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Plant diversity and structural dynamics of Sub-Tropical Broad-leaved Forests of the Bhutan Himalaya

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The objective of the study is to understand the sub-tropical broad-leaved forest which is under sever human threats, and its dynamics for biodiversity conservation and for management of the natural forest at the southern foothills of Bhutan Himalaya. The detail analysis of vegetation revealed a total of 168 species. *Schima wallichii*, a sub-tropical element belonging to evergreen broad-leaved tree was appeared as the most common dominant in all the three series. Gomtu series was mainly dominated by *Shorea robusta* in a relatively shallow soil while other sites were dominated by diverse tree species. The dominants along Pasakha series are *Aphanamixis polystacya*, *Duabanga grandiflora*, etc., while Dechiling series were mainly dominated by *Syzygium cumini*, *Persea minutiflora*, and *Altingia excelsa*. Dendrogram showed 6 different forest types of the sub-tropical belts. 1) Riverrine, 2) True Oak-Laurel, 3) *Schima-Castanopsis* (Evergreen broad-leaved forest), 4) *Shorea robusta* (sub-tropical deciduous forest), 5) *Salix tetrasperma* (deciduous wetland forest), and 6) *Altingia excelsa* (refuge relic evergreen broad-leaved forest). The nomenclature of forest types were purely based on the dominants and its environmental requirement. Therefore, the information generated by this study serves as important baseline information for the good management plan of the subtropical broad-leaved forest in the Bhutan Himalayas.

INTRODUCTION

The natural subtropical evergreen broad-leaved forests are mainly confined to eastern Asia, Southern China, South-south western Japan, a few regions of Vietnam, Laos, Thailand, Myanmar, India, Nepal and Bhutan (Kira 1991, Ohsawa 1993, Tagawa 1995 in Tang et al. 2007). According to Ohsawa (1987), the transitional zones of tropical-subtropical and temperate zone on the southern slopes of Nepal has become merely visible due to heavy disturbances by cultivation and human activities. However, in Bhutan it is still prevalent in some parts although similar threat exists. True tropical rain forest is absent in the Bhutan Himalaya, however several tropical genera and species are found along the foothills which are broadly classified as subtropical forest ranging between altitudinal range from 200-1000 m a.s.l. (Grierson and Long 1983). Although, Sal and Savannah forest are absent, *Shorea robusta* one of the tropical species occurs as scattered trees in some part of the area and are probably the last refuge in the country.

The understanding of both ecological and economical importance of this diverse forest

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ecosystem is critical for sustainable management and conservation.

The significant portions of the southern foothills of Bhutan Himalaya are still under intact natural forest. However, these forests (*Tetrameles nudiflora, Pterospermum acerifolium, Daubanga grandiflora* and *Albezia* species) are under severe human threats. Therefore, the present study was strategically planned to conduct a basic research and to generate important ecological information in respect to the sub-tropical broad-leaved forest.

OBJECTIVES

The objective of the study is to understand the sub-tropical forest ecosystem and its dynamics. Particularly the study aims at understanding the *Shorea* (Sal) forest along the southern foothills. Specifically, the study aims to achieve the following objectives;

1) Floristic diversity and structural dynamics of the dominant sub-tropical tree species, life-form and forest types and,

2) To compare and contrast the subtropical forest along W-E gradient in the foothills and,

3) Thus, can help us to understand the importance of subtropical forest for biodiversity conservation and for management of the natural forest.

STUDY SITES

The present study area is located along the southern foothills of Bhutan stretching from east to west (Fig 1). The research sites are located along the southern foothills (260 m a.s.l.) of sub-tropical forest including hill Sal forest (600 m a.s.l.), sub-tropical evergreen broad-leaved forest (800 m a.s.l.) and Wet-land deciduous broad-leaved forests (900 m a.s.l.) respectively. The study area covers three districts of Bhutan namely Samtse, Chukha and Pemagatsel (Fig. 1C, D, E).

METHODOLOGY

1. Climatic data

A meteorology station equipped with automatic HOBO Onset data logger (Onset Computer Co.

