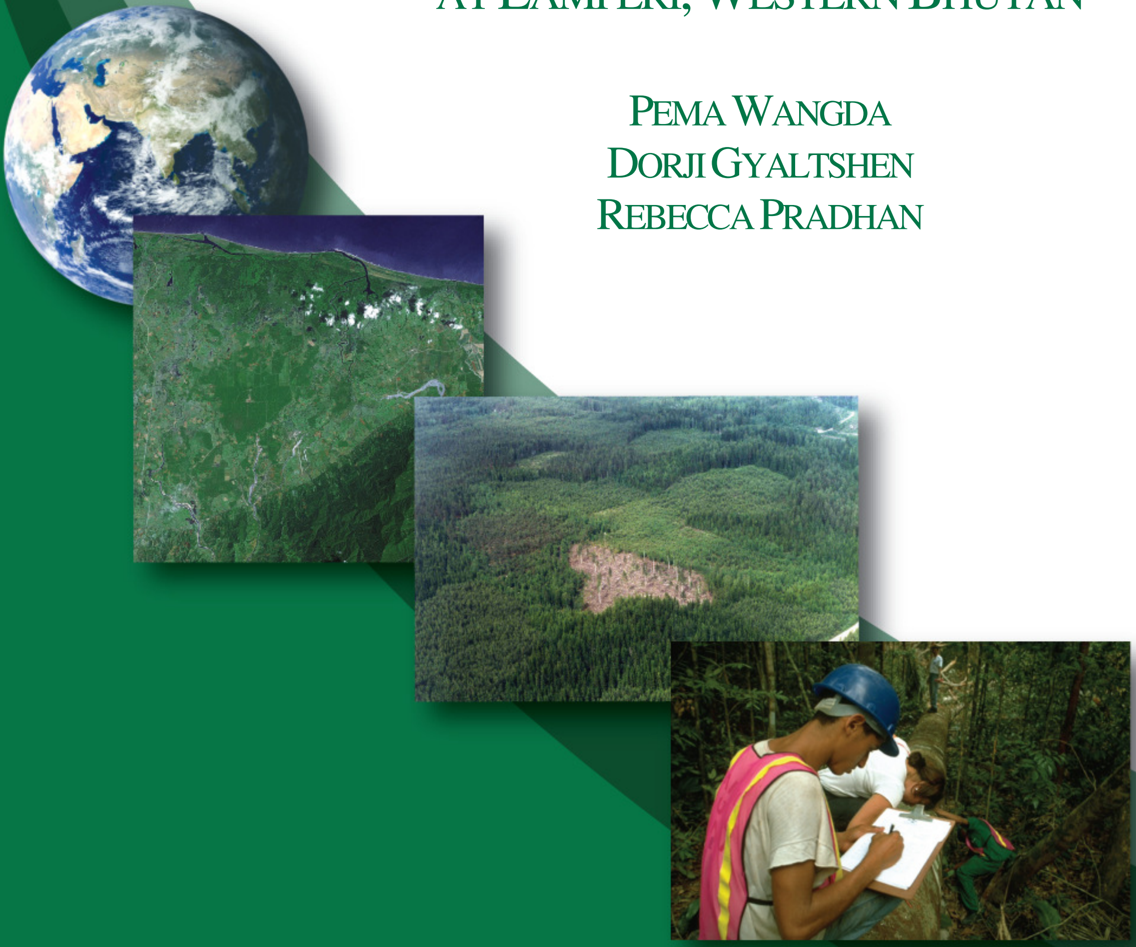
Forest Resources Assessment Working Paper 164

CASE STUDIES ON MEASURING AND ASSESSING FOREST DEGRADATION

IMPACT OF DEVELOPMENTAL PROJECTS IN THE HUMID EVERGREEN BROAD-LEAVED FOREST: WASABI PILOT PROJECT AT LAMPERI, WESTERN BHUTAN

PEMA WANGDA
DORJI GYALTSHEN
REBECCA PRADHAN



December, 2009

Sustainably managed forests have multiple environmental and socio-economic functions which are important at the global, national and local scales, and they play a vital part in sustainable development. Reliable and up-to-date information on the state of forest resources - not only on area and area change, but also on such variables as growing stock, wood and non-wood products, carbon, protected areas, use of forests for recreation and other services, biological diversity and forests' contribution to national economies - is crucial to support decision-making for policies and programmes in forestry and sustainable development at all levels.

Under the umbrella of the Global Forest Resources Assessment 2010 (FRA 2010) and together with members of the Collaborative Partnership on Forests (CPF) and other partners, FAO has initiated a special study to identify the elements of forest degradation and the best practices for assessing them. The objectives of the initiative are to help strengthen the capacity of countries to assess, monitor and report on forest degradation by:

- Identifying specific elements and indicators of forest degradation and degraded forests;
- Classifying elements and harmonizing definitions;
- Identifying and describing existing and promising assessment methodologies;
- Developing assessment tools and guidelines

Expected outcomes and benefits of the initiative include:

- Better understanding of the concept and components of forest degradation;
- An analysis of definitions of forest degradation and associated terms;
- Guidelines and effective, cost-efficient tools and techniques to help assess and monitor forest degradation; and
- Enhanced ability to meet current and future reporting requirements on forest degradation.

The Global Forest Resources Assessment programme is coordinated by the Forestry Department at FAO headquarters in Rome. The contact person is:

Mette Løyche Wilkie
Senior Forestry Officer
FAO Forestry Department
Viale delle Terme di Caracalla
Rome 00153, Italy
E-mail: Mette.LoycheWilkie@fao.org

Readers can also use the following e-mail address: fra@fao.org
More information on the Global Forest Resources Assessment programme can be found at: www.fao.org/forestry/fra

The coordinators of this work would like to acknowledge the financial contributions made by the Governments of Finland and Norway and by FAO, the GEF BIP programme and ITTO.

Forestry Department
Food and Agriculture Organization of the United Nations

Forest Resources Assessment Working Paper

Case Studies on Measuring and Assessing Forest Degradation

Impact of Developmental Projects in the Humid Evergreen Broad-leaved Forest:
Wasabi Pilot Project at Lamperi, Western Bhutan

Pema Wangda
Dorji Gyaltshen
Rebecca Pradhan

December, 2009

Forest Resources Assessment Programme | Working Paper 164
Rome, Italy, 2009

Abstract

The extent of forest degradation on the humid oak-laurel forest was investigated, following the failed Wasabi pilot project, to protect and conserve further deterioration of native endangered species diversity of the Bhutan Himalaya. Quantitative vegetation analysis revealed that the Wasabi pilot project has significantly changed the forest composition and structure as well as soil properties.

A total of 38 tree species (1 conifer, 18 evergreen broad-leaved, 19 deciduous broad-leaved) belonging to 22 families were recorded. Floristically, natural forest comprised of oak-laurel species (evergreen-*Quercus, Cinnamomum, Litsea, Neolitsea*) with a rich relic of rare native species such as *Tetracentron sinense, Decaisnea insignis, Magnolia* spp. was compared with the disturbed site which comprised deciduous-evergreen mixed species (*Quercus, Magnolia, Prunus, Rhus*). The number of species lost as a result of Wasabi cultivation constituted 44.4 percent of the natural forest and the most characteristic feature was that all were understorey shrubby species of evergreen habit.

