Carbon Accounting in the Forests of Bhutan

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March 2004

Report of the survey and analysis trip to Bhutan in December 2003 - January 2004 carried out by Professor Steven C. Wofsy, Scott R. Saleska, V.Y. Chow, and Lucy Hutyra of Harvard University jointly with the Bhutanese counterparts, Rebecca Pradhan; Thinley Namgey and Kumbu Drukpa of the National Environment Commission of Bhutan, Kinley Tshering and Dechen Dorji of the Department of Forest Bhutan. Funding provided by the Harvard University Center for Environment.

Bumthang, January 2004.

*Original title: "**Carbon and Nitrogen Uptake and Pollution Effect on Forest Health in Bhutan"** November, 2004.*

ADMINISTRATIVE

This project, "Study on Carbon and Nitrogen Uptake and Pollution Effect on Forest Health", was approved by Nado Rinchhon, Deputy Minister of the National Environmental Commission Secretariat (NEC), on 22 October 2003. The project was a joint effort of Bhutan's NEC and Forest Department of the Ministry of Agriculture, and Harvard's Forest and Atmosphere Research Group and the Harvard University Center for the Environment (HUCE). A photocopy of the approval letter is attached at the end of this report (Appendix A).

BACKGROUND

Concentrations of carbon dioxide (CO_2) are 35% higher than observed at any time in the last 450,000 years. During the last ice age, CO_2 concentrations were estimated at 190-ppm. CO_2 concentrations were estimated at 280-ppm between the end of the last ice age and the year 1800 and rose to about 370-ppm today. This rise in CO_2 began before the industrial revolution due to deforestation and development agriculture.

From 1980 to 1990, the global sources of CO_2 were fossil fuel emissions (5.3 Pg C/year; 1Pg = 1 billion tons, as carbon, in CO_2) and tropical deforestation (between 1 and 2 Pg C/year) totalling in a range from 6.3-7.2 Pg C/year. Only about half of this emitted CO_2 (3.2 Pg C/year) stayed in the atmosphere. The rest went into the ocean (1.7 Pg C/year) and into organic matter in forests (1 to 2 Pg C/year; Ciais et al. 1995). From the start of observations in 1958 until the present, more than 45% of fossil fuel CO_2 has been removed from the atmosphere, and evidence suggests that much of this "missing "CO_2" has been taken up by forests. The importance of forests in the global carbon cycle was recognized in the Kyoto Protocol, and, with the Protocol coming into effect in late 2004, there is a strong interest in Bhutan to understand the role of its great expanses of forest in the global carbon budget.

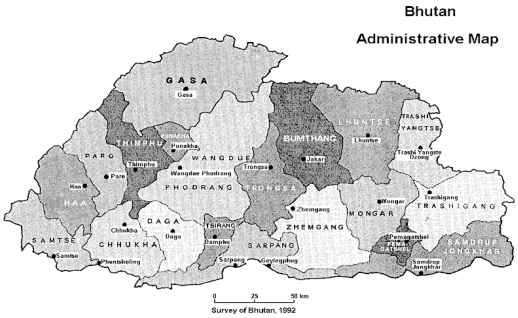
The joint Harvard-Bhutan project was intended to learn about what global changes in CO_2 and climate mean for Bhutan. Indications of climate change have been manifested in unusual climatic events. Food production has shifted with parts of Bhutan, with winter crops able to grow at higher altitudes than previously. Reductions in the volumes of mountain glaciers are evident, with potentially significant effects on the hydroelectric resources of Bhutan. Notable weather anomalies included a dry, snowless winter in 1998, and torrential rains caused flash floods in the summer of 2000, resulting in casualties and significant damage to Bhutan's infrastructure and natural resources (NEC 2000).

For Bhutan, where 79% of the population depends on agriculture and natural resources and where hydroelectric power generation is a dominant source of national income, the negative impacts of climate change could be especially severe (NEC 2002). Bhutan signed the Convention on Climate Change at Rio de Janeiro in 1992; the National Assembly ratified it in 1995 and committed Bhutan fully to the United Nations Framework Convention on Climate Change. In 1994, Bhutan's Master Plan for Forestry Development identified changes in forest woody biomass as major sinks for carbon (NEC 2000). However, reliable and comparable data on changes in land use are still not currently available for Bhutan.

