	0.2		0.0				0.0			25.5
Chenomorpha fragrans	0.1	0.1	0.2			0.7	0.1		3.0	568.7
Sterculia hamiltonii	0.1	0.0	0.2		0.0					58.7
Flueggea virosa	0.0								0.1	13.0
Dalbergia stipulacea	0.0	0.0	0.1		0.1	0.9	0.2	1.7	0.8	693.6
Brucea mollis	0.0									1.8
Dalbergia pinnata		0.0								7.5
Clerodendrum viscosum		0.0			0.0	0.0				13.4
Eurya acuminata			0.1						3.9	512.9
Maesa chisia				0.0	0.0					7.3
Holmskioldia sanguinea					0.0	0.0			0.0	12.9
Damnacanthus sp.						0.0				4.9
Goniothalamus sesquipedalis						0.0				1.1
Leea indica							2.0		6.3	1227.0
Flacourtia jangomas							0.1			20.4
Ostodes paniculata							0.1			13.9
Catunaregam longispina								0.4		81.7
Ficus subincisa									5.4	683.5
Helicia nilagirica									1.4	173.3
Phlogacanthus thyrsiformis									0.0	4.9
Prismatomaris tetrandra									0.0	2.0
Baccurea ramiflora									0.0	1.1
Boehmeria lifera									0.0	0.8
Sub-total	**3.3**	**2.2**	**2.3**	**0.2**	**1.5**	**4.4**	**3.1**	**3.7**	**21.5**	**6350.8**
Palm trees										
Phoenix rupicola									1.8	227.0
Caryota urens									0.2	31.7
Calamus erectus									0.1	18.9
Sub-total	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**2.2**	**277.6**
Woody Climbers										
Butea parviflora	3.9									495.6
Beaumontia grandiflora	0.1									11.9
Schefflera roxburghii		0.1			0.0	0.2	0.0	0.0		48.2
Tetrastigma rumicispermum		0.0					0.0	0.1		24.6
Desmos dumosus		0.0	0.1			0.0	0.2	0.1	0.1	89.4
Toddalia asiatica		0.0								1.1
Acacia pennata								0.1	1.8	244.9
Sub-total	**4.0**	**0.1**	**0.1**	**0.0**	**0.0**	**0.2**	**0.2**	**0.2**	**1.9**	**915.9**
Unidentified										
Rubiaceae (Mango like)	0.0		0.0						2.3	301.2
Premna like		0.3							1.0	161.4
Rubiaceae			0.0							3.8
Morinda Like					0.0					0.8
Acer like							4.0		3.2	1277.6
Leea Like								0.2		33.2
Harey								0.0	0.1	17.9
Sub-total	**0.0**	**0.3**	**0.1**	**0.0**	**0.0**	**0.0**	**4.0**	**0.2**	**6.6**	**1795.9**
TOTAL	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**159967.4**