Forest structural features of total basal area and stem density were also reduced significantly by 77.4 percent and 90 percent in the Wasabi project site when compared to the contiguous natural forest. The life-form spectrum showed that disturbed sites were mainly dominated by deciduous broad-leaved species of pioneer or seral habit while natural forest was dominated by evergreen broad-leaved species. Similarly, the disturbed sites showed high annual and low perennial species richness compared to the natural forest leading to the invasion of noxious annual weeds following the disturbances.

Disturbance of forest soil leads to changes in soil nutrient properties. Accordingly, soil organic carbon and total nitrogen were reduced significantly by more than 50 percent. Similarly soil pH was slightly increased.

Socio-economically, the grazing area has been significantly reduced leading to a high concentration of grazing pressure on the limited forest area.

Considering the significant loss of native, relict tree species, functional and structural traits including soil nutrients and grazing area, it is concluded that the developmental projects such as Wasabi plantation project can be destructive resulting in irreversible change to the pristine nature. The results of the present study provided a basic ecological database for the policy makers and stakeholders on the extent of forest degradation after the failed Wasabi project. Hence, it is highly recommended that such projects in future should undergo strategic environmental impact assessment before implementation for the purpose of conserving biological diversity in the humid evergreen broad-leaved forests.

Finally, the research methods applied in the present study were appropriate to determine the impact of forest under human influence and could be adopted in similar situations of other developing countries.

Key words: Biomass, soil properties, grazing, pilot project, development

1. Introduction

The Kingdom of Bhutan is probably one of the least known sections lying along the Himalayan range for approximately 2250 km between Nanga Parbat and Namcha Barwa (Barry, 1981, Schweinfurth, 1992). Bhutan is located in the southern foothills of the humid eastern Himalaya. The Tibet autonomous region of China lies to the north, while to the west, east and south lie the Indian states of Sikkim, West Bengal, Assam and Arunachal Pradesh (Figure 1 A).

Topographically, Bhutan is a mountainous country with flat land limited to a few broad river valleys only. The mountain terrains are characterized by huge variations in altitude from 150 m a.s.l. along the southern foothills to over 7500 m a.s.l. in the northern high Himalaya. The geographical diversity combined with equally diverse climate conditions contributes to Bhutan's outstanding range of biodiversity and ecosystem complexity. At present 72 percent of the total land area are under vegetation cover that includes tropical/subtropical broad-leaved forest, temperate mixed coniferous and alpine vegetation. The remaining 28 percent land cover constituted of agriculture, pasture, snow/glacier, settlement, water spread and landslide/erosion (Figure 1B). Much of Bhutan's flora remains undisturbed and the government is determined to conserve the forest cover and has set a national policy to maintain at least 60 percent of land under forest cover for the future. Bhutan's strategic development policy is that development of the country should not be adopted at the cost of the natural environment and culture of the country. To ensure and promote such development policy it is also important to know the basic ecological information for the conservation and sustainable utilization of the resources. Though Bhutan is careful in its developmental activities in preserving old tradition and culture, and protecting and conserving its natural environment, yet with agricultural globalization sometimes unavoidable developmental activities have resulted in the destruction of its pristine nature and this may lead to further degradation of natural resources. A good example of this is the failed Wasabi Pilot Project in the humid evergreen broad-leaved forest in western Bhutan.

In Bhutan, human utilization of the natural resources can be grouped into three broad categories; firstly, the traditional use of non-timber forest products, selective logging of timber for house construction, firewood, fodder and leaf litter collection, and agricultural implements which are in harmony with forest maintenance (Wangda, 2006a), secondly, the traditional farming system of rotating the field for agricultural crops such as shifting cultivation of bush fallow (tsetri) and grass fallow (pangshing) that has prevailed since thousands of years and proved sustainable (Wangda & Ohsawa, 2007), and now with globalization, the recent agricultural development such as Wasabi Pilot Projects, and the hydropower projects among others.

1.1 Background on Wasabi Pilot Project

The Bhutan Wasabi Pilot Project (WP) was established by the Bhutan Agrotech Research & Development Organization (BARDO) in 1998 at Lamperi humid broad-leaved forest, Western Bhutan by a joint venture (two Taiwanese, one Malaysian) and a Bhutanese national with the objective to promote cash crops for increasing the income of rural farmers. The land under Wasabi cultivation was leased from farmers of the nearby village which was initially registered as grazing land. The area was fenced and all the undergrowth shrubs and herbs were cleared for Wasabi cultivation. The forest tree roots lying within 30 cm were cut and extracted. The cleared land was tilled to approximately 30 cm and the soil beds were raised with fine soil for cultivation. BARDO planted US $ 510,000 worth of Wasabi saplings brought from Taiwan with the hope of harvesting 30,000 to 40,000 Wasabi plants an acre every year (Kuensel online, April 08, 2004).

However, after three years of project establishment, the Wasabi Pilot Project failed and the BARDO president announced its closure surrendering all its assets to the Bhutan Development Finance Corporation. The project site remains abandoned leaving behind disturbed forest and its floor with no understorey plants. The abandoned sites were heavily disturbed by wild boar and were mainly colonized by noxious perennial weeds such as *Rumex, Sambucus,* and *Senecio*.