OBJECTIVES OF TRIP

We were invited to Bhutan by Rebecca Pradhan and the Royal Society for the Protection of Nature to understand the impacts of air pollution and climate change on forest resources and the carbon cycle in Bhutan. Our specific goals were to:

1. Help the National Environment Commission develop a Carbon Program by integrating methods for a forest carbon inventory into the existing and planned National Forest Inventory program. The carbon inventory will provide reliable and comparable data on changes in land use across Bhutan's Forest Management Units;
2. Inspect areas of high elevation fir dieback and determine possible linkages to climate change and air pollution;
3. Provide assistance towards organizing and analyzing existing floristic data;
4. Provide examples how to complete data analysis for carbon; and
5. Develop a shareable database of existing floristic data.



Our trip was based out of the capital, Thimphu, and we traveled by bus throughout four Dzongkhags in Bhutan: Paro, Chhukha, Bumthang, and Punakha.

Chele La, Paro

The first site we visited was Chele La, a mountain pass at 4000-m elevation between Paro and Ha. Just below treeline, Chele La is dominated by fir with hemlock a minor species. Mixed conifer forests with pine, spruce, hemlock, and larch are located between 2000 and 2700-m in elevation. It is primarily a conifer forest with some oaks that is similar to the forests of the drier regions of the Pacific Northwest in the USA and Canada.

Forest Dieback. . The fir dieback at the top of the pass appears to have occurred 7-8 years earlier, and there may have been a fire later. The mortality zone is distinctly marked as a contour around the mountain, suggesting an atmospheric (climate or pollution) cause rather than insects or disease. Due to the length of time we could not determine the cause of the dieback. Photos of fir needles were taken but we are doubtful they will provide any useful information. The needles demonstrate some chlorosis but causes were indeterminable. Regeneration appeared robust with good vigour.

Possible causes of mortality include ozone and transient severe climate event(s) such as a sudden frost. Fir dieback at high elevations is common throughout Bhutan, often at sites remote from pollution, suggesting a climatic event. Understanding dieback will require monitoring of air pollution and weather in vulnerable areas, currently beyond capabilities in Bhutan.

Fir needles with indications of chlorosis at Chele La

Forest dieback near Chele La, December 2003. Note the sharp demarcation of the dead zone.

Forest Inventory Plots for Carbon Budgets and Change Detection. We worked with foresters from the Forest Management Unit (FMU) and Kinley Tshering (Paro FMU forestry planner) to install prototype carbon inventory plots near Chele La. Four plots were established, two in an undisturbed area with 42-percent slope and two more within a logged area located in Chandane.

The Bhutanese foresters we met were well trained in forest inventory techniques and experienced with almost all measurements required for a carbon inventory. The relatively minor differences between Bhutanese specifications of measurements and the methodologies and requirements for carbon inventories will be explained later in this report.

Plot installation provided us with a better understanding of the challenges facing foresters in Bhutan. Steep slopes, rough terrain, and thick understories of *Rosaceae* are ubiquitous, creating two particular problems: how to correct the plot radii for slope distance, and how to speed the measurement of tree heights.

Landslide on the road to India, Gedu.

Gedu, Chhukha

Our second research area was situated in Gedu, located in southern Bhutan. The vegetation changes quickly with the decreasing elevation. High altitude evergreen forests shift to mixed conifer and broadleaf forests and, at lower elevations, broadleaf to subtropical forests. Gedu is located 15-km from the Indian border at an elevation of 1500m. Two National Environment Commission (NEC) staff accompanied us on this portion of the trip: Pelden Tshering, an engineer, and Kumbu Dukpa, programme officer in the NEC research monitoring and statistics section. The first Gedu site was near a landslide 1.5-km from the Indian border. Forest degradation, road building, and high rainfall combine with the region's unstable geology to cause large landslides that may significantly disrupt transportation and hence the economy and communications systems within Bhutan.

Children during their 3-month winter vacation gather fodder with their family to feed their cattle and goats.

We established two plots close to Gedu with the help of local forestry officers. There were virtually no coarse woody debris located in these highly degraded plots: The forests surround Gedu are heavily used for grazing, fodder, fuelwood, and commercial and community resources. Forest areas in close proximity to roads experience the most disturbance as small trees are cut for fencing, leaves and bushes gathered for fodder, and dead wood collected for fuel.