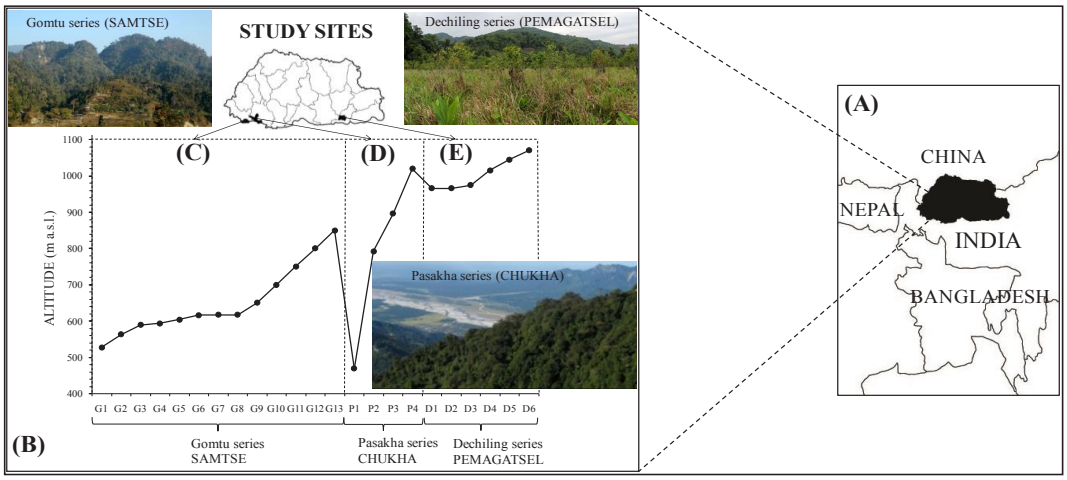

Fig. 1 Map of the study area; (A) Map of South Asia indicating Bhutan, (B) Study sites, (C) Gomtu Series, (D) Pasakha Series and (E) Dechiling Series

MA, USA) (temperature, humidity and rainfall) was installed at Pagli, Gomtuenclosed by well fenced at the end of 2012 (Fig. 2a, b, c). The HOBO data loggers were set at hourly interval recording and downloaded every after three months of recording. Rainfall and temperature data of Pasakha (Phuenstholing) and Dechiling were gathered from existing meteorology stations maintained by Department of Hydromet Services, Ministry of Economic Affairs. In addition two HOBO data loggers (Temperature and Relative Humidity) were installed at Dechiling and Phuentsholing.

2. Vegetation survey

A total of 23 vegetation plots were laid in three different study sites from Gomtu (Samtse) in the west to Dechiling (Pemagatsel) in the east. The quadrat sampling was adopted for inventorying the tree layer. The trees occurring within the quadrat attaining a height greater than 1.3 m ($H \geq 1.3$ m) were measured, identified and recorded for tree height (H, m), and diameter at breast height (DBH, cm at 1.3 m above ground).

For regeneration survey, all seedlings and saplings occurring inside the plot measuring 2 m by 2 m were identified and their height and age were estimated by counting branch tiers and/or bud-scale scars. The fieldworks wereconducted from late December 2012 to October 2013. Nomenclature of plants followed after Flora of Bhutan (Grierson and Long 1983-2000, Noltie 1994-2000), The Orchids of Bhutan (Pearce and Cribb 2002), Weeds of Bhutan (Parker 1992), Wild Rhododendrons of Bhutan (Pradhan 1998), Flowers of the Himalaya: A supplement (Stainton 1988), Flowers of the Himalaya (Polunin and Stainton 1984), and Photo-album of plants of Eastern Himalaya (Hara 1968).

DATA ANALYSIS

1. Climate data analysis

HOBO Onset data loggers were downloaded using BoxCar Pro for Windows, Version 4.3 provided by Onset Computer Co. and HOBOWARE. Simple climate analysis using excel was performed in addition to Walter climate software.

2. Vegetation data analysis

Species basal area (BA, cm^2) was calculated from DBH data of tree individuals and calculated the relative proportion of each species' basal area in percent (Relative Basal Area, RBA %). The RBA of each species was used as abundance measure of species in a community. The dominant were determined based on the dominance analysis

Fig. 2 Establishment of Meteorology station (a) iron post erecting, (b) mesh wire fencing around iron post and (c) installed HOBO loggere (Rain gauge and Temperarure, Humidity)