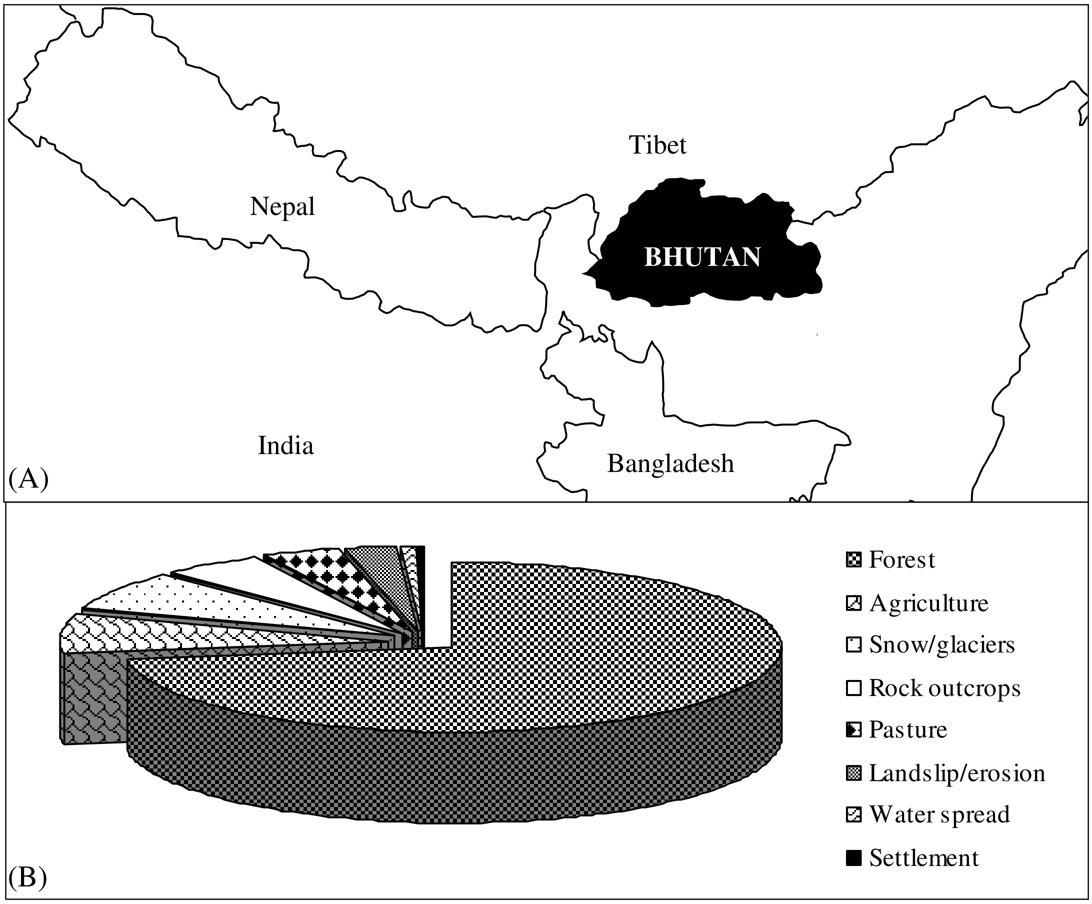


Figure 1. (A) Location map of the Kingdom of Bhutan along the Himalayan range; and (B) A pie chart showing land-use type of the Bhutan Himalaya.

1.2 Study area

The study area is located in western Bhutan, 30 km from Thimphu (2350 m a.s.l.) the capital city. The vegetation consists of humid oak-laurel evergreen broad-leaved species. There are also some important relict tree species found in the area such as *Tetracentron sinensis* belonging to the Tetracentraceae family (monotypic species), which is one of the monotypic east Asiatic families of Trochodendrales. *T. sinensis* is an ancient relict angiosperm with no vessel in its trunk that is distributed from central and southwest China up to Burma, Bhutan and Nepal. This primitive angiosperm should be conserved because of its peculiar remnant botanical features. Another species is *Decaisnea insignis* (Lardizabaraceae) a species limited to the Himalayas and western China. It has attractive foliage and a bell-shaped flower, followed by striking blue fruits in autumn. Based on the occurrence of the important relic species, the study area deserved to be protected and conserved for educational and research purposes. Wangda and Ohsawa (2006b) reported that the eastern slope of the Dochula pass including the Lamperi study area provide a representative sample of the vegetation along the whole of the Himalayas including dry west and humid east Himalaya. Hence the development of a proper management and conservation scheme is essential and useful for future generations.

Besides the Lamperi forest (study area) being an ecological hot spot and socio-economically important as a traditional grazing area, and for watershed protection as well as for the collection of minor forest products, the establishment of the Wasabi Pilot Project was a serious concern. Hence, the present study was conducted with the objective to investigate the impacts of the Wasabi Pilot Project on the broad-leaved forest. Specifically, the study aimed to achieve the following objectives:

1. Investigate the change in species composition and forest structural features,
2. Understand the impact of the Wasabi project on the soil nutrient status (contents) and
3. Provide basic ecological information for the conservation of biological resources

2. Methods and data collection

2.1 Plot lay out and vegetation survey

Two plots measuring 50 m by 200 m (1 ha) each, one in the Wasabi Project site and the other, the control, in the nearby natural forest were set up (Figure 2). Each plot was sub-divided into sub-plots of 10 m by 10 m with a total of 100 sub-plots in each plot.

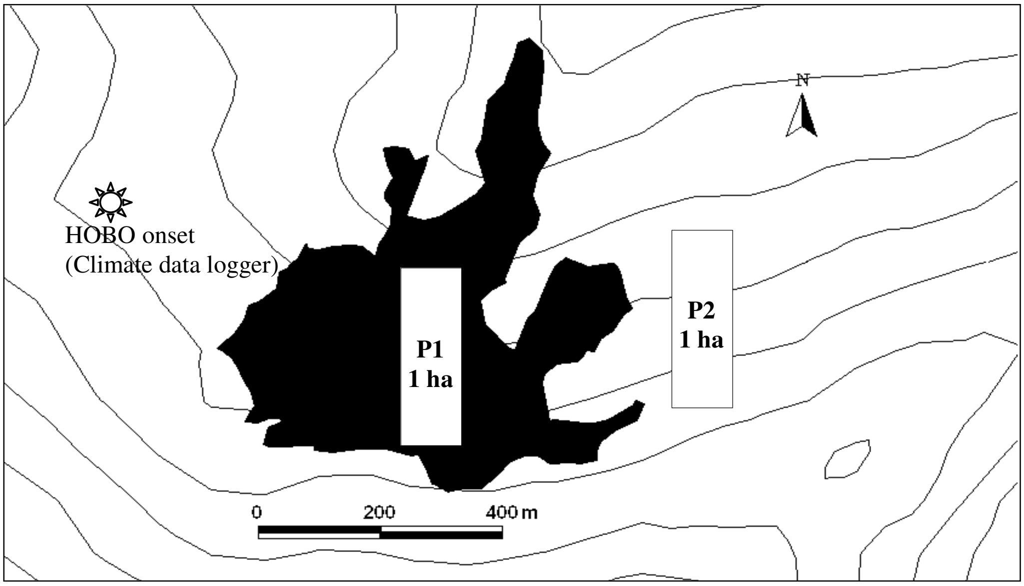


Figure 2. Map showing the Wasabi Pilot project site and sampling plots: P1 inside the pilot project site; and P2 outside in the natural forest; each measured 50 m by 200 m. The irregular shape of the Wasabi project site follows the topography of the area.

Tree individuals occurring inside the experimental plots were classified into three major categories based on height as follows: (1) tree ($H \geq 1.3$ m), (2) sapling ($0.5 \leq H < 1.3$ m), and (3) seedling ($H < 0.5$ m). In the tree category, diameter at breast height (1.3 m above the ground) and total height (H) were measured and recorded. Crown projection mappings were also carried out (see Figure 3A).

Ground vegetation was surveyed by measuring the maximum height (H, cm) and percent coverage (C %) of each species occurring within the sampling plots to determine the biomass equivalent volume (Figure 3B). All plants including ground vegetation occurring within the quadrat were identified and labelled.

