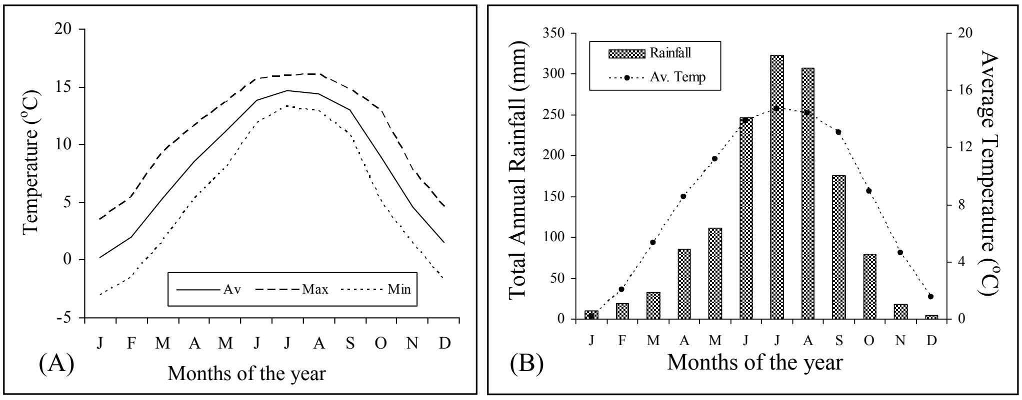
Study of climate change impact on Wetland ecosystem Phobjikha, West Central Bhutan



Royal Society for Protection of Nature
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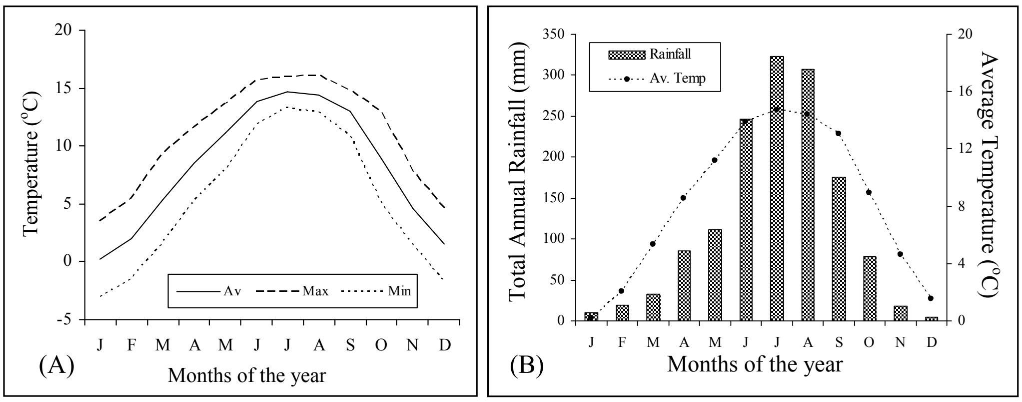

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Table of Contents

I. Background 1

I a. Objectives of the study 2

II. Study sites 2

III. Materials and methods 3

III a. Vegetation survey 3

III b. Environmental survey 3

III c. Data analysis 3

IV. Results and Discussion 4

IV a. General climatic background of Phobjikha 4

IV b. Environmental conditions along two aspects (NW and SE series) 4

IV c. Floristic composition and major life-forms 5

IV d. Forest types 7

IV e. Structural traits of the forest 8

IV f. Floristic Composition and Major Life-forms (Wetland ecosystem) 10

IV g. Impact of developmental activities in the core wetland 14

IV h. Water discharge measurement of the streams 14

V. Conclusion 15

VI. Bibliography 16

VII. Appendices I 17

VIII. Appendices II 22

IX. Appendices III 24

X. Appendices IV 25

I. Background

Phobjikha valley is considered as one of the important wetland ecosystem and a winter roosting site for the Black necked Crane (*Grus nigricollis*), an endangered bird species in the world. Phobjikha is also the largest winter roosting habitat and nearly c. 300 cranes arrive every winter. The core wetland area lies at 90^o 5’ 55” – 90^o 17’ 30” and 27^o 22’ 16” – 27^o 31’ 27” East covering an area of 161.9 km^2. The Landscape adjoins the north western boundary of Jigme Singye Wangchuck National Park and strengthens the forest corridors between Jigme Singye Wangchuck National Park and Jigme Dorji National Park.

The valley also serves as a water source for drinking and irrigation for people living around and downstream. The water drains through the open grassland to the Nakeychhu, Khewang chu and Chhukap rivers and other small annual and perennial streams. Most of the areas along the streams are marshy covered by grasses, bamboos, and several species of shrub and herbs including thick sphagnum moss. It is an important eco-system harboring various life forms. Besides providing water, wetland also serves as a sink for dust and brings cooling effect to the environment. Vegetation cover in the wetland helps to conserve water from evaporation effect and protects soil erosion.

Climatically, Phobjikha valleys fall in the temperate regions of the inner Bhutan Himalayas. Phobjikha valley has cold and relatively dry, clear winters and wet, cloudy summer. The annual mean temperature of Phobjikha valley was 8.3 ^oC with a maximum temperature of 15.3 ^oC in July and a minimum of -0.3 ^oC in January (HOBO ONSET logger 2001-2010). In the past ten years from 2001-2010, the maximum absolute temperature recorded was 23.6 ^oC on August 10, 2007 at 1 PM and the absolute minimum temperature was -11.9 ^oC on December 10, 2010 at 6 AM. Quantitative data analysis for the past seven years showed that Phobjikha experienced relatively warm winter in 2009 and 2006 with a cold winters in 2008 (Wangda *et.al*. 2009)

Phobjikha valley is both culturally and aesthetically important. Gangtey Lhakhang is an important religious centre overlooking the core wetland and people believed that the first arrival of the crane actually fly around Gangtey Lhakhang before landing on the wetland. The same is repeated when they migrate to Tibet. Therefore, Gangtey Lhakhang is an important centre for both local community and Cranes. Secondly, the valley is aesthetically beautiful and receives many visitors year round. Therefore, to sustain the ecosystem and adapt to the climate change it is important to understand the climatology and ecology of the valley.

Besides, the local people depend on agricultural crops and rear cattle. They also started using chemical fertilizers which may impact the wetland ecosystem in the long run. Thus there are many pressing issues to be addressed and taking up basic climate related studies is one way of understating the change.

The present study was designed to understand the climate change impact and involves vegetation, climate and water monitoring. The study was carried out in separate expeditions. The first and second expedition was focused on canopy vegetation study around the wetland while third and fourth expedition was mainly focused on climate and water including ground vegetation along the wetland.

I a. Objectives of the study

The general objective of the study is to build baseline information to understand the impact of climate change on the wetland ecosystem. Specifically the study aims to achieve the following goals:

1. Compile and analyze existing meteorological data of Phobjikha valley,
2. Classify forest types and structural traits surrounding the wetland (NE & SW series) which acts as source of water to the wetland,
3. Impact of developmental activities (road, buildings, tourists) on the wetland (invasive species),
4. Monitor and measure water discharge from seasonal and perennial springs into the wetland and,
5. Finally compile the vegetation and climate data to understand the current situation in respond to climate change.

II. Study sites

The study sites were selected along two altitudinal series (NE & SW series) for the forest canopy vegetation and core wetland for water and ground vegetation study respectively. The field works were carried out in May 2012 along Nalagang (SW series) from 3550 m a.s.l. to 2900 m a.s.l., June 2013 along the RSPN Office (NE series) from 3550 m a.s.l. to 2900 m a.s.l. and core wetland including water was carried out from August to December 2013 (Fig. 1).