A Project Management Team (PMT) created to implement climate change strategy is exploring the need to survey the use of fuelwood in Bhutan. The PMT realize that CO_2 emitted from cooking, heating, and drying foods and spices is significant. Without some method of measuring of coarse woody debris moving in and out of the system, the carbon inventory would be incomplete.

Air pollution streaming across the Indian border south of Gedu.

The Southern border regions of Bhutan are most susceptible to air pollution impacts, but the severity of the problem is not known because there is no atmospheric monitoring data for damaging pollutants such as ozone, sulphur dioxide, nitric acid, or acid fog in vulnerable forest areas.

Bumthang
Located in east central Bhutan at an elevation of 2700m, Bumthang is dominated by conifers. Due to a snowstorm, we could not establish any plots but did manage to survey the area on foot. The forests surrounding Bumthang have stands with large, greater than 100-cm DBH, older conifers more than 30-m in height. Had we established standard-radius plots in one of these stands, one tree would be located in each plot. To achieve statistical significance, plots with larger radii might be needed in areas such as these.

Damji, Gasa
The last we site visited was located near the village of Damji in the Gasa valley in northwestern Bhutan. The site of the Damji test plot was specifically chosen to overlay with several of Rebecca Pradhan's floristic plots to provide us an opportunity to compare the differences between carbon inventory measurements and her floristic inventory measurements, and to have a time series of data. The comparison enabled us to understand her sampling and data collection methodology.

Rhododendron trees characterize the sloping plot we established over Rebecca's existing transects. There was little understory vegetation and minimal amounts of coarse woody debris, with evidence of foraging for firewood. Height measurements again required significant time and some the tree heights were estimated rather than measured as the hour grew late.

CARBON INVENTORY PLOTS – comparison of methods
Bhutan's administrative land area is divided into Forest Management Units (FMUs), biological corridors, and protected areas. Within the FMUs, Bhutan has already developed a comprehensive set of procedures and guidelines for inventory and development of a management plan. The policy stipulates that utilisation of forest resources within an FMU is guided by a forest management plan with duration of 10 years (Lautmans 1994). Inventories are conducted using stratified random plot-based sampling. General plot information including land use, slope, azimuth, elevation, and canopy height are recorded. Each plot (the sampling unit) consists of three concentric circles with each circle delineating a subplot. Every fourth plot is a special sampling unit, or special plot, with additional measurements taken that include total tree height, log grading, radial wood increment, and bark thickness.

Our procedure was to use the attributes of a forest inventory special plot as a basis for the carbon inventory. Six test plots were established in collaboration with local forest workers at various sites throughout Bhutan. These test plots demonstrated that only small changes to a *subset* of the special plots are needed for a Bhutan carbon inventory. For example, one out of ever four special plots could contain the measurements required for a carbon inventory. The current forest inventory special plot measurements are shown in Table 1.

Sub-plot	Radius* (m)	Area (m2)	Area (ha)	DBH of tagged trees
Regeneration	3.57	40	0.004	0 to 9-cm, taller than 1.3-m
Minor	5.64	100	0.010	10 to 29-cm
Major	12.62	500	0.050	Greater than 30-cm

Table 1 – Current measurements in a Forest Inventory Special Plot. *slope corrected radius

The following modifications to the special plots would address the need for permanent sampling units (**PSU**s, not protected). Each **PSU** must be accurately located and the boundary identified, to enable accurate determination of change over time (a concise summary can be found in Table 2):

Tree is tagged above the buttress and DBH measured 10-cm above the tag, a requirement to insure accurate measurements of buttress trees. Gedu, Bhutan.

1. Plot locations should be marked and documented to allow return to exactly the same plots for successive measurements including recruitment. The center of each **PSU** could be marked with an iron pipe and the boundary well marked with tags or stakes to help determine recruitment and to ensure that only trees tagged during plot establishment are included in later surveys;

2. Trees > 10 cm are tagged throughout the major sub-plot using aluminium nails and tags; DBH tapes are placed 10-cm above the nail, thus ensuring that subsequent measurements will be made at the same height, and allowing growth of individual trees to be tracked accurately;