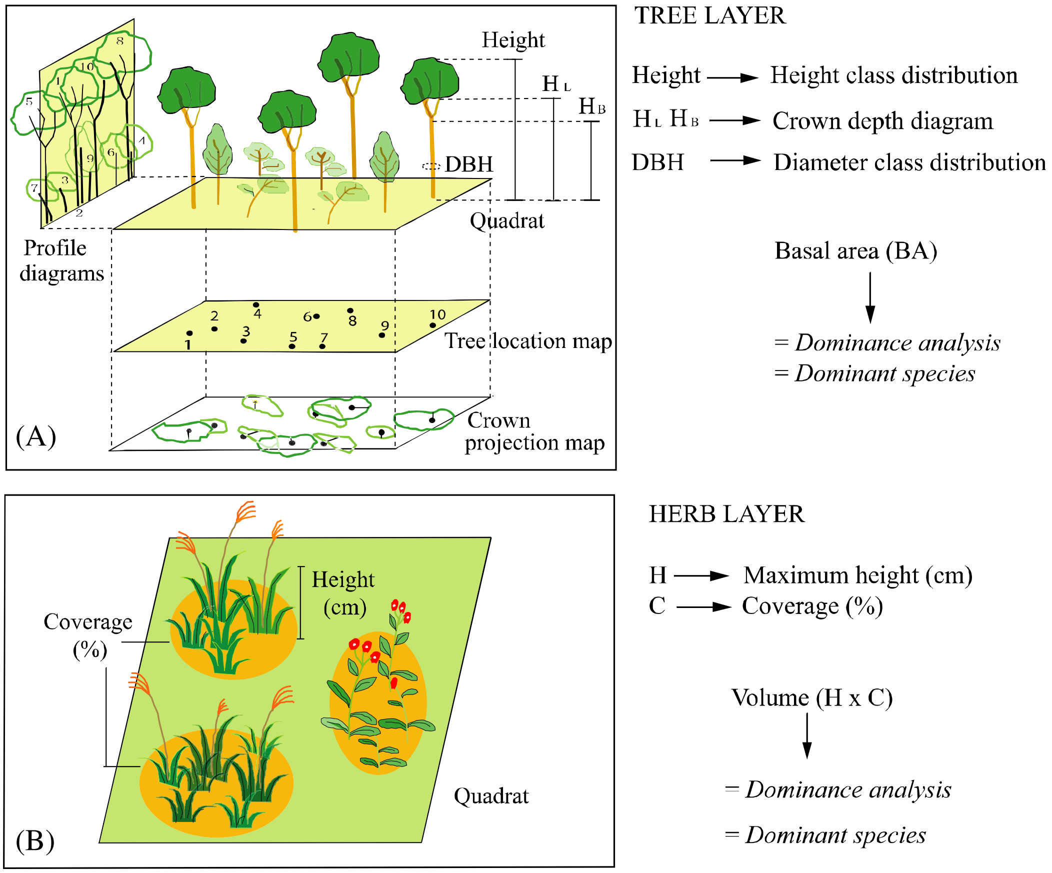


Figure 3. Vegetation survey methods: (A) Tree layer survey measurements; and (B) Ground/herb layer vegetation survey methods adopted in the present study.

Nomenclature of plants followed "Flora of Bhutan; Vol. I Part 1, 2, 3, Vol. II Part 1, 2, 3, Vol. III Part 1, 2" (Grierson & Long, 1983-2000), "Flowers of the Himalaya" (Polunin & Stainton, 1984), "Concise flowers of the Himalaya" (Polunin & Stainton, 1987), "Flowers of the Himalaya, A supplement" (Stainton, 1988), "Wild Rhododendrons of Bhutan" (Pradhan, 1998), "Photo album of plants of Eastern Himalaya" (Hara, 1968), "Flowers of Bhutan" (Nishioka & Nakao,1984) and "Weeds of Bhutan" (Parker, 1992).

2.2 Litter and soil samplings

Litter and soil samples were collected by setting small quadrats (0.5 m by 0.5 m) both in the natural forest and in the Wasabi Project disturbed site that were further sub-divided into 0.25m by 0.25m (see Figure 4A and B). Litter samples were separated into litter layer (L-layer) having intact leaf shape and form and fermentation-humus layer (F-H layer) when partially decomposed, and soil surface layer (A-layer) from ca. 5 cm soil depth.

(A) (B)

Figure 4. Litter and soil sampling methods: (A) Quadrat sampling with four sub-quadrat (S1-S4); and (B) Taking surface soil sample after litter collection.

2.2 Data Analyses

Tree inventory data were processed to obtain basal area (cross-sectional area of tree trunks at breast height 1.3 m above the ground: BA cm^2/area) from DBH data. The checklists of floristic composition were prepared using pivotal tables of MS Excel. Then we calculated the relative proportion of each species' basal area in percent (RBA %), which was used as an abundance measure. Dominant species in each plot were determined by dominance analysis (Ohsawa, 1984; Kikvidze & Ohsawa, 2002). If in a community dominated by single species, its relative dominance may be stated at 100 percent. If, two species share dominance, the relative dominance of each should ideally be 50 %, or if there are three co-dominants, 33.3 percent, and so on. The number of dominant species is that which shows the least deviation between the actual relative dominance values and the expected percent share of the corresponding co-dominant-number model.

$$d = 1/N \{\sum_{i \in T} (x_i - x')^2 + \sum_{j \in U} x_j^2\}$$

Where, x_i is the actual percent share (relative basal area) 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; x' is the ideal percent share based on the model as mentioned above and x_j is the percent share of the remaining species (U). N is total number of species.

Species diversity index (H′) was calculated by using Shannon-Wienner diversity index H′ (Pielou, 1977).

$$\text{Diversity (H')} = -\sum_{i=1}^{N} pi \log pi$$

Where N = number of species in a plot, pi=decimal fraction of a relative basal area

$$\text{Basal area (BA)} = \{(DBH)^2 * \pi\}/4$$

DBH=diameter at basal area

For the ground cover vegetation, volume (biomass) was used as a species abundance measure. Volume was calculated by multiplying the height of tallest individual by the percent coverage of each species (V=max Ht in cm*C %) (Figure 3B).

2.3 Soil sample analysis

The soil samples were air dried for one week followed by oven drying at 40 ^{o}C for 48 hours in the laboratory of the Research Centre Yusipang. The fresh weight (FW), air dry weight (ADW) and oven dry weight (ODW) were determined before being processed for further analysis.

The processed soil samples were taken to the Soil and Plant Analytical Laboratory (SPAL) for soil analysis. The methods and procedures used by the soil laboratory were; (1) soil pH was measured in suspensions of the soil in distilled water and 1M KCL (1:2:3) using a PHM 83 automatic pH meter, (2) total nitrogen (N) was extracted and converted into ammonium form by micro-Kjeldahl digestion with H_2SO_4 and a Se-based catalyst, (3) Ammonium-N and nitrate-N were extracted by shaking with 0.01M $CaCl_2$ for two hours, and (4) organic carbon was measured by the Walkley-Black method of low temperature oxidation with acidified $K_2Cr_2O_7$ and titration of the excess dichromate (SPAL method).

3. Results and discussion

3.1 Vegetation change

3.1.1 Change in crown and diameter projection

Based on the crown projection map of the portion of study area, it was clear that after the disturbance, a large area (gaps) were created in the forest (Figure 5 B). Additionally, the life-form changed from evergreen broad-leaved to deciduous broad-leaved (Figure 5 A and B). Such depletion of the forest can be visible only after projecting the maps. Similarly, the diameter projection mapping showed clear loss in evergreen broad-leaved trees after the forest disturbance (Figure 6 A and B).