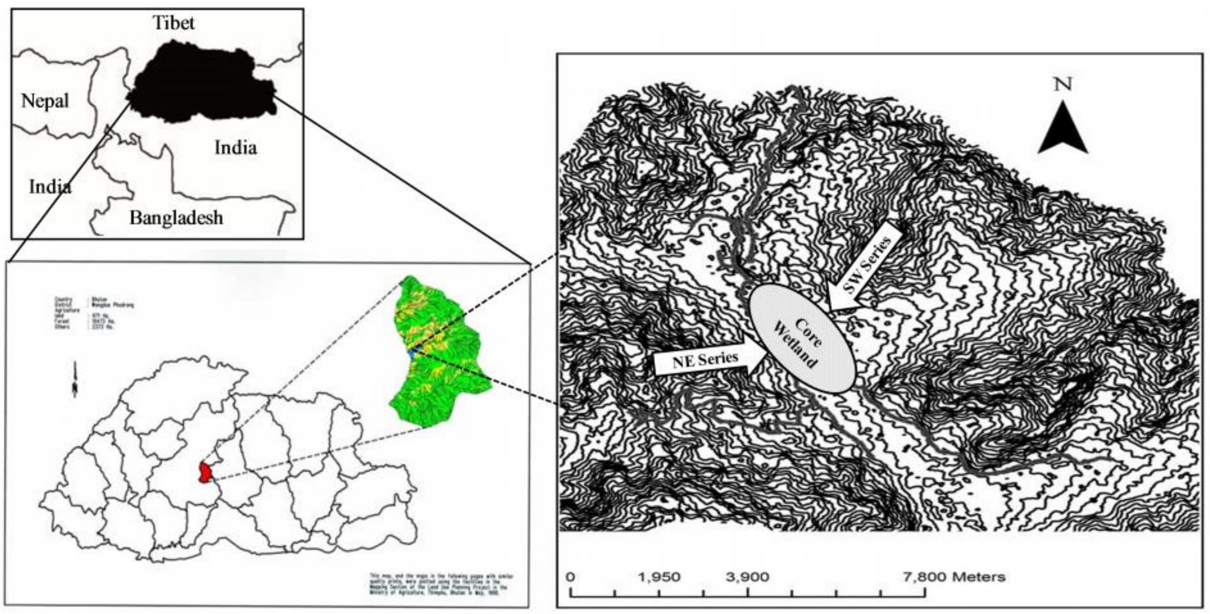

Fig. 1. Map of the study site showing the location of the four study sites

III. Materials and methods

III a. Vegetation survey

The present study was carried out along two series surrounding the wetland (Fig.1 & 2). The first series was along Nalagang carried out in May 2012 (SW series) stretching from 3550 m a.s.l. to 2900 m a.s.l. with c. 50 m interval between plots. The second study site was along RSPN Office (NE series) carried out in June 2013 stretching from 3550 m a.s.l. to 2900 m a.s.l. respectively. A total of 29 plant communities (20 in upper catchment forest and 9 in the wetland) were sampled along the altitudinal gradients including wetland (Figure 3). The plot size measuring 20 x 20 m for tree layer was adopted while one sub-plots of 2 x 2 m for seedling and ground layer were selected within the larger plots. Field equipments such as digital hypsometer, compass, clinometer, GPS, diameter tape and measuring tape were used in the field survey.

In the tree layer, it was further classified into two categories based on tree height; (1) tree (>1.3 m) and (2) seedling (< 1.3 m). For tree, all tree individuals occurring within the quadrat attaining a height greater than 1.3 m were measured. In this category, diameter at breast height (DBH) was measured to determine the basal area (BA) and the tree height (H) to determine height distribution and regeneration type. For seedling, all tree individuals occurring within the sub-quadrat (2 x 2 m) having height <1.3 m were measured in centimeter and its approximate age were recorded to determine density and age class distribution.

III b. Environmental survey

Soil moisture content, relative humidity, air temperature and soil hardness were measured along the gradients in each plot. Soil moisture content were measured by HydroSense (CD 620 + CS 620) (CAMPBELL SCIENTIFIC INC. Logan, Utah) bearing 20 cm probes. Similarly, soil hardness was measured by push cone (Yamanaka's soil hardness tester, Kiya Seisakusho Ltd. Tokyo) and the relative humidity and air temperature using VAISALA instrument.

III c. Data analysis

III c. a. Vegetation data analysis

The diameter at breast height (DBH) data of tree individuals were used to calculate species basal area (BA cm^2) and then the relative proportion of each species relative basal area in percent (RBA%) was calculated. The RBA of each species were used as abundance measure of species in a community.

Shannon & Wienner Diversity Index (H′) was calculated by using RBA data. The preliminary data were processed using PivotTable of the Microsoft Excel 2010. Once the data was processed and species composition compiled, analysis was carried out by using PC-ORD version 5.1. Cluster analysis was performed to determine the forest type using distance measure of Relative Sorensen and Group Average as linkage method.

III c. b. Meteorological data analysis

Temperature, relative humidity and rainfall data were downloaded after three to six months and reset by the research centre Yusipang, DoFPS, MoAF. The downloaded data were processed using PivotTable in the Microsoft Excel to means and the total of daily, monthly and yearly to determine various thermal indices as required.

IV. Results and Discussion

IV a. General climatic background of Phobjikha

Climatically, Phobjikha valley falls in the cool temperate zone. The average temperature recorded for the past eleven years (2001-2011) was 8.2 °C and the mean maximum temperature of 14.7 °C in the month of July while mean minimum temperature of 0.2 °C was recorded in January (Fig. 2A). The mean total annual rainfall of Phobjikha for the past 12 years (1992-2003) was 1411.4 mm with a maximum rain fall in July (323.3 mm) followed by August (307.1 mm) and a minimum rain fall in December (4 mm) followed by January (10.3 mm) respectively (Fig. 2B). The seasonal rainfall pattern clearly showed arrival of monsoon from June to August and slowly rainfall decreased during Autumn-Spring.

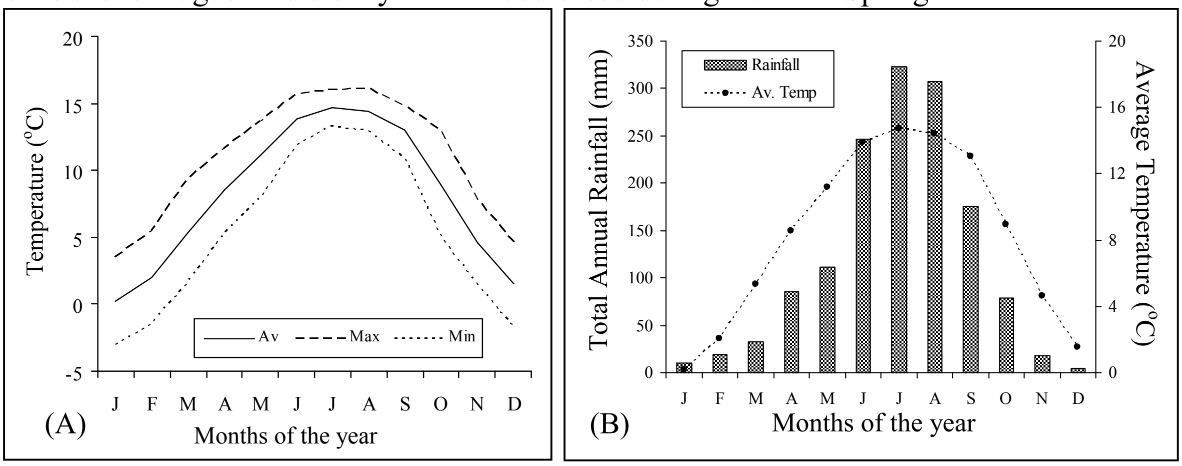

Fig. 2: Climatic background of Phobjikha (A) Average, Maximum and Minimum temperature (°C), (B) Average mean temperature and annual total rainfall (mm) of Phobjikha.

IV b. Environmental conditions along two aspects (NW and SE series)

Soil moisture and soil hardness were measured in all the altitudinal series (NW &SW series) of the study sites (Fig. 3). The result showed that mountain tops of both sites indicated higher soil moisture content and decreased at the lower altitude (Fig. 4). The soil moisture increased again towards the wetland and lowest soil moisture content was recorded along the blue pine forest coinciding with the human use (community/sokshing). Similarly, soil compaction measured by soil hardness tester (push cone) showed higher soil compaction at the lower altitude of transition to wetland indicating trampling by both human and cattle population

(Fig. 4). Soil compaction was found to be high along the buffer zone (forest- wetland) coinciding with the low soil moisture.