Table 1 Climatic indices of the study sites

Location	Altitude(m)	AMT (°C)	WMT (°C)	CMT (°C)	WI	ART (°C)	PER	PPT (mm)	AI	Remarks
PCAL, Gomtu	290	25.1	30.1	17.9	238.9	12.2	0.4	4109.0	117.1	1980 to 2011
Phuntsholing	220	25.3	29.4	18.3	239.0	10.7	0.4	4278.0	121.2	1994 to 2006
Dechenling	1042	18.1	22.9	11.1	156.8	11.9	0.3	3916.6	139.5	1986 to 2006

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

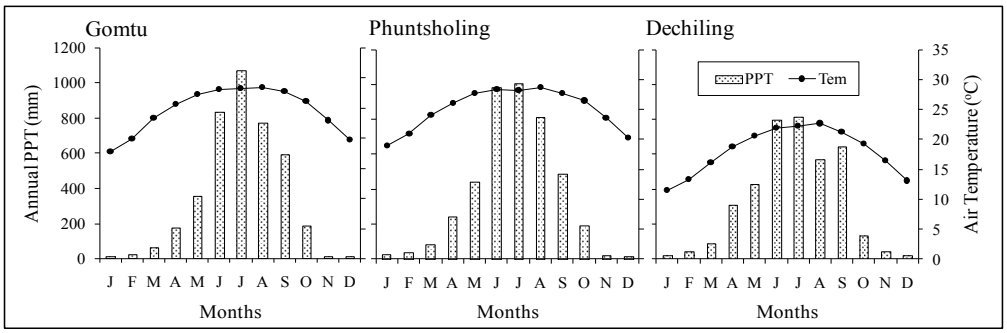

Fig. 3 Rainfall and tempereture pattems of the three study sites

(Ohsawa 1984, Kikvidze and Ohsawa 2002).

The preliminary data was processed using pivotal table of the Microsoft Excel. Once the data was processed, analysis was carried out by using PC-ORD version 4 (McCune and Mefford 1999) and cluster analysis was performed using distance measure of Sorensen (Bray-Curtis method).

RESULTS

1. Climatic background of the study area

The annual mean temperature of the study area were 25.1 °C, 25.3 °C and 18.1 °C with a mean maximum temperature of 30.1 °C, 29.4 °C, and 22.9 °C and a mean minimum temperature of 17.9 °C, 18.3 °C, 11.1 °C in the three study sites (Gomtu, Phuentsholing and Dechiling) respectively. The annual total rainfall of the three study sites were recorded at 4109.0 mm, 4278.0 mm and 3916.6 mm respectively (Table 1, Fig. 3). The warmth index of Gomtu was calculated and found to be 230.0 indicating suitable available heat energy for Shorea zone as report by Kawakita in Numata ed. (1983). Hence, there are presence of natural stands of Sal in Gomtu regions.

Similarly the aridity index (AI), an indicator of dryness showed all three sites falls within the humid wet forest zones.

2. Vegetation and their structural traits

1) Plot description and life-form distribution pattern

A total of twenty three (23) plots were selected and established along the three study sites i.e. Gomtu series (G), Pasakha series (P) and Dechiling series (D) respectively in Table 2. The detail analysis of vegetation revealed a total of 168 species comprised of evergreen broad-leaved trees (70) and shrubs (48), deciduous broad-leaved trees (26) and shrubs (10), Palm (5) and climbers (9). Gomtu series showed the highest number of species (107) and families (39) while Pasakha series showed 46 species and 25 families. Dechiling series showed the lowest number of species (35) and families (26). There are 37 evergreen broad-leaved tree species