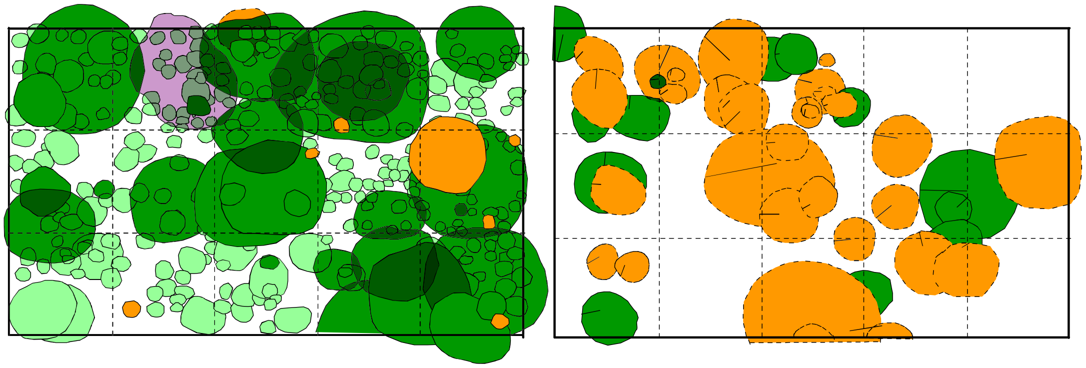


Figure 5. Crown projection mapping (10 by 50 m sub plots) plot of the natural forest (A) and disturbed forest (B).

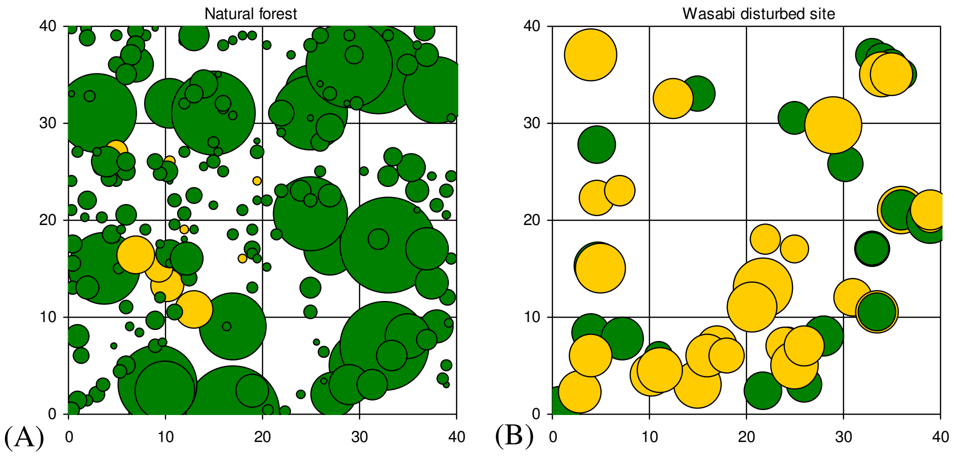


Figure 6. A diameter projection mapping (40 m by 40 m subplots) of the natural forest (A) and disturbed forest (B)

3.1.2 Change in floristic composition

Even though both plots were set along the same topography, the impact of the Wasabi project was clearly revealed by contrasting floristic composition in the two plots (Table 1) and the significant change in floristic composition was determined.

The natural forest (P2) comprised eight evergreen broad-leaved trees, nine evergreen understorey shrubs, nine deciduous broad-leaved trees, two understorey deciduous shrubs, and a conifer tree (*Taxus baccata*). The dominant tree species are oak-laurel such as evergreen broad-leaved *Quercus oxyodon, Q. glauca, Litsea kingii, Cinnamomum impressinervium, C. bejolgota, Neolitsea* sp. and deciduous *Magnolia campbellii, Acer campbellii, A. hookerii.* The understorey species are mainly evergreen species of *Symplocos ramosissima, S. lucida, S. glomerata, S. dryophila, S. sumuntia, Ilex dipyrena, Eurya acuminata, Daphne bholua* and deciduous shrubs of *Tetradium fraxinifolium, Viburnum erubescens* (Table 1). In total there were 38 species belonging to 21 families among which dominant families were Lauraceae, Fagaceae and Symplocaceae in the natural forest while Aceraceae and Rosaceae dominated in the disturbed forest respectively.

Table 1. Floristic composition of natural forest (NF) and Wasabi disturbed site (WB) classified into life forms (conifer, evergreen and deciduous broad-leaved) both for trees and shrubs.

TREE LAYER VEGETATION	FAMILY	NATURAL FOREST	WASABI SITE
CONIFEROUS TREES		RBA (%)	RBA (%)
Taxus baccata	Taxaceae	2.4	
Sub-total		2.4	0.0
EVERGREEN BROAD-LEAVED TREES			
Quecus oxyodon	Fagaceae	54.4	0.2
Litsea kingii	Lauraceae	5.6	8.6
Neolitsea sp.	Lauraceae	1.6	
Cinnamomum bejolgota	Lauraceae	1.5	
Rhododendron hodgsonii	Ericaceae	0.4	
Cinnamomum impressinervium	Lauraceae	0.3	1.6
Rhododendron arboreum	Ericaceae	0.2	0.1
Quercus glauca	Fagaceae	0.2	7.6
Sub-total		64.2	18.1
EvERGREEN BROAD-LEAVED SHRUBS			
Symplocos ramosissima	Symplocaceae	14.3	0.0
Ilex dipyrena	Aquifoliaceae	6.2	12.5
Eurya acuminata	Theaceae	0.9	1.2
Daphne bholua	Thymeliaceae	0.2	1.5
Symplocos lucida	Symplocaceae	0.1	
Symplocos glomerata	Symplocaceae	0.0	
Ficus nemoralis	Moraceae	0.0	
Symplocos dryophila	Symplocaceae	0.0	
Symplocos sumuntia	Tetracentraceae	0.0	
Osmanthus suavis	Oleaceae		0.5
Sub-total		21.6	15.8
DECIDUOUS BROAD-LEAVED TREES			
Magnolia campbellii	Magnoliaceae	4.1	6.7
Acer campbellii	Aceraceae	3.3	0.4
Acer hookeri	Aceraceae	2.7	0.4
Prunus cerasoides	Rosaceae	1.1	1.5
Alangium alpinum	Alangiaceae	0.2	1.3
Prunus rufa	Rosaceae	0.1	30.1
Betula utilis	Betulaceae	0.1	
Corylus ferox	Zingiberaceae	0.1	0.2
Lyonia ovalifolia	Ericaceae	0.0	0.0
Rhus javanica	Rosaceae		3.1
Prunus cornuta	Rosaceae		2.7
Acer sterculiaceum	Ranunculaceae		2.6
Sub-total		11.7	48.9
DECIDUOUS BROAD-LEAVED SHRUB			
Tetradium fraxinifolium	Rutaceae	0.0	
Viburnum erubescens	Caprifoliaceae	0.0	0.1
Viburnum sp (A52)	Caprifoliaceae		13.0
Euonymus sp.	Celastraceae		3.1
Decaisnea insignis	Lardizabalaceae		0.8
Elaeagnus parvifolia	Elaeagnaceae		0.2
Zanthoxylum armatum	Rutaceae		0.0
Sub-total		0.1	17.3
GRAND TOTAL		100	100