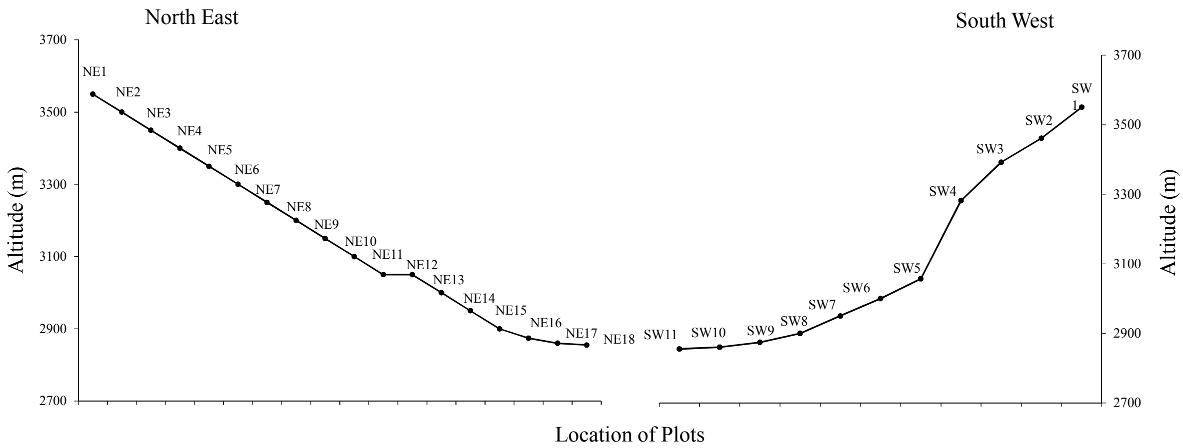

Fig. 3. Plot location along NE and SW altitudinal series of the study sites

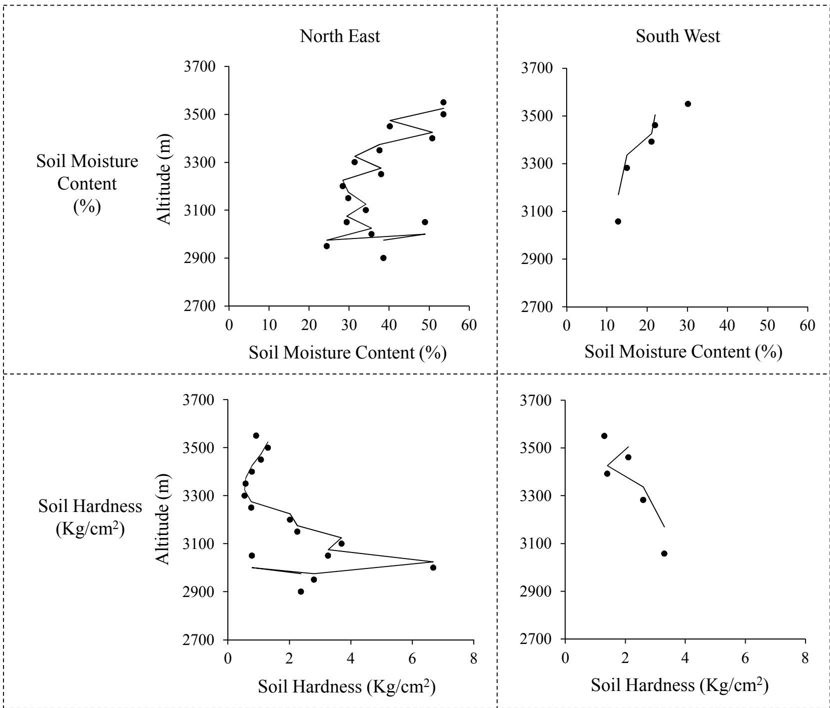

Fig. 4. Environmental attributes measured during the study period of the two aspects

IV c. Floristic composition and major life-forms

A total of 29 plant species belonging to 13 families were recorded along the two series. Mixed conifers in the present study were composed of *Tsuga, Abies* and *Junipers*. The major life-form along the north east series (NE) was found to be Mixed-Conifer forest (3050- 3550 m a.s.l.) at the mountain top and Blue Pine forest at the lower altitude (2900-3000 m a.s.l.) located near the human settlement indicating subtle disturbances such as timber harvesting for local house construction. The mixed conifer forest was dominated by Pinaceae (*Abies* *densa, Tsuga dumosa*). On the contrary, along south west series (SW) the major life-form was found mainly Blue Pine (*Pinus wallichiana*) forest (3057-3550 m a.s.l.) stretching form mountain top to the lower altitude (Fig. 5, Tab. 1). Interestingly, the upper most plot at 3550 m a.s.l. showed diverse life-form (deciduous, evergreen and conifers) while lower altitude revealed only blue pine and mixed conifer (Fig. 5). The result clearly revealed that the NE series were stretched further lower altitude (2900 m a.s.l.) and adjoins the wetland compared to the SE series (3057). The result also clarified that NE series found to be composed of diverse life-form along the humid series.

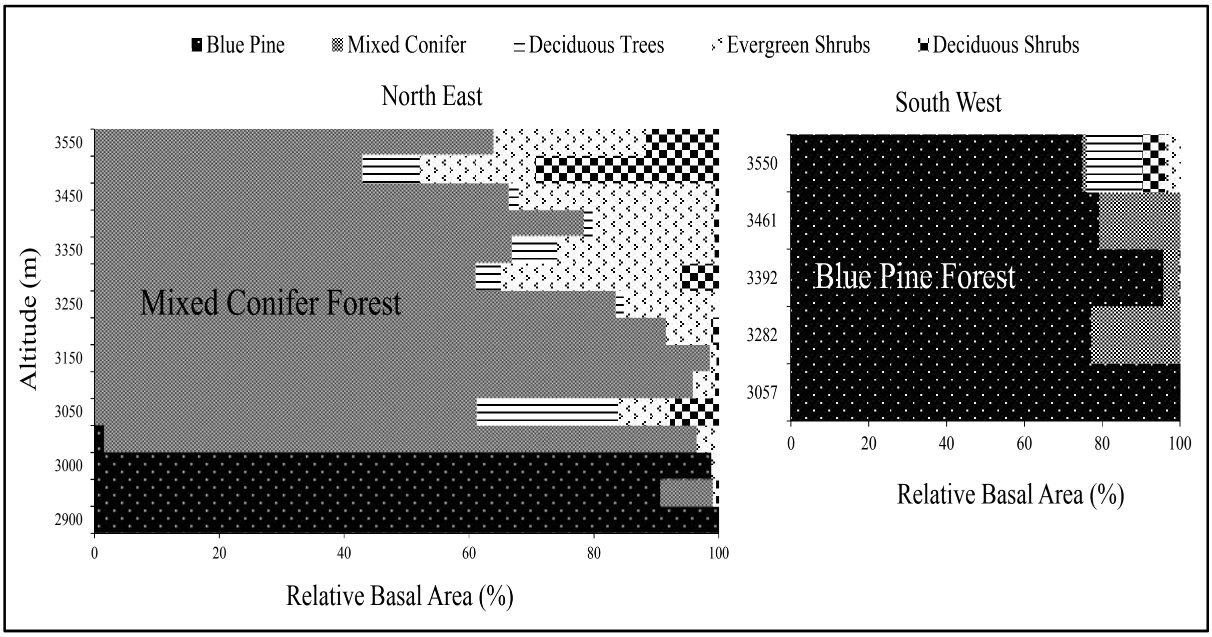

Fig. 5. Altitudinal distribution of major life-forms in the two aspects

Floristically, the study area is composed of coniferous trees (6 species), deciduous trees (8 species), deciduous shrubs (7 species), evergreen shrubs (8 species) respectively (Tab. 1). Coniferous species were *Tsuga dumosa, Abies densa, Juniperus recurva, Larix griffithiana, taxus baccata* & *Pinus wallichiana* respectively (Tab. 1). *Abies densa* and *Taxus baccata* were not found along the SW series. Evergreen shrubs were mainly Rhododendron (7 species) and only two species were found along the SW series. Similarly, eight deciduous trees and seven deciduous shrubs were found in the study sites. Accordingly, most of the deciduous trees and shrubs were found along the NE series compared to SW series.