Table 2 Plot details of the study area

Plot ID	Plot No	Altitude (m)	Plot Size (m^2)	Total BA (cm^2)	Species Diversity (H')	Species Richness (N)	No of Dominants	Species Eveness (J')	Maximum DBH (cm)	Maximum Ht. (m)	Stem Density (/400m^2)
Lower Limit	G1	527	400	20086.2	1.7	25	5	0.4	75.5	34.8	131
Transition	G2	563	400	21614.8	1.8	30	2	0.4	64.3	41.3	150
Below Ridge Top	G3	589	400	15903.6	1.4	25	2	0.3	49.0	27.7	147
North Facing	G4	593	400	13831.6	1.0	26	1	0.2	59.3	27.7	130
Ridge Top	G5	604	400	25329.6	0.7	14	1	0.2	72.0	39.0	102
North East Facing	G6	616	400	22650.9	0.8	25	1	0.2	88.5	27.3	127
South West Facing	G7	617	400	12574.0	1.6	29	3	0.3	48.8	22.4	140
South East Facing	G8	617	400	15265.5	0.7	28	1	0.1	52.0	26.7	154
Above Uttarey Minning	G9	650	400	16414.0	1.9	25	5	0.4	48.0	35.2	122
Lower Uttarey	G10	700	400	22165.3	2.2	34	6	0.4	69.5	40.6	148
Mid Uttarey	G11	750	400	14152.5	1.8	23	4	0.4	75.0	34.5	129
Upper Uttarey	G12	800	400	15178.6	2.6	34	5	0.5	44.0	21.5	183
Uttarey Top	G13	850	400	27538.2	1.9	17	5	0.5	99.3	31.8	94
Above Rinchending	P1	469	400	49051.0	2.4	12	4	0.7	134.0	41.5	20
Terminallia	P2	792	400	66242.2	2.2	12	2	0.6	160.0	41.0	28
Above Pasakha	P3	896	400	23023.1	3.0	22	5	0.7	94.0	41.3	60
Below Kamji to pasakha	P4	1020	400	33582.8	2.0	21	2	0.4	102.0	35.0	52
Peling Tsho Forest	D1	966	100	18700.9	0.6	10	1	0.2	140.0	32.0	32
Peling Tsho (Core zone)	D2	966	100	3895.0	1.4	11	3	0.4	28.0	15.2	29
Khailaborang (Altingia forest)	D3	974	100	17980.3	0.7	9	1	0.2	110.0	45.0	17
Kailaboang (Lithocarp Forest)	D4	1015	100	3999.2	1.1	7	2	0.4	27.0	16.8	23
Coppice forest (12-15 yrs Tseri)	D5	1045	100	505.2	1.8	14	2	0.5	11.0	9.0	23
Khailaborang	D6	1070	100	2788.5	1.0	7	2	0.4	24.0	18.8	23

and 11 deciduous broad-leaved trees along Gomtu series, while Dechiling series showed 17 evergreen broad-leaved trees, 13 evergreen shrubs and 5 deciduous trees. Similarly Pasakha series revealed 22 evergreen broad-leaved trees, 18 evergreen shrubs, 7 deciduous trees, 6 deciduous shrubs and 1 palm and 3 climbers representing subtropical elements.

Gomtu series was found mainly dominated by *Shorea robusta*(deciduous tropical element) while Dechiling series was dominated by *Salix tetrasperma* (deciduous wetland elements). Pasakha series showed mainly evergreen broad-leaved tree species.

Floristic compositions of dominant tree species were determined along the three series (Table 3). A total of 32 dominant trees were enumerated from the three study sites. All three series showed presence of both evergreen and deciduous broad-leaved dominants. Pasakha series showed 9 dominant tree species (7 evergreen broad-leaved and 2 deciduous broadleaved), Gomtu series revealed 18 dominants (13 evergreen broad-leaved and 5 deciduous broad-leaved) and Dechiling series showed the least dominant species of 7 (5 evergreen broad-leaved and 2 deciduous broad-leaved) respectively.

Schima wallichii, a sub-tropical element belonging to evergreen broad-leaved tree was appeared as the most common dominant in all the three series. Gomtu series was mainly dominated by *Shorea robusta*, a subtropical deciduous broad-leaved species in a relatively shallow soil while other sites were dominated by *Talauma hodgsonii, Cinnamomum camphora*, *Picrasmajavanica*, *Pterospermum acerifolium*, *Castanopsis tribuloides* and *Engelhardia spicata*. The dominant evergreen broad-leaved species along Pasakha series are *Aphanamixis polystacya*, *Duabanga grandiflora*, T*erminalia myriocarpa, Cryptocarya bhutanica, Castanopsis hystrix*, *C. indica,* while Dechiling series are mainly dominated by *Syzygium cumini*, *Perseaminutiflora, Altingia excelsa* and *Lithocarpus fenestratus* respectively (Table 3).