In contrast, the floristic composition of the Wasabi disturbed site (P2) was composed of five evergreen broad-leaved trees, five evergreen understorey shrubs, eleven deciduous broad-leaved trees and six deciduous understorey shrubs respectively. The dominants were mainly deciduous species of *Magnolia campbellii, Prunus rufa, P. cerasoides, P. cornuta, Acer sterculiaceum, Rhus javanica* and evergreen *Quercus glauca, Litsea kingii* and *Ilex dipyrena*. Lower numbers of understorey species were observed in the disturbed site. The missing species in the disturbed sites included *S. ramosissima, E. acuminata, D. bholua, S. lucida, Osmanthus suavis* and deciduous *Viburnum* sp., *Euonymus* sp., *Decaisnea insignis*, *Elaeagnus parviflora* and *Zanthoxylum armatum* (Table 1).

The impact of the Wasabi project on species composition was clearly represented by the absence of dominant oak-laurel species in the disturbed site that was instead dominated by pioneer deciduous broad-leaved species of *Prunus, Viburnum, Acer* and *Rhus.* The proportion of evergreen broad-leaved trees and shrubs that were present in the nearby natural forest (control plot) but absent in the disturbed site constituted 37.5 percent and 55.6 percent respectively indicating removal of both evergreen canopy and understorey species while cultivating Wasabi plants (Table 1). On the contrary, pioneers deciduous broad-leaved species were found abundant in the disturbed site.

3.1.3 Species richness, dominance- diversity relation and life-form spectra

The number of evergreen broad-leaved trees and evergreen broad-leaved shrubs was found to be high with a species number of eight and nine in the control plot inside natural forest in comparison to Wasabi disturbed site having five evergreen broad-leaved trees and five evergreen broad-leaved shrubs only (Figure 7 A and B, Table 1).

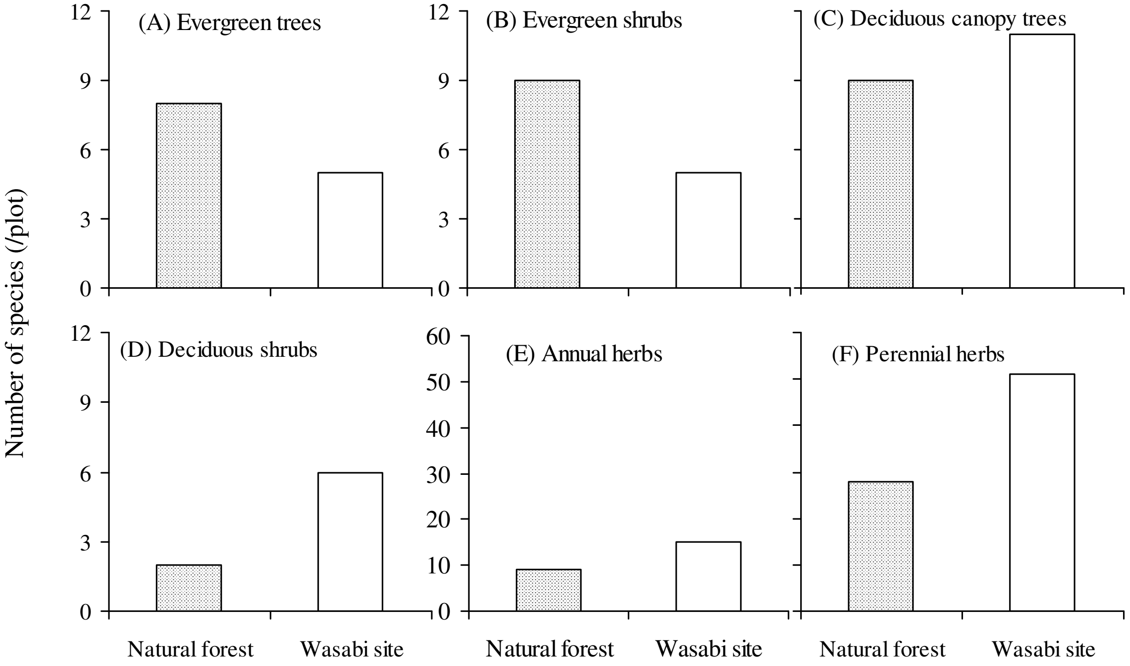


Figure 7. Species richness: (A) evergreen broad-leaved trees; (B) evergreen broad-leaved shrubs; (C) deciduous board-leaved trees; (D) deciduous broad-leaved shrubs; (E) Annual herbs; and (F) perennial herbs occurring in the nearby natural forest plot (control) and in the Wasabi project disturbed site plot.

On the contrary, the number of deciduous broad-leaved trees and deciduous understorey shrubs were found lower with a species number of nine and six in the natural forest while eleven deciduous broad-leaved trees and six deciduous shrubs were recorded in the Wasabi disturbed site (Fig. 7 C, D, and Table 1). Total number of species remained similar with a species number of 29 in the natural forest and 27 in the Wasabi disturbed sites respectively. Similarly total numbers of species of ground vegetation (herb layer) were 36 species (9 annuals, 28 perennials) in natural forest and 66 (15 annuals, 51 perennials) in the Wasabi disturbed site (Figure 7 E and F, and Table 2).

The life-form spectrum of both ground vegetation layer and tree layer indicates significant difference between natural forest and Wasabi project disturbed site. Even though perennial herbs dominated in both the natural forest and the disturbed site, the relative biomass proportion of annual herbs is much higher in the disturbed forest, and lower in the natural forest. By contrast, the relative biomass of the perennial herbs is much higher in the natural forest and lower in the Wasabi disturbed forest, indicating the invasion of annual herbs after disturbances. While the relative basal area of evergreen broad-leaved species dominated the natural forest, deciduous broad-leaved species dominated the Wasabi disturbed site indicating evergreen broad-leaved has been removed mostly from understorey while preparing for Wasabi cultivation. (Table 1). The presence of understorey deciduous board-leaved as represented by the relative basal area indicated that only negligible proportion was found in the natural forest while larger portion was still observed in the disturbed forest. This life-form distribution pattern indicates differences in forest types and the impact of disturbance on the forest tree species.