Tab. 1. Floristic composition of the study sites (NE and SW series). Relative Basal Area indicated by RBA in % and dominant species shown by shaded color.

Plot ID	NE1	NE2	NE3	NE4	NE5	NE6	NE7	NE8	NE9	NE10	NE14	NE11	NE12	NE13	NE15	SW1	SW2	SW3	SW4	SW5
Altitude (m)	3550	3500	3450	3400	3350	3300	3250	3200	3150	3100	3050	3050	3000	2950	2900	3550	3461	3392	3282	3057
Aspect	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	SW	SW	SW	SW	SW
Relative Basal Area (%)	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA	RBA
Conifer Trees																				
Abies densa	63.9	36.8	2.2	10.4	9.6															
Tsuga dumosa		5.5	64.2	60.9	57.2	61.1	79.6	91.5	96.7	95.7	61.3	94.8		8.5					22.8	
Juniperus recurva		0.6														1.2	13.6	4.3		
Larix griffithiana				7.1													7.2			
Taxus baccata							4.0		1.9	0.2										
Pinus wallichiana								0.0				1.6	98.8	90.6	100.0	74.9	79.2	95.6	77.2	100.0
Sub-Total	63.9	42.9	66.4	78.4	66.9	61.1	83.5	91.5	98.6	95.8	61.3	96.5	98.8	99.1	100.0	76.1	100.0	99.9	100.0	100.0
Deciduous Trees																				
Acer campbellii		3.3									12.7									
Gamblea ciliata		3.3	0.8	0.9	7.2	4.0														
Acer pectinatum		1.3	0.8	0.4			1.2													
Betula alnoides		1.3																		
Sorbus microphylla					0.1											1.1				
Acer hookeri											5.9									
Corylus ferox											3.9									
Sorbus cuspidata																13.1				
Sub-Total	0.0	9.1	1.6	1.3	7.3	4.0	1.2	0.0	0.0	0.0	22.5	0.0	0.0	0.0	0.0	14.2	0.0	0.0	0.0	0.0
Evergreen Shrubs																				
Rhododendron campylocarpum	24.4			0.2												0.2				
Rhododendron keysii		9.0	0.2	3.0			0.1			1.0	2.7									
Rhododendron kesangiae		4.1	31.3	14.8	25.2	28.6	7.1	7.2	0.0	0.0										
Rhododendron barbatum		3.4		0.8																
Rhododendron arboreum		2.0		0.7		0.1	8.1	0.1	1.0	2.5	5.6	3.5	0.6							
Daphne bholua									0.0	0.0	0.1		0.5	0.2						
Rhododendron thomsonii														0.3						
Rhododendron cinnabarinum																3.7				
Sub-Total	24.4	18.5	31.5	19.5	25.2	28.7	15.3	7.2	1.0	3.6	8.3	3.5	1.2	0.6	0.0	3.8	0.0	0.0	0.0	0.0
Deciduous Shrubs																				
Lyonia ovalifolia	8.2				0.1											1.6				
Enkianthus deflexus	3.4	8.5	0.2	0.7	0.6	6.0			0.2	0.6						4.3				
Viburnum mullaha		20.7	0.3			0.2														
Hydrangea aspera		0.3						1.2												
Lindera neesiana									0.2		7.8									
Berberis praecipua									0.0	0.0				0.2	0.0					
Rosa sericea														0.2				0.1		
Sub-Total	11.6	29.4	0.6	0.7	0.7	6.2	0.0	1.2	0.4	0.6	7.8	0.0	0.0	0.4	0.0	5.8	0.0	0.1	0.0	0.0
Grand Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

IV d. Forest types

Based on the quantitative data and similarity index, three major forest types were depicted arbitrarily at 50 % similarity (Fig. 6). Three major forest types were: Type I: *Abies* dominated forest (Fir forest) with *Rhododnendron campylocarpum* of the NE series (1 & 2); Type II: *Tsuga* dominated (Hemlock forest) with dominant associated species of *Rhododendron kesangiae*, *Acer campbellii* along the NE series (Fig. 6). While Type I & II were found along the NE series, Type III (Blue pine forest) dominated by *Pinus wallichiana* was found along the SW series including plots NE 12 &15. Three forest types were clearly depicted surrounding the wetland at Phobjikha indicating temperate conifer forest types. These forest types serve as water source for the wetland. Humid conifer forest recharges the groundwater and several springs were originated from these forests. Therefore, an emphasis should be given to the surrounding forest for sustainable management.

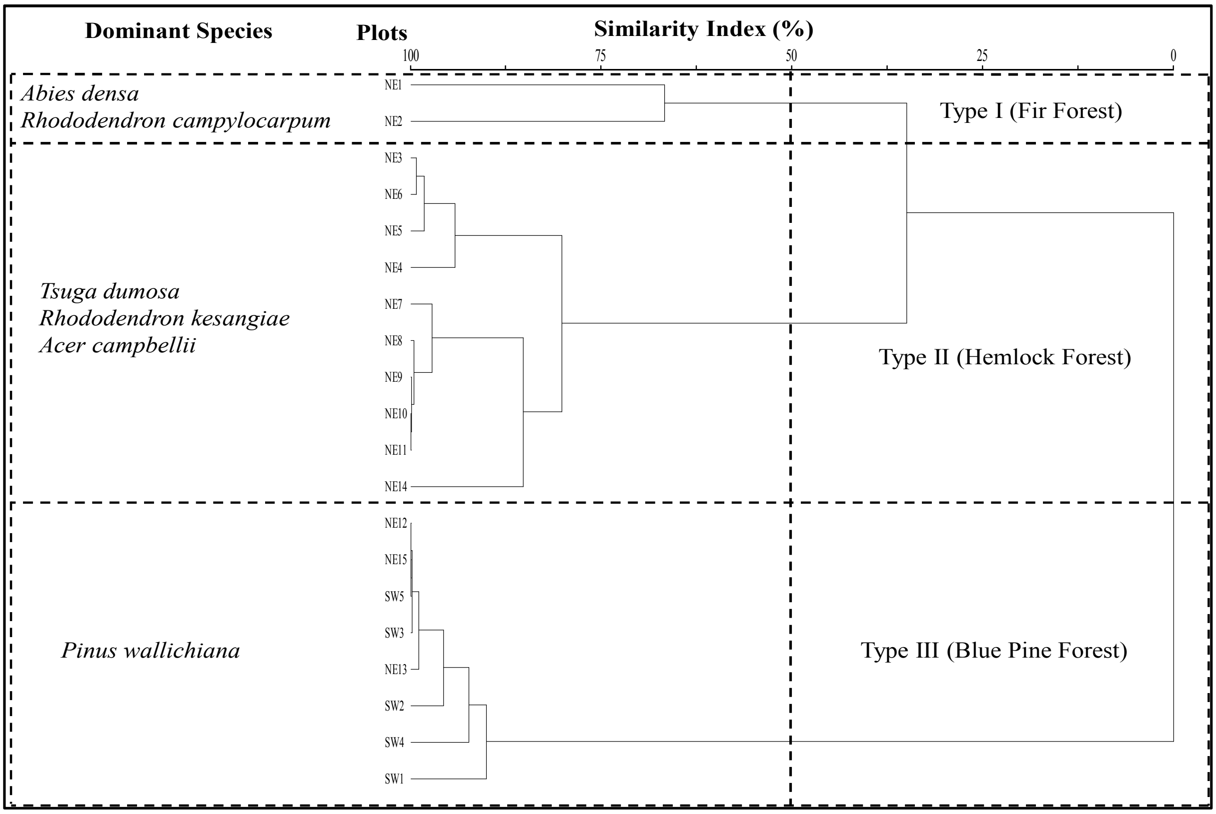

Fig. 6. Dendrogram depicting different forest types

IV e. Structural traits of the forest

Accumulated total basal area showed significantly high along the NE series compared to SW series. Total basal area was highest at the mid-altitude and lower basal area at the higher and lower altitude along both series. On the contrary, the stem density was found highest at the high and low altitude indicating subtle human disturbances along the lower pine forest (Fig. 7). Total basal area was c. 6 (six) times higher at the mid-altitude of NE series compared to SW series (Fig. 7). However, stem density was lower at the mid-altitude indicating mature forest stand.