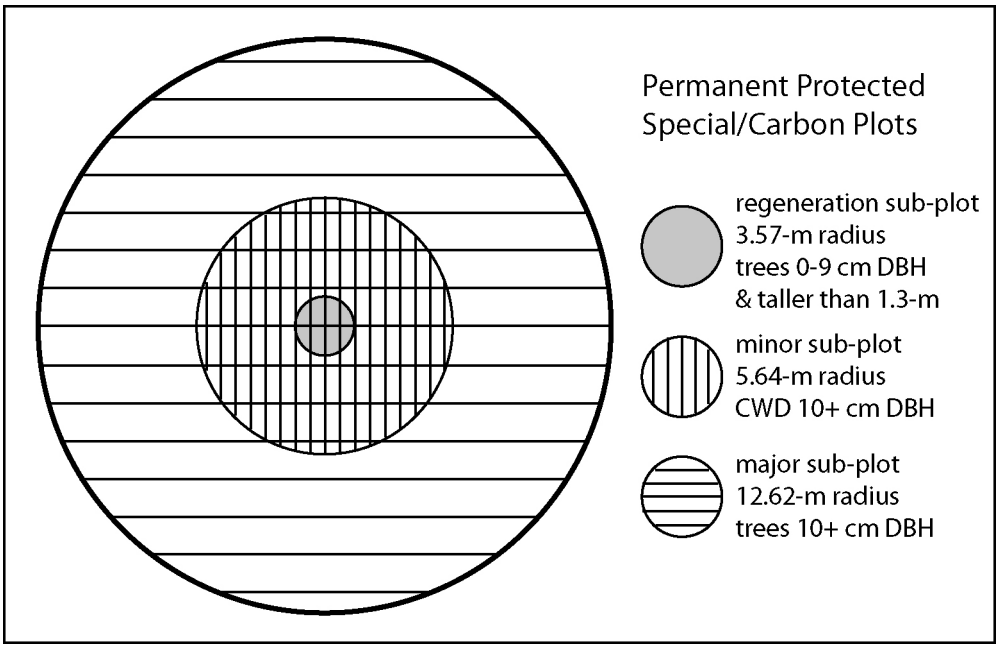
3. The amounts of dead wood (coarse woody debris, CWD), greater than 10-cm DBH, should be measured in the minor sub-plot;

4. DBH of all trees and CWD should be recorded to 0.1-cm accuracy;

5. A small number or permanent *protected* study units (**PPSUs)** should be established to provide baseline data for forest growth;

Bhutan is already planning to do almost all the measurements required for a carbon inventory during the upcoming National Inventory, and already has well-trained forestry staff doing inventories in the Forest Management Units. Table 2 summarizes current Bhutanese practices for Special Plots and **boldface** type shows the differences required for Carbon/Change Detection Special Plots (**Permanent Study Units,** denoted herein as **PSU**s). Incorporating **PSU** design requirements in ¼ of the Special Plots in Bhutan's National Inventory will enable detection of changes in many key parameters relating to forest health, including Carbon Budgets, species-specific growth rates, regeneration, regional trends in forest degradation, and many others. Detection of these trends will greatly assist a wide range of management objectives for Bhutan.

Figure 2 – Special permanent plots (**PSU**s) incorporating carbon and change-detection measurements



Meetings/Presentation/Interviews

During the course of our visit, we met with a number of different people throughout the country. Without their time and effort, this research survey would not have been possible.

Deputy Minister of National Environment Commission Bhutan, Dash Nado Rinchen,
Technical Advisor to the National Environment Commission Bhutan, G.K. Pradhan,
Joint Director, Forest Resources Development Division D.B Dital
Divisional Forest Officer in Gedu Sonam Tshering.
Many local foresters and engineers including Kumbu Dukpa, Pelden Tshering, Kinley Tshering, Dechen Dorji, Thinley Namgyel, SB Mongar, Sonam Wangda, and others.

On January 5th, 2004, we participated in the seminar "Global Carbon Cycle and the Carbon Budget for Bhutan". Please see Appendix B for the list of participants. After the seminar, Professor Wofsy was interviewed by the Bhutan Broadcasting Service.

Our host, Rebecca Pradhan, provided expert advice throughout as well as arranging for excellent help with logistics and with official formalities.

Table 2 –**Differences** between design requirement for **PSUs** and Bhutan's forest inventory special plots.