All three study sites of the sub-tropical forest

Table 3 Dominant species composition of the three study sites

	PASAKHA SERIES				GOMTU SERIES												DECHILING SERIES					
Plot Number	P1	P2	P3	P4	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G12	G13	D1	D2	D5	D3	D4	D6
EVERGREEN BROAD-LEAVED TREES (RELATIVE BASAL AREA %)																						
Aphanamixis polystachya	28.8																					
Duabanga grandiflora	27.1	27.0																				
Terminalia myriocarpa		44.7																				
Schima wallichii			**30.1**	**36.9**	**53.2**	**32.5**	**31.8**							**24.7**		**23.8**			**47.0**		**42.2**	**46.8**
Cryptocarya bhutanica			19.3																			
Castanopsis hystrix			16.8																			
Castanopsis indica			8.8	47.5																		
Sapium baccatum					9.7																	
Acronychia pedunculata					8.4																	
Persea glaucescens					5.5																	
Talauma hodgsonii													45.6		10.8							
Acer oblongum													10.5									
Cinnamomum camphora														18.4								
Picrasma javanica														17.4								
Toona ciliata														8.5								
Pterospermum acerifolium														8.3	17.5	11.9						
Castanopsis tribuloides															9.3	34.9						
Engelhardia spicata																11.1						
Syzygium cumini																5.2						
Syzygium kurzii																		20.4				
Persea minutiflora																		16.1				
Altingia excelsa																				**80.8**		
Lithocarpus fenestratus																					51.3	44.9
DECIDUOU SBROAD-LEAVED TREES (RELATIVE BASAL AREA %)																						
Tetrameles nudiflora	20.1																					
Acrocarpus fraxinifolius	10.5																					
Shorea robusta					**10.7**	**37.8**	**51.1**	**76.2**	**74.7**	**82.2**	**56.8**	**86.0**										
Sterculia villosa											10.8											
Holarrhena pubescens											9.1											
Adenanthera microsperma													10.2									
Garuga pinata													7.7									
Salix tetrasperma																	84.9	52.2				
Rhus chinensis																			20.5			

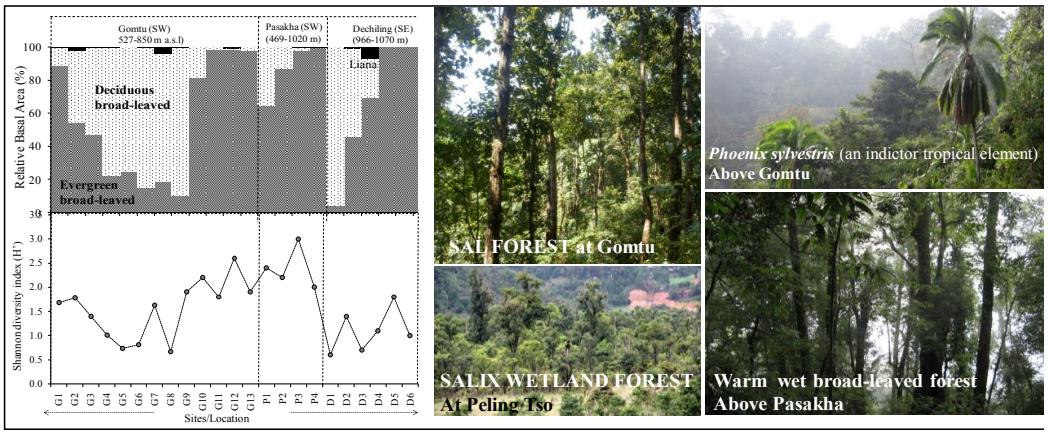

Fig.4 Life-form and diversity structural traits of sub-tropical broad-leavbed forest

showed clear existence of deciduous broad-leaved life-form (Fig. 4). The most dominant deciduous broad-leaved at Gomtus series was *Shorea robusta,* and *Tetramelesnudifolora* and *Acrocarpus fraxinifolius* along Pasakha series while Dechiling series was mainly dominated by *Salix tetrasperma Rhus chinensis* (Fig. 4, Tab. 3).