In line with the total basal area, the maximum diameter and height of the tree was found significantly higher at the mid-altitude (Fig. 8) indicating more productively at the mid-altitude. Comparatively, NE series showed higher productivity compared to SE series. The maximum diameter of *Tsuga dumosa* measuring 134 cm was recorded at 3400 m a.s.l. and maximum height of 43 m of *Tsuga dumosa* was recorded at 3150 m a.s.l. However, the along the SW series, both diameter and height were significantly lower compared with NE series (Fig. 8).

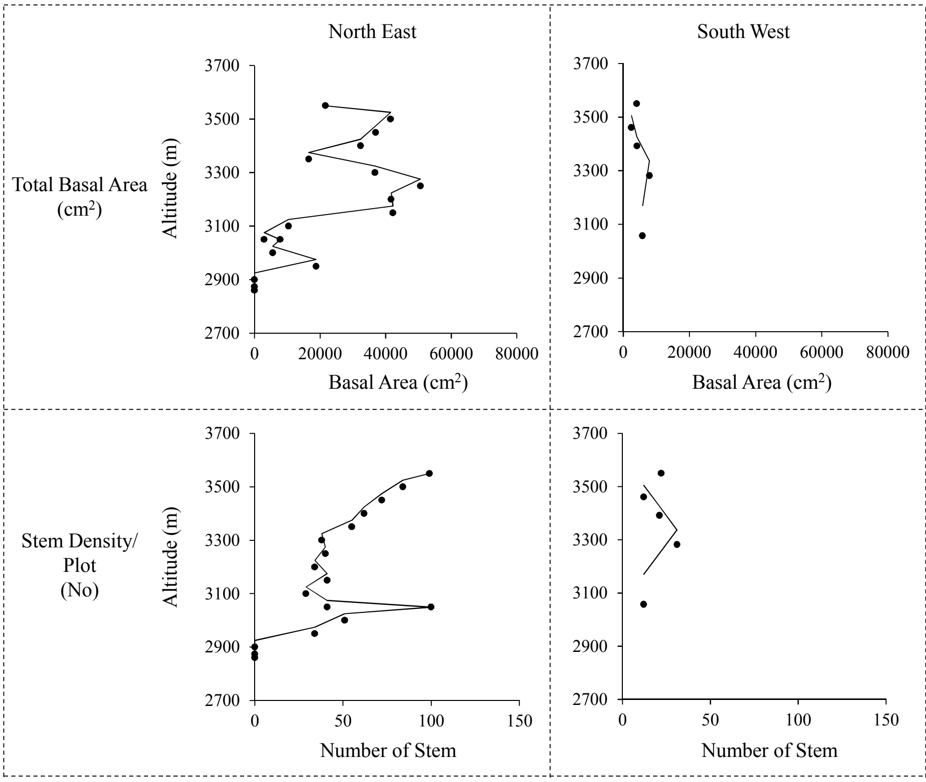

Fig. 7. Total basal area and stem density along the two series

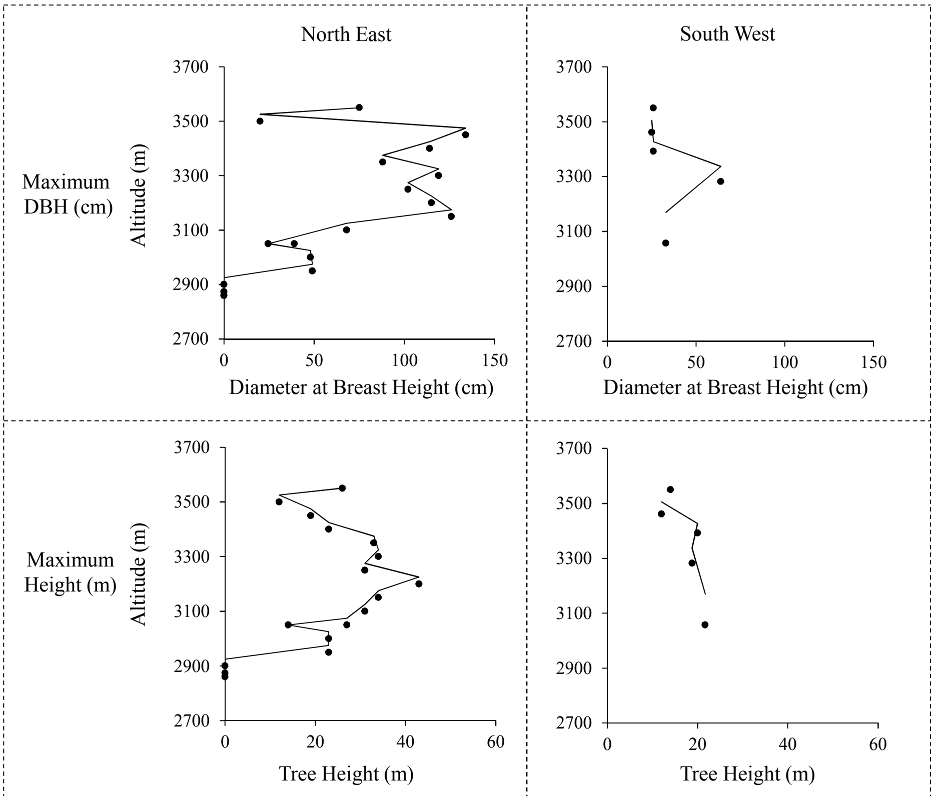

Fig. 8. Maximum DBH (cm) and height along the two series

Floristically, the NE series showed higher diversity and species richness compared to SW series (Fig. 9). The highest species number was recorded at the highest altitude along NE series which was three times higher than SE series. The lowest species diversity and richness were recorded at the pine zone.