Table 2. Ground layer floristic composition of natural forest and Wasabi site

SPECIES	Life form	NATURAL FOREST	WASABI SITE
ANNUALS			
Persicaria nepalensis	A	10.3	3.8
Chenopodium album	A	1.7	1.1
Amaranthus sp.	A	1.1	3.7
Setaria pumila	A	0.2	1.4
Cynoglossum furcatum	A	0.2	0.8
Polypogon fugax	A	0.1	0.0
Poa annua	A	0.1	11.9
Oxalis corniculata	A	0.0	0.5
Geranium nepalensis	A	0.0	0.9
Galium aparine	A		6.4
Swertia sp.	A		0.3
Bidens pilosa	A		0.1
Gnaphalium affine	A		0.1
Sonchus sp.	A		0.0
Capsella sp.	A		0.0
Annual sub-total		13.7	31.1
PERENNIALS			
Kyllinga squamulata	P	24.9	1.6
Impatiens discolor	P	24.9	1.7
Geum sikkimensis	P	7.8	2.7
Yushania microphylla	P	7.1	2.1
Ainsliaea latifolia	P	5.5	0.4
Viola bhutanica	P	3.2	0.6
Lecanthus peduncularis	P	2.4	
Carex sp.	P	1.8	1.8
Dryopteris sp.	P	1.3	
Cirsium sp.	P	1.2	0.6
Aconogonum molle	P	1.1	0.5
Hedera nepalensis	P	1.1	2.4
Rubia cordifolia	P	0.7	0.7
Pilea umbrosa	P	0.7	
Pouzolzia hirta	P	0.6	2.6
Elatostema obtusum	P	0.4	
Hedychium sp.	P	0.4	
Artemisia parviflora	P	0.3	0.3
Paris polyphylla	P	0.1	1.5
Fragaria nubicola	P	0.1	0.7
Arisaema concinnum	P	0.1	2.6
Hemiphragma hetrophyllum	P	0.1	3.1

Table 2. continued.

SPECIES	Life form	Natural forest	Disturbed site
PERENNIALS			
Panax pseudo-ginseng	P	0.1	0.0
Aconitum bisma	P	0.1	0.5
Eupatorium mairei	P	0.1	
Anaphalis busua	P	0.0	1.2
Thalictrum foetidum	P	0.0	0.5
Cymbidium hookerianum	P	0.0	
Rubus calycina	P		8.2
Rumex nepalense	P		7.8
Megacarpacea sp.	P		5.6
Pteridium aquilinum	P		4.7
Uitrica sp.	P		2.2
Viola sp.	P		1.8
Paspalum distichum	P		1.8
Eleocharis sp.	P		1.5
Primula denticulata	P		1.5
Selaginella sp.	P		0.8
Senecio densiflora	P		0.8
Potentilla sp.	P		0.5
Hypericum sp.	P		0.4
Hedera helix	P		0.4
Juncus sp.	P		0.4
Scutellaria sp.	P		0.4
Sambucus densiflora	P		0.6
Wasabia japonica	P		0.3
Plantago erosa	P		0.3
Sibbaldia sp.	P		0.2
Trifolium repens	P		0.2
Smilacinia sp.	P		0.1
Cyperus sp.	P		0.1
Asplenium sp.	F		0.1
Erioscirpus comosus	P		0.1
Phytolacca acinosa	P		0.1
Calanthe sp.	P		0.0
Arundinella sp.	P		0.0
Schoenoplectus sp.	P		0.0
Apium sp.	P		0.0
Perennial Sub-total		86.3	68.9
GRAND TOTAL		100	100

3.1.4 Comparison of forest structural traits (Natural forest and Wasabi disturbed forest)

Forest community structural traits of maximum height, maximum diameter at breast height, stem density and total basal area of the natural forest and the Wasabi project disturbed site are illustrated in Figure 8. The maximum height of trees in the Wasabi project disturbed site of *Magnolia campbellii* and *Prunus cerasoides* were 20 m each. This is 44.9 percent of 44.5 m measured for *Q. oxyodon* in the nearby natural forest indicating structurally weaker forest (Figure 8A). Similarly the diameter at breast height of *Q. glauca* was 63 cm in the disturbed site. This is 42 percent of 150 cm diameter measured for *Q. oxyodon* in the natural forest (Figure 8B). Similarly the total basal area in the Wasabi disturbed site was 15.7 m^2/ha compared with 53.6 m^2/ha in the nearby natural forest which makes it only 29.3 percent of that of the natural forest (Figure 8 C). Therefore 70.7 percent of the biomass (basal area) was removed from the natural forest for Wasabi plantation. Since most of the understorey evergreen species were removed during the preparation for Wasabi cultivation, the stem density in the Wasabi project disturbed site was 326 stems/ha compare to 3023 stems in the nearby natural forest. Hence 90 percent of the forest stems were removed for cultivation of the Wasabi plants thereby opening the canopy (Figures 5, 6, & 8D).

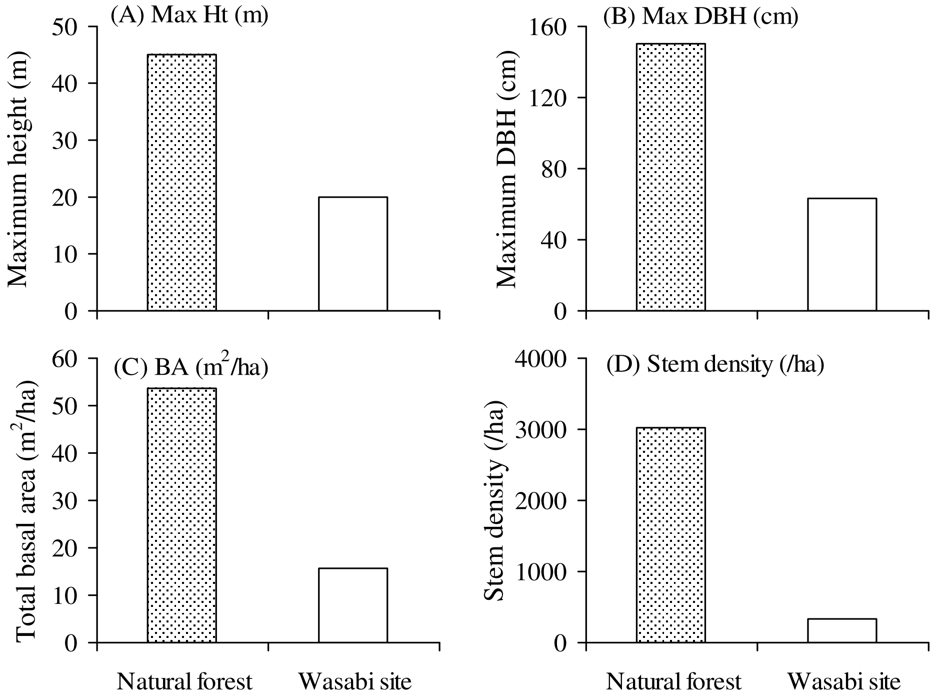


Figure 8 (A-D). Comparison of forest structural traits between nearby natural forest (control) and the Wasabi site at Lamperi study site.