2) Dendrogram depicting different forest types of

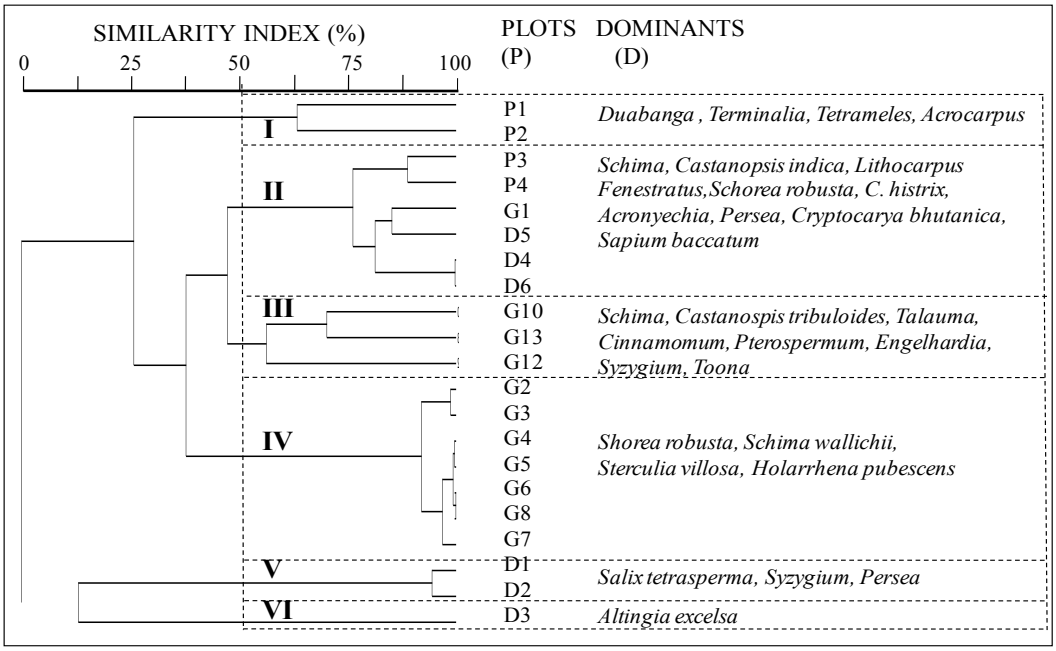

Fig.5 Life-form and diversity structural traits of sub-tropical broad-leaved forest

the sub-tropical belts.

The preliminary study of the three subtropical foothills of Bhutan Himalaya showed presence of diverse forest types. Based on the quantitative data analysis and using similarity index at c. 50 % similarity index, seven forest types were depicted (Fig. 5);

1. Riverrine forest type:

This forest type is dominated by evergreen broad-leaved *Duabanga grandiflora, Terminalia myriocarpa,* and deciduous broad-leaved *Tetrameles nudiflora* and *Acrocarpus faxinifolius* respectively. Thus, such forest appears as special relic type of forest. This type is mainly shown by Pasakha series.

2. True Oak-Laurel forest:

This type of forest represents mainly true oak-laurel forest as clearly represented by dominats species of *Schima wallichhii*, *Castanopsis indica*, *C. histrix*, *Lithocarpus fenestratus*, *Acronyechia pedubculata*, *Persea glaucescens, Cryptocariya bhutanica* and *Sapiumbaccatum*. This forest type serves as important resources both wildlife habitats as well as resources for the people.

3. *Schima-Castanopsis* (Evergreen broad-leaved forest):

Schima-castanopsis evergreen broad-leaved forest represents the southern sub-tropical elements and most common type along the foothills of the Bhutan Himalaya. These forests are also under subtle use and appeared mostly as secondary forest. However, in some parts of Bhutan, such forest types appeared as climax forest reaching more than 40 m tree height and over 100 cm DBH.

4. *Shorea robusta* (sub-tropical deciduous forest):

The existence and distribution of the natural Sal forest of the Bhutan Himalaya is least studied.

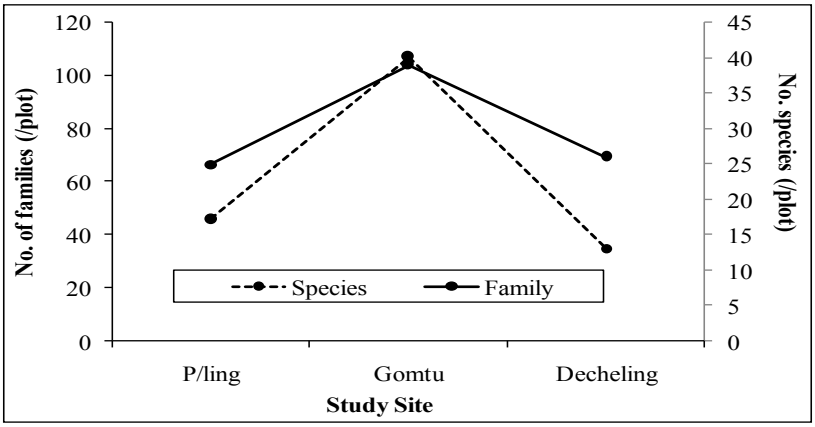

Fig.6 Life-form and diversity structural traits of sub-tropical broad-leaved forest