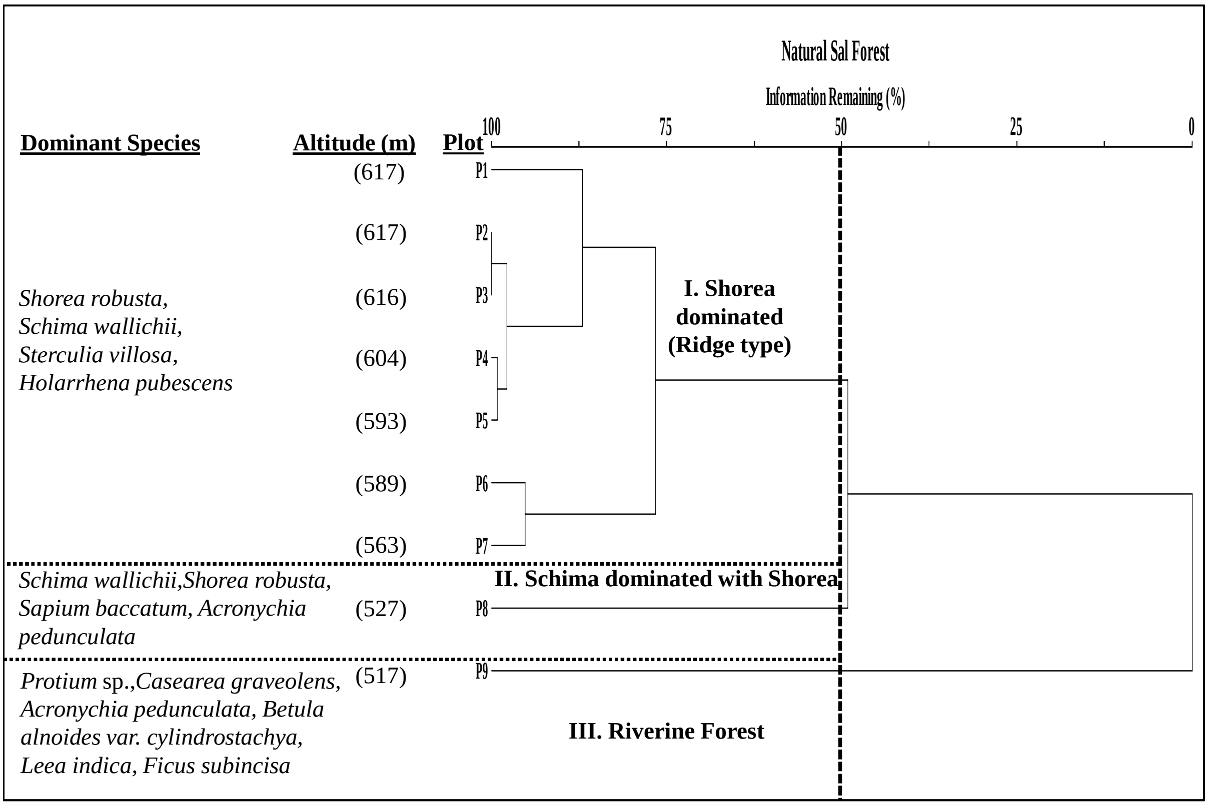

Figure 5. A dendrogram showing similarity of forest tree species of the Hill Sal forest, (P) represents plot

These three forest types were named based on the dominant species occurring in the clustered groups.

Shorea dominated type (563-617 m)

The mid and upper altitude between 563 to 617 m (P1, P2, P3, P4, P5, P6, and P7) were classified as *Shorea* dominated forest type based on the dominance of *S. robusta. Sterculia villosa* and *H. pubescens*. The lower two plots (P6 and P7) shared its dominants between *S. robusta* and *Schima wallichii*. According to Stainton (1972) and Ohsawa (1983), the Hill Sal forest usually does not grow above 1300 m and its normal range is below 900 m. In the present study site, the minimum suitable range was observed around 600 m, however, the maximum range was limited by the height of the hill in the present study site. The under-story was dominated by evergreen broad-leaved trees composed of Lauraceae (*P. glaucenscens, P. odoratissima, L. salicifolia*), Meliaceae (*A. polystachya*), Myrtaceae (*S. cumini, S. ramosissimum*), Rutaceae (*A. pedunculata*) and Annonaceae (*P. simiarum*). Evergreen shrubby species were composed of *Tabernaemontana divaricata, Croton caudatus, Murraya koenigii, Chenomorpha fragrans, Sterculia hamiltonii, Dalbergia stipulacea*, while woody climbers of *Butea parviflora, Beaumontia grandiflora, Desmos dumosus* were recorded frequently.

Schima dominated with Shorea type (527 m)

The lower elevation of 527 m (P8) was dominated by *Schima wallichii* followed by *S. robusta* while the middle layer story was dominated by *A. pedunculata*. Other associated species were *P. glaucenscens, S. cumini, S. operculatum, Castanopsis tribuloides* and *Sapium baccatum*. From this range, *S. robusta* was observed to be decreasing and exhibited the lower limit (northwest facing). Compared to Type I, only a few evergreen shrubby species and woody climbers were prevalent, composed of *T. divaricata, D. stipulacea, Schefflera roxburghii, Tetrastigma rumicispermum* and *Desmos dumosus*.

In the Nepal Himalaya, the hill *Shorea* zone usually falls between 300 m to 1000 m and *Schima* zone occupies from 1000 to 1500 m (Ohsawa, 1983). However, in Bhutan, the present study site exhibited quite different attributes. The lowest range of *Shorea* zone is found at about 520 m in the northwest facing slope and 360 m in the southeast facing ridge tops. The presence of *S. wallichii* around this altitude and dominating the plot with *Shorea* was a unique characteristic of the hill Sal forest in this particular area.