3.1.5 Change in soil properties

Similar to the impacts caused on the forest composition and community structural traits, edaphically significant changes occurred as a result of the Wasabi project. The results of soil nutrient analysis are shown in Table 3. The amount of litter accumulated under each of the forest plots indicates significant change. The litter accumulated under the natural forest plot was 5.4 DW ton/ha (DW=oven dry weight) while it was 1.2 DW ton/ha under disturbed forest which is only one fifth of the natural forest indicating a loss of four fifths (90 percent) after forest destruction. Because of the change in litter accumulation, significant changes in soil nutrient properties were also observed. After the Wasabi cultivation, the soil acidity (pH) has reduced to 4.8 while it is 4.3 under natural forest. The change in soil pH can be attributed to the application of lime and other fertilizers during Wasabi cultivation. Similarly soil organic carbon and total nitrogen were 50 percent less than in the nearby natural forest. The removal of understorey shrubs and the tillage of forest top soil during the Wasabi cultivation led to the loss of soil organic carbon and nitrogen. However C/N ratio remains similar in both plots. Available phosphorus was also reduced by about 50 percent following cultivation because it was required that there was no burning of forest residues during preparation of the site for Wasabi cultivation (Table 3).

Table 3. Results of the soil nutrient analysis in the nearby natural forest and Wasabi disturbed site

PLOTS	pH (H_2O)	Available P (mg/kg)	C (%)	N (%)	C/N (Ratio)
Natural forest	4.3	53.0	20.0	1.6	12.2
Wasabi site	4.8	23.7	9.4	0.8	12.7

4. Conclusions

Humid evergreen broad-leaved forests are valuable resources for the people of Bhutan considering that 79 percent of the total population are engaged in farming: integrating crop productions, livestock rearing and use of forest resources as watershed, non-timber forest product (mushroom, orchid, cane), timber for house construction, grazing, fodder, litter for cattle bedding, organic manure, agricultural implements among others of traditional type, and all well adapted to the local environment (Wangda & Ohsawa 2006c). At the same time modernization (agricultural globalization) of the country brings development activities particularly in the field of agriculture for improving the livelihood of the rural people. The Wasabi pilot project was one of the agricultural development packages established without considering the impact on the humid evergreen broad-leaved forest ecosystem and with the hope of a successful business project. However the project failed in a short span of time mainly due to its inappropriate habitat and methods of cultivation resulting in environment and ecosystem damage to the humid evergreen broad-leaved forest.

The impact of the Wasabi project at Lamperi includes the following:

- Loss of native species that are presently occurring in the control plot but missing under the Wasabi project disturbed site including *Q. oxyodon, Cinnamomum bejolgota, Neolitsea* sp.
- Structural traits of forest revealed that about 70 percent of the forest biomass represented by total basal area has been removed.
- Stem density revealed a 90 percent reduction compared to the nearby natural forest.
- Affects to the forest soil included reduced soil organic carbon and total nitrogen by about 50 percent compared with the nearby natural forest.
- Poor regeneration of the tree species. Seedlings and saplings recorded in the Wasabi project disturbed site were found to be only 25 percent of the regeneration occurring in the natural forest.
- The removal of understorey evergreen shrubs and scraping of forest floor top soil to a depth of 30 cm for the establishment of Wasabi cultivation resulted in the degradation of the forest including biomass loss and surface-soil erosion as well as loss of grazing area of the nearby villagers.

We recommend that the policy makers and foreign promoters conduct detailed impact assessment and feasibility studies before implementation of any such projects. The Wasabi pilot project was a total failure in Bhutan and a lesson to be remembered in future for similar situations. We recommended that forest stakeholders (yak, cattle herders, nearby farmers) should be included and consulted within the management plans of any development projects for conserving forest ecosystems and for utilizing resources without impacting biodiversity of the area.

Acknowledgements

The PRO NATURA Foundation-Japan was acknowledged for the research support. The research team form RNRRC-Yusipang, Biodiversity Centre and Royal Society for Protection of Nature (NGO) were duly acknowledged for the successful fieldwork/inventory.

References

Barry, R.G. 1981. Mountain weather and climate. Methuen & Co. 733 Third Avenue, NY 10017.

Bhutan Wasabi Pilot Project. Undated. A draft proposal.

Central Statistical Organization, Planning Commission 2002. Statistical yearbook of Bhutan. Royal Government of Bhutan, Thimphu.

Grierson, A.J.C. & Long, D.G. 1983-2000. Flora of Bhutan Vol. I. Part 1,2,3. Vol. II. Part 1,2,3 & Vol. III. Part 1,2. Edinburgh.

Hara, H. 1968. Photo album of plants of Eastern Himalaya. Inoue Book Company, Tokyo.

Hocking, D., & Wangdi, J. 2000. Review of the literature in Bhutan on Agroforestry. Bhutan: Agroforestry Literature Review; Hunting Technical Services Ltd. Hemel Hempstead, UK.

Kikvidze Z. & Ohsawa M. 2002. Measuring the number of co-dominants in ecological communities. Ecological Research 17. 519-525.

Kuensel online, April 08, 2004. Failed project highlights bad loan. Bhutan National News Paper.

Kuensel online, November 9, 2005. A Botanical garden in Lamperi. Bhutan National News Paper.

LUPP (Land Use Planning Project) 1997. Atlas of Bhutan. Ministry of Agriculture, Royal Government of Bhutan.

McCune, B. & Mefford, M.J. 1999. PC-ORD: Multivariate Analysis of Ecological Data, Version 4. MjM Software Design, Gleneden Beach, Oregon.

Nishioka, K. & Nakao, S. 1984. Flowers of Bhutan. Asahi Shimbun Publishing Company, Tokyo Japan.

Noltie, H.J. 1994-2000. Flora of Bhutan: Part 1 & 2, vol. 3. Royal Botanic Garden, Edinburgh.

Ohsawa M. 1984. Differentiation of vegetation zones and species strategies in the subalpine region of Mt. Fuji. Vegetatio. 57: 15-52.

Parker, C 1992**.** Weeds of Bhutan. National Plant Protection Centre Simtokha, Roral Government of Bhutan, Department of agriculture, Thimphu, Essen and Exeter.

Pielou E. C. 1977. Mathematical Ecology. Wiley, New York

Polunin, O. & Stainton, A. 1987. Concise flowers of the Himalaya.

Polunin, O. & Stainton, A. 1984. Flowers of the Himalaya. Oxford Univ. Press. New Delhi.

Pradhan, R. 1998. Wild Rhododendrons of Bhutan. Quality Printers, Kanthmandu, 53 pp.

Schweinfurth, U. 1992. Mapping mountains: Vegetation in the Himalaya. GeoJournal. 27: 73-83.

Stainton, R. 1988. Flowers of the Himalaya. Quality Printers, Kathmandu, 53pp.

Wangda, P., & Ohsawa, M. 2007. Vegetation succession and soil recovery in the abandoned field at Tshokothangkha. Journal of Renewable Natural Resources Bhutan. 3 (1): 68-92.

Wangda, P., 2006a. Mountain forest pattern and management of natural resources in the Bhutan Himalaya. PhD dissertation, The University of Tokyo, Japan.

Wangda, P., & Ohsawa, M. 2006b. Forest pattern analysis along the topographical and climatic gradient of the dry west and humid east slopes of Dochula, western Bhutan. Journal of renewable Natural Resources Bhutan. 2 (1): 1-17.

Wangda, P., & Ohsawa, M. 2006c. Structure and regeneration dynamics of dominant tree species along altitudinal gradient in dry valley slopes of the Bhutan Himalaya. Forest Ecology and Management. 230: 136-150.