S.robusta is considered as one of the most valuable species in the country and are probably the only remnant forest regionally. Elsewhere, human activities have become a major challenge posing a bigger threat to the sustainability of the Sal forest particularly, the mining activities which are conspicuous in the area (Gyaltshen 2013). Therefore, Sal forest is very important for the conservation of biodiversity and fauna habitat.

5. *Salix tetrasperma* (deciduous wetland forest):

Deciduous wetland forest represented by the presence of *Salix tetrasperma* popularly known by the common name Pelingshingis strictly restricted to Dechiling series (PelingTso or Pelinglake) in eastern Bhutan. Salix in other locations were appeared as shrubs or used for pollarding. However, in the wetland of Dechiling, salix appeared as big tree reaching up to 38 m high and over 100 cm DBH. Thus, this particular ecosystem is found to be very important for conservation of wetland and thus habitat for other fauna including aquatic lives.

6. *Altingiaexcelsa* (refuge relic evergreen broad-leaved forest types):

This forest type appeared as sporadic and in Dechiling it appeared as dominant in many sites. Timber from Altingiaexcelsa is durable and people do extract Altingia timber for construction purposes. This particular species are also found in south East Asia like Malaysia, Indonesia and considered an important timber species. Thus, importance needs to be given to such forest for conservation.

The nomenclature of forest types in the present study were purely based on the dominant species and its environmental requirement. Therefore, the information generated by the present study serves as important baseline information for the good management plan of the subtropical forest.

CONCLUSION

Bhutan still has pristine sub-tropical forest ecosystem compared to its neighboring countries. The present study is one of the first of its kind to be undertaken in the foothill areas of the Bhutan Himalaya particularly focusing on the sub-tropical broad-leaved forest. Therefore, the present study generated important ecological and climatological

information.

The study clarified that Gomtu series revealed high diversity represented by both species and families (Fig. 6). However, this trend may be influenced by the different sizes of the study plots. Therefore, it is recommended to take up standard plot size in future and the present study serves as a baseline study.

The present study suggests that such important pristine forest ecosystem deserves to be well protected, conserved and managed properly for the future generation. This forest ecosystem also harbors diverse fauna such as Royal Bengal Tiger, Asian Elephant, among many important species. Hence deserves to be managed sustainably, and also should be widely known to academic society through scientific study of this kind.

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ブータンヒマラヤの亜熱帯広葉樹林における植物多様性と森林構造に関する研究

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本研究の目的は，ブータンヒマラヤ南山麓において人間の脅威にさらされている亜熱帯林を理解し，その動態を解明することで，生物多様性の保全および自然林の管理に資することである．植生に関する詳細な解析により 168 種が確認された．亜熱帯要素の常緑広葉樹である *Schima wallichii*, は 3 シリーズ全てで最も普遍的な優占種であった．Gomtu シリーズでは，相対的に土壌の薄い場所では *Shorea robusta* が優占する一方，それ以外の場所では多様な高木種が優占していた．Pasakha シリーズでは *Aphanamixis polystacya*, *Duabanga grandiflora* 等が，Dechiling シリーズでは主に *Syzygium cumini*, *Persea minutiflora*, *Altingia excelsa* が優占していた．デンドログラムにより調査地の森林は 6 つのタイプに区分された．1：河畔林タイプ，2：True Oak-Laurel forest タイプ，3：*Schima-Castanopsis*（常緑広葉樹林）タイプ，4：*Shorea robusta*（亜熱帯季節林）タイプ，5：*Salix tetrasperma*（湿地性落葉樹林）タイプ, 6：*Altingia excelsa*（遺存性常緑広葉樹のレフュジア）林タイプ．本研究で確認された森林タイプの体系は，優占種とその環境要求に基づいたものである．それゆえ本研究で得られた情報は，ブータンヒマラヤの亜熱帯性広葉樹林のよりよい管理計画作成のために重要な基礎情報として役立つ．（北澤哲弥訳）

1: 森林公園サービス管理局 2: 自然保護王立協会