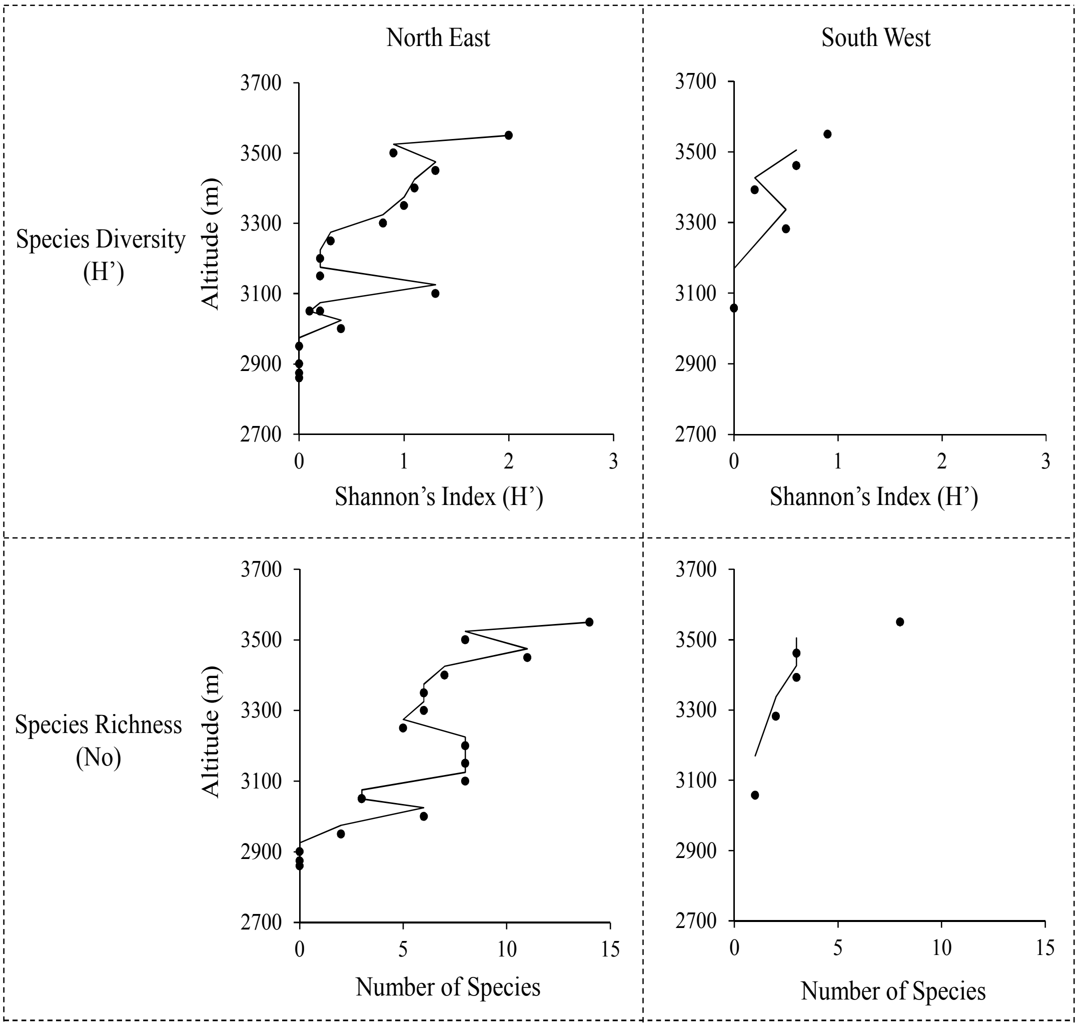

Fig. 9. Diversity indices along the study sites

IV f. Floristic Composition and Major Life-forms (Wetland ecosystem)

A total of 38 families belonging to 103 species were recorded in the core wetland, the Black-necked Crane habitat. Three major life-forms; bamboo and grasses, perennial herbs and shrubs were exhibited (Fig. 10). Among these, bamboo (*Yushania microphylla*) and grasses (*Carex, Eragrostis and Agrostis*) were dominant followed by perennial herbs across the area.

However, shrubs like *Rhododendron thomsonii* were growing mainly along the seasonal streams. *Berberis* and *Artemesia* were growing along the agriculture field edge while *Cotoneaster microphyllus* along the natural trail (Tab. 2).

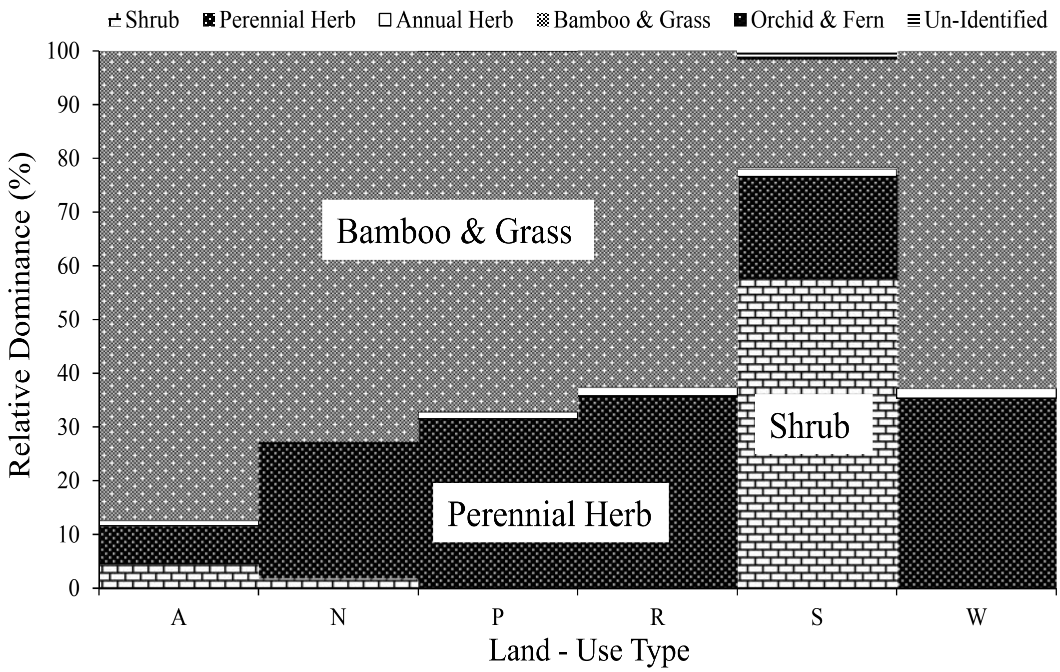

Fig. 10. Major Life-forms of the Core Wetland (Black-necked Crane habitat). Agriculture field edge (A), Nature trail (N), Perennial stream (P), Road side (R), Seasonal Stream (S) & Core wetland (W).

Floristically, the wetland vegetation was composed of bamboo (one species), grasses and sedges (25 species), perennials herbs (48 species), annuals herbs (20 species), shrubs (four species) and two ground orchid and fern species (Tab. 2). The most common grasses found were *Carex spp., Eragrostis sp. and Agrostis sp.*

Interestingly, few endemic species like *Eriocaulon bhutanicum* and *Euphrasia bhutanica* were recorded from the study area. The heights of all the *Yushania microphylla* were of same height (c. 20 to 30 cm) which resulted from cattle grazing. This clearly revealed that maintaining of the bamboo height is crucial for Crane feeding, breeding and roosting activities in the area. Therefore, cattle grazing is an integral part of maintaining crane habitat, and is a management tool for maintaining the optimal height of bamboo.

Tab. 2. Floristic Composition of the Wetland ecosystem

Plot ID			**A**	**N**	**P**	**R**	**S**	**W**
Relative Dominance (%)			**RD**	**RD**	**RD**	**RD**	**RD**	**RD**
Shrubs	**Family**	**LF**						
Artemisia sp	Asteraceae	S	4.5					
Cotoneaster microphyllus	Rosaceae	S		1.8				
Rhododendron thomsonii	Ericaceae	S					56.5	
Berberis cooperi	Berberidaceae	S					0.9	
Sub-Total			4.5	1.8	0.0	0.0	57.4	0.0
Perennial Herbs								
Rumex nepalensis	Polygonaceae	P	1.8	3.5	0.6	11.5		
Plantago erosa	Plantaginaceae	P	1.6	2.3	1.6	2.3	0.0	0.6
Trifolium repens	Fabaceae	P	0.7	0.7	8.4	11.0		10.0
Fragaria nubicola	Rosaceae	P	0.7	0.2	1.7	2.1	0.1	1.5
Senecio rhaphanifolius	Asteraceae	P	0.5	0.1	0.5	1.6	0.0	0.7
Persicaria runcinata	Polygonaceae	P	0.5					
Potentilla sp	Rosaceae	P	0.3	9.4				1.4
Cyanotis vaga	Commelinaceae	P	0.3	0.3	0.1	0.2	0.4	1.7
Aster sp	Asteraceae	P	0.2	0.4			2.9	1.6
Persicaria nepalensis	Polygonaceae	P	0.2	0.1	0.7	0.2	1.7	
Cirsium eriophoroides	Asteraceae	P	0.1		6.7	0.0		0.4
Geranium sp	Geraniaceae	P	0.1		0.1			0.2
Rubia cordifolia	Rubiaceae	P	0.0					
Prunella vulgaris	Labiatae	P	0.0	0.3	2.6	2.4	2.3	4.3
Viola biflora	Violaceae	P	0.0		0.2	0.0		1.4
Clinopodium umbrosum	Labiatae	P	0.0		0.8		0.0	0.5
Primula denticulata	Primulaceae	P	0.0			0.3	0.5	
Anaphalis magaritacea	Asteraceae	P		2.3	0.0		0.7	0.1
Hemiphragma heterophyllum	Scrophulariaceae	P		1.8		0.0		0.0
Persicaria hydropiper	Polygonaceae	P		1.3				
Primula capitata	Primulaceae	P		1.3				
Anaphalis adnata	Asteraceae	P		0.4				3.2
Delphinium cooperi	Ranunculaceae	P		0.4				
Chrysosplenium sp	Saxifragaceae	P		0.2				
Pedicularis siphonantha	Scrophulariaceae	P			2.9		2.8	0.4
Gyura bicolor	Asteraceae	P			1.6			
Euphorbia griffithii	Euphorbiaceae	P			0.9			0.7
Sanguisorba filiformis	Rosaceae	P			0.7		0.0	
Hydrocotyle himalaica	Umbelliferae	P			0.5	0.0		
Potentilla polyphylla	Rosaceae	P			0.5		0.1	
Geranium nepalense	Geraniaceae	P			0.2			
Cortia depressa	Umbelliferae	P			0.1		2.0	
Argemone sp	Papaveraceae	P			0.1			
Primula sp	Primulaceae	P			0.0		0.0	1.6
Stelaria monosperma	Caryophyllaceae	P			0.0			
Eriocaulon bhutanicum	Eriocaulaceae	P			0.0		0.0	
Potentilla arbuscula	Rosaceae	P				3.3		
Aster neoelegans	Asteraceae	P				0.5		
Anaphalis busua	Asteraceae	P				0.2		
Styachys melissaefolia	Lamiaceae	P				0.0		
Oenanthe hookeri	Umbelliferae	P				0.0		
Saxifraga brunonis	Saxifragaceae	P				0.0		
Roscoea alpina	Zingiberaceae	P				0.0		
Caltha palustris	Ranunculaceae	P					5.6	
Anaphalis sp	Asteraceae	P					0.1	
Parochetus communis	Fabaceae	P					0.0	
Legularia sp	Asteraceae	P					0.0	5.0
Hydrocotyle sp	Umbelliferae	P						0.0
Sub-Total			7.1	25.1	31.5	35.8	19.2	35.4