Riverine forest (517 m)

The lowest altitude (517 m) of the study area (P9), located near the river bed (Khanabarti), was outside the lower limit of the *Shorea* forest and was found with multi-dominant stand of heterogeneous composition. The result supported the finding made by Wangda and Ohsawa (2006). The forest was classified as riparian based on its location closer to the river bed and composed of *Phoebe lanceolata*, *S. wallichii*, *Protium* sp., *Lithocarpus fenestratus*,

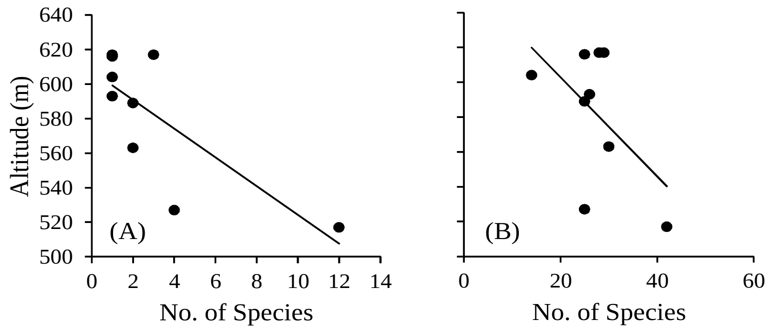

Figure 6. Forest structural traits; (A) No. of dominants/Plot & (B) Species Richness (N)/Plot

and *Betula alnoides* var. *cylindrostachya*, while the middle layer story was composed of *A. pedunculata*, *Casearea graveolens*, *Pandanus furcatus*, *Antidesma acuminatum*, and *Dillenia pentagyna*. The dominant shrub species consisted of *Chenomorpha fragrans*, *Eurya acuminata*, *Leea indica*, and *Ficus subincisa*. Interestingly, three palm species; *Phoenix rupicola*, *Caryota urens*, and *Calamus erectus* were recorded in the plot.

Structural traits of the Hill Sal forest

Structural traits of the Hill Sal forest along the altitudinal gradients were described based on six features (Figure 6 and 7). Accordingly, some of the structural features of *S. robusta* were compared with the total species to evaluate how hill Sal occupies the community (Figure 7).

Total number of species richness and number of dominants were assessed. The lowest elevation (517 m) showed the maximum species richness while the upper elevation (604 m) dominated by *S. robusta* showed minimum richness, 42 and 14 respectively. However, the trend revealed a low association to altitudinal gradients (Figure 6: B), $r = -.20$, $p < .01$. The results supported the statement of Stainton (1972) for the Sal forest as "species poor" as compared to the riparian plot; however, the present findings revealed better composition compared to the Conifer and *Alnus* plantations as reported by Wangda *et al.* (2009). Similarly, Panday and Shukla (2003) in Nepal also confirmed a similar trend in the natural Sal forest compared to plantations of Sal forest and to other species. The number of dominant species, which ranged from 1 to 12 (Figure 6: A), was identified by dominance analysis. The maximum number of dominant species decreased with the increase of altitudes ($r = -.63$, $p < .01$).

The maximum tree height of *S. robusta* increased from 22.4 m at 617 m (P1) to 41.3 m at 563 m (P7) indicating a highly negative correlation along the