Annual Herbs								
Hypericum japonicum	Hypericaceae	A	0.6		0.1		0.1	0.6
Elsholtzia sp	Lamiaceae	A	0.2					
Capsella bursa-pastoris	Brassicaceae	A	0.1					
Cerastium glomeratum	Caryophyllaceae	A	0.1		0.6			0.0
Galinsoga parviflora	Compositae	A	0.0		0.0	0.0		
Drosera peltata	Droseraceae	A		0.2				
Galium aparine	Rubiaceae	A			0.3		0.3	
Halenia elliptica	Gentianaceae	A			0.1		0.5	0.3
Spergula arvensis	Caryophyllaceae	A			0.1	0.0		
Spharanthus indica	Asteraceae	A			0.1			0.1
Gentiana capitata	Gentianaceae	A			0.0		0.0	
Scrophularia sp	Scrophulariaceae	A				1.4	0.0	
Euphrasia bhutanica	Scrophulariaceae	A				0.1		
Callitriche stagnalia	Callitrichaceae	A				0.1		
Pseudognaphalium affine	Compositae	A				0.0		
Impatens cristata	Balsaminaceae	A					0.3	
Utricular minor	Lentibulariaceae	A					0.2	
Persicaria pubescens	Polygonaceae	A					0.1	0.8
Cardamine sp	Brassicaceae	A					0.0	0.0
Galium sp	Rubiaceae	A						0.0
Sub-Total			1.0	0.2	1.3	1.6	1.5	1.8
Bamboo & Grass								
Yushania microphylla (L)	Gramineae	B	0.6	0.4	6.4	1.0	7.2	4.9
Yushania microphylla (D)	Gramineae	B		0.4				15.4
Carex myosurus	Cyperaceae	G	40.1			1.5		
Carex sp	Cyperaceae	G	34.4		27.9	0.0	8.1	27.5
Agrostis sp	Gramineae	G	5.8		12.5		4.6	8.5
Eragrostis sp	Gramineae	G	5.0	58.7				
Juncus sp1	Juncaceae	G	1.3	0.7	0.7		0.3	5.1
Digitaria cruciata	Gramineae	G	0.1	0.8	1.2			0.1
Poa annua	Gramineae	G	0.0	0.7	4.6	7.5		0.5
Juncus sp3	Juncaceae	G		5.7				
Juncus prismatocarpus	Juncaceae	G		3.0	0.2			
Juncus ochraceus	Juncaceae	G		2.6				
Cyperus sp	Cyperaceae	G			10.0			
Brachypodium sylvaticum	Gramineae	G			2.4		0.1	
Fimbristylis ovata	Cyperaceae	G			0.8			
Blysmus compressus	Cyperaceae	G			0.4			
Agrostis hookeriana	Gramineae	G				41.7		
Luzula plumosa	Juncaceae	G				5.7		
Cyperus cyperoides	Cyperaceae	G				1.9		0.8
Digitaria ciliaria	Gramineae	G				1.6		
Juncus grisebachii	Juncaceae	G				0.8		
Cyperus myosurus	Cyperaceae	G				0.4		
Kyllinga brevifolia	Cyperaceae	G				0.4		
Axonopus sp	Poaceae	G					0.1	
Sub-Total			87.4	72.9	67.1	62.6	20.4	62.8
Orchid & Fern								
Botricum sp	Ophioglossaceae	F			0.0			
Salegenella sp	Selaginellaceae	F			0.0			
Spiranthes sp	Orchidaceae	O				0.0		
Malaxis sp	Orchidaceae	O					0.4	
Sub-Total			0.0	0.0	0.0	0.0	0.4	0.0
Un-Identified								
Grass 1	Gramineae	G					0.8	
Grass 3	Gramineae	G					0.3	
Grass 2	Gramineae	G					0.1	
Sub-Total			0.0	0.0	0.0	0.0	1.1	0.0
Total			100	100	100	100	100	100

IV g. Impact of developmental activities in the core wetland

Study on invasive species and its distribution were done in different land use type: agriculture field edge, natural trail, perennial and seasonal streams, road side and in the core wetland. In each type, two replicates were carried out with a plot size of 1 x 20 m. The maximum numbers of invasive species were found along the road sides, at the edge of the agriculture fields and along the perennial streams (4) while minimum in the seasonal stream (Fig. 11). The result clearly revealed that the development of road network have greater impact compared to other land uses due to frequent vehicle movement which enhances invasive seed dispersal.

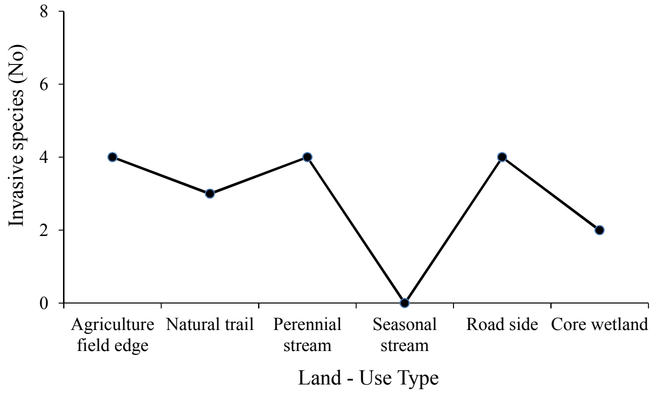

Fig. 11. Invasion of invasive species in different land-use

IV h. Water discharge measurement of the streams

Water discharge measurements were initiated along different springs/streams surrounding the wetland for long-term measurement and observation. There were about seven springs/streams showing discharge more than 200 l/s in the month of August. Twenty springs/streams surrounding the core wetland were selected for observation and measurements (Fig. 12). Change in land-use and climate change may change the trend of water discharge. Therefore, long-term observation of the water discharge is necessary.

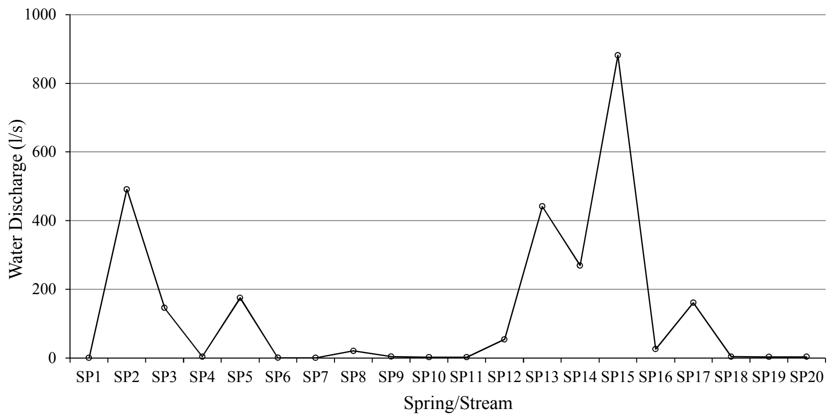

Fig. 12. Water discharge during the month of August surrounding the core wetland at Phobjikha.

V. Conclusion

The mountain tops of both Northeast and southwest series indicated higher soil moisture content and decreased at the lower altitude and again soil moisture increased towards the wetland. However, the lowest soil moisture content was recorded along the blue pine forest coinciding with the human use (community/*sokshing*). Similarly, soil compaction showed higher at the lower altitude of transition to wetland indicating trampling by both human and cattle population coinciding with low soil moisture.

The major life-form along the NE series was found to be Mixed-Conifer forest at the mountain top and Blue Pine forest at the lower altitude located near the human settlement indicating subtle disturbances such as timber harvesting for local house construction. On the contrary, along SW series the major life-form was found mainly Blue Pine forest stretching form mountain top to the lower altitude. Interestingly, the upper most plot at 3550 m a.s.l. showed diverse life-form (deciduous, evergreen and conifers) while lower altitude revealed only blue pine and mixed conifer. The result clearly revealed that the NE series were stretched further lower altitude (2900 m a.s.l.) and adjoins the wetland compared to the SE series (3057). The result also clarified that NE series found to be composed of diverse life-form along the humid series.

Three forest types were clearly depicted surrounding the wetland at Phobjikha indicating temperate conifer forest types: Type I (Fir) and Type II (Hemlock forest) in the NE series while Type III (Blue pine forest) was found along the SW series. The forest types of the NE series serve as water source for the wetland. Humid conifer forest recharges the groundwater and several springs were originated from these forests. Therefore, an emphasis should be given to the surrounding forest for sustainable management.

In the core wetland (Crane habitat), three major life-forms; bamboo (*Yushania microphylla*) and grasses (*Carex, Eragrostis and Agrostis*), perennial herbs and shrubs were exhibited. Interestingly, few endemic species like *Eriocaulon bhutanicum* and *Euphrasia bhutanica* were recorded from the study area. The result revealed that the maintaining of the bamboo height to a certain level was crucial to facilitate the Crane feeding, breeding and roosting activities. Thus, cattle grazing were found necessary and are an integral part of crane habitat management.

The maximum numbers of invasive species were found along the road sides revealing the greater impact of road network due to frequent vehicle movement which enhances seed dispersal of the invasive species. Twenty springs/streams surrounding the core wetland were selected for observation and measurements. There were about seven springs/streams showing discharge more than 200 l/s in the month of August. Change in land-use and climate change may change the trend of water discharge. Therefore long-term observation of the water discharge is necessary.

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VII. Appendices I

(Landscape & uses)

Photo 1. Northeast facing slope with mid. & upper altitude (3050 – 3550 m a.s.l.) dominated by mixed conifer forest while lower altitude (2900 – 3000 m a.s.l.) near the settlement dominated by an even-aged Blue pine forest.

Photo 2. Blue pine forest dominating the whole Southwest facing series from the lower to upper most altitude (3050 to 3550 m a.s.l.).

Photo 3. Heavy timber harvesting in the Dungshing-Pokto Community Forest creating big openings.

Photo 4. Profuse regeneration of *Tsuga dumosa* in the openings created by the local users.

Photo 5. Core wetland, the Crane habitat surrounded by the settlements and forest cover.

Photo 6. Cattle grazing an integral part of the Core wetland management, the Crane habitat.

Photo 7. The Permanent Sample Plot established in 2012 inside the core wetland. Dense and over grown ground vegetation inside the fenced plot.

Photo 8. Water discharge measurement in the main stream.

Photo 9. Potato field: potato is one of the main cash crops for the Phobjikha community.

Photo 10. Formation of Bog in the wetland indicating degradation of the wetland ecosystem in Phobjikha.

VIII. Appendices II

(Flora diversity)

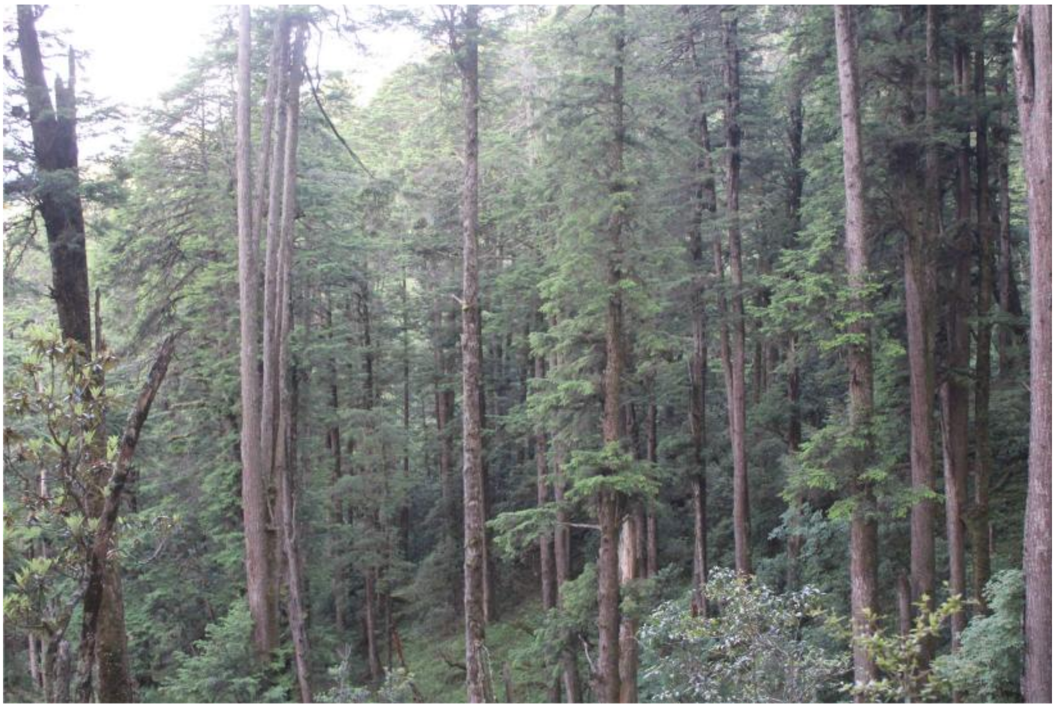

Photo 11. Hemlock (*Tsuga dumosa*) forest an important water reservoir for recharging the wetland ecosystem.

Photo 12. *Rhododendron kesangiae*

Photo 13. *Rhododendron arboreum*

Photo 14. *Rhododendron barbatum*

Photo 15. *Rhododendron thomsonii*

Photo 16. *Rhododendron campylocarpum*

Photo 17. *Rhododendron keysii*

Photo 18. *Rhododendron cinnabarinum*

Photo 19. *Eriocaulon bhutanicum*

IX. Appendices III

(Fauna diversity)

Photo 20. *Grus nigricollis*

Photo 21. *Lophophorus impejanus*

Photo 22. *Spizaetus cirrhatus*

Photo 23. *Panthera pardus* predating Black-necked Crane (captured in the Camera Trap)

Photo 24. *Rusa unicolor* (captured in the Camera Trap)

X. Appendices IV

(Field equipment procured)