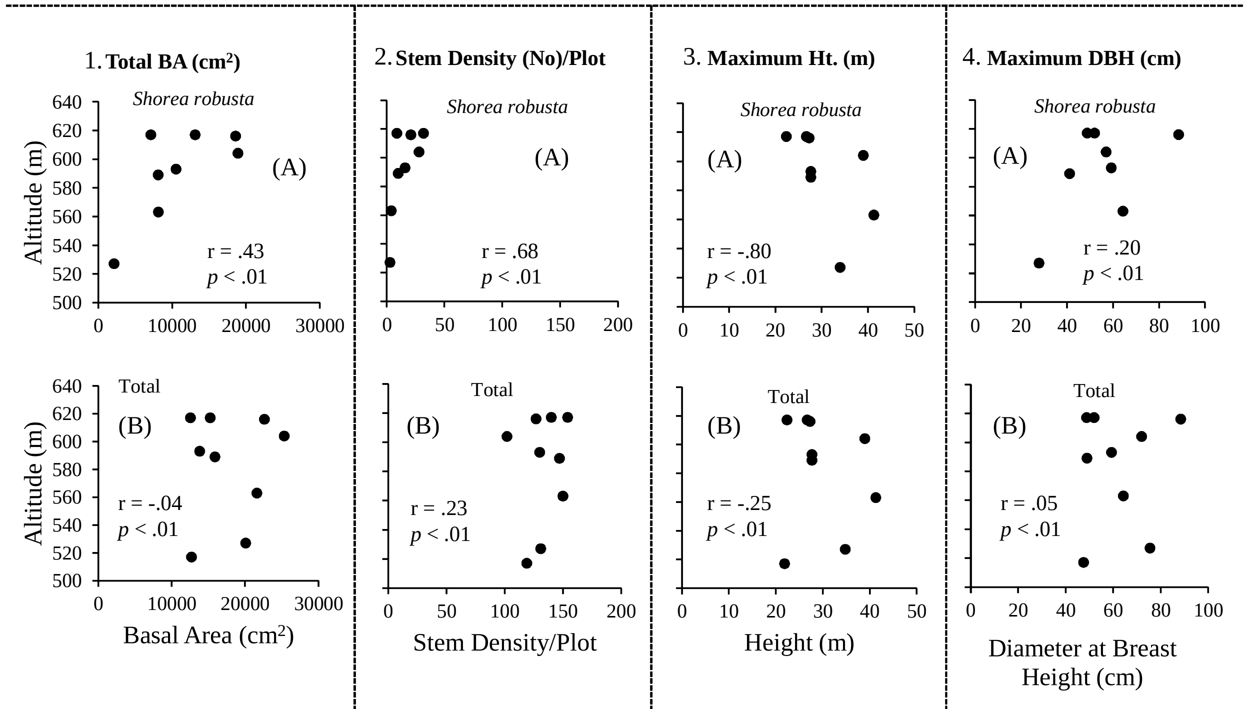

Figure 7: Comparison of structural traits between *Shorea robusta* (A) and total species (B)

altitude gradients, $r = -.80$, $p < .01$(Figure 7: 3A). Compared to the total species (Figure 7: 3B), it clearly indicated the dominance of the canopy layer but only emergent in the lower altitudes (563 m and 527 m) suggesting competition with other species. A similar trend was reported in Nepal hill Sal forest (Stainton, 1972 and Ohsawa, 1983). The maximum diameter of *S. robusta* at DBH increased from 27.9 cm at 527 m to 88.5 cm at 616 m along the altitudinal gradients, but showed a low correlation. *Shorea* exhibited the maximum height and DBH from the total species and this corresponds with the results of Timilsina *et al.* (2007).

The total basal area of *S. robusta* was maximum at 604 m with 18,925.96 cm^2/3,200 m^2 while the minimum was at 527 m with 2,146.19 cm^2 /3,200 m^2 in a decreasing trend with altitude ($r = .43$, $p < .01$). However, no trend was observed in the total species against the altitude (Figure 7: 1B). From the total basal area, *Shorea* constituted about 54.3% while the remaining 45.7% comprised of other tree species in the study area.

The maximum stem density of *Shorea* was observed at the ridge top (617 m) with a stem density of 32 stems/plot while the minimum was at 527 m with only three stems/plot revealing significant correlation against the altitude (Figure 7: 2A). The result clearly indicated the preference of *S. robusta* for the ridge top above 600 m. The total species stem density in the study area was 1,200 stems/3,600 m^2 of which *Shorea* accounted for 123 stems/3,200 m^2.

Conclusion

Climatic data clarified the existence of a special type of microclimate suitable for the Sal forest ecosystem of Bhutan. Floristically, the forest was dominated with two major life-forms; deciduous forest in the upper altitude and evergreen forest in the lower altitude. The Sal forest was classified into three forest types using cluster analysis based on dominant species; *Shorea* dominated type in the ridge top, *Schima* dominated with *Shorea* in the mid altitude and riparian type in the lower altitude. Structurally, the number of dominant trees and species richness decreased as the altitude increased. Similarly, the maximum diameter at breast height decreased while the height increased as the altitude decreased. The lower limit of Sal was found around an altitude of 527 m on a northwest facing ridge slope. However, the upper limit was restricted by the height of the hill and to clarify this, similar studies are necessary along the continuous mountain systems where both the lower and upper limit exist. The present study suggested that the suitable range of the Bhutan Hill Sal forest is around 600 m. The natural Sal forest in Bhutan may be the only remnant forest regionally and, therefore deserves to be studied intensively.

Acknowledgement

The authors would like to thank the anonymous reviewers for their critical comments and suggestions. The RNR-RDC, Yusipang, WMD and CNR are greatly acknowledged for their support in bringing the paper to fruition. Thanks to the RNR-EC and the Geog Office, Gomtu for their logistics support for nearly all of the field work. Our heartiest thanks are due to Professor Dr. Masahiko Ohsawa and Ms. Rebecca Pradhan for their guidance and continuous support. We are very grateful to the Bhutan Trust Fund for their generous financial assistance. Thanks are also due to Karma, Pema Tenzin, D.K. Ghimirey, Tshewang Norbu, Homlal, and Ugyen for their hard work and assistance in the field.

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