Measurement	**Current Bhutan Forestry Inventory (special plots)**	**PSUs: Permanent Sampling Units for Carbon Inventory and Change Detection**	**Note on reason for difference for carbon**
Plot Type	Temporary plot	**Permanent sample unit (PSU)**	Need to re-measure later to get *changes* in carbon
Plot Location	Gridded ground-based survey	**GPS located, staked center**	Permanent Sampling Unit (revisit exactly the same plot)
Major Subplot	12.62 m	Same (but **mark** plot boundary)	*Accurate* boundary to measure recruitment on revisit
Minor Subplot	5.64 m	Same	No Change!
Individual Tree	Not noted	**All trees tagged** with aluminum nails and numbered tags	Allows later measurement of individual tree growth and mortality
Tree size/basal area (diameter at breast-height, or DBH)	>30-cm major subplot >10-cm minor subplot accuracy: 1 cm	>**10-cm *major* subplot** accuracy: **0.1 cm**	Mid-size trees also important for carbon Less error on carbon change when re-measured
Tree Genus & Species	Identify	Same	No Change!
Tree Height	Measure height	Same	No Change!
Tree Regeneration	Regeneration subplot	Same	No Change!
Coarse Woody Debris, (standing and fallen dead wood)	Not measured	**Measure >10-cm DBH on minor subplot**	**Dead wood is an important part of carbon stocks; determine removals**
Permanent protected plots	Not included	**PPSUs**, a small number, in a stratified sub-sample	Baseline data, allowing detection of removals, climate impacts, etc.

FINDINGS

From National Forest Inventory to Forest Carbon Inventory for Bhutan

The measurements already planned for Bhutan's National Forest Inventory program encompass more than 95-percent of those needed for a carbon inventory and for change detection essential for managers to monitor the health of Bhutan's forests. As such, Bhutan is well situated to complement its National Inventory with only small changes to existing inventory design. It is important to note that since a national scale inventory requires a long time to complete, the process could easily become a cyclical event depending on the period of re-inventory. For example, if Bhutan implemented a 5-year inventory cycle, the initial carbon inventory could take the full five-years, but this would not pose any problems for starting the re-inventory; providing the same method of stratification and timing of measurements is used.

Data Structure and Analysis

Ideally, a carbon inventory will encompass the whole kingdom and not just the Forest Management Units. However, the FMUs provide an excellent network of workers and data support for initial implementation of the carbon inventory. The field crews already working in the FMUs are well versed in forestry techniques. The measurement of coarse woody debris and careful demarcation of boundaries and tree tagging are the only areas the field workers will need training; the crews we worked with needed less than one-half day of supplemental field training.

Currently, Bhutan uses the PLOT software to process their forestry data. PLOT is a guided user interface (GUI) program that analyzes the inventory data with silvicultural and commercial parameters. Several people have been identified by the National Environment Commission to be trained in programming this software. It appears likely that PLOT can be adapted to process carbon data but, in the interim, other software programs can be utilized. For example, a statistical analysis freeware called "R" can be downloaded from the internet and installed on any Windows or Linux computer (see http://www.r-project.org), and is readily adaptable used for carbon inventories and change detection.

Land Management & Carbon Cycle in Bhutan

Challenges facing forest management in Bhutan stem primarily from community uses of the forest. Commercial and rural logging practices are documented, although the accuracy is hard to ensure. Fuelwood collection, grazing, and other non-timber forest products are not measured. Permanent protected plots (**PPSUs**) recommended here would serve as control plots, providing baseline data to help monitor distinguish the changes in forests due to human actions from the effects of climate change and air pollution.

Acknowledgements

This work was made possible by the support of The Royal Government of Bhutan, who granted permission to conduct research, and by the kind support of Dasho Nado Rinchen, Deputy Minister of the National Environement Commission and Dasho Dawa Tshering, Director of Forests Bhutan. We thank the Harvard University Center for the Environment for financial support and its former director, Prof. Michael B. McElroy for making this work possible. Rebecca's initiation to conduct this study in Bhutan combined with her advice and knowledge provided the foundation for this work along with the hospitality and hard work of her colleagues, friends, and family.

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The juxtaposition of ecotones along steep altitude gradients makes the wildlife of Bhutan extraordinarily diverse and abundant.

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Appendix A
Letter of Authorization and Participants in the Study

ROYAL GOVERNMENT OF BHUTAN
NATIONAL ENVIRONMENT COMMISSION SECRETARIAT
P.O.BOX 466 THIMPHU, BHUTAN

NEC/DM/F-25/03/ 6034 22 October 2003

Mrs. Rebecca Pradhan
Royal Society for Protection of Nature (RSPN)
Thimphu

Dear Mrs. Rebecca Pradhan,

Sub: **Study on Carbon and Nitrogen uptake and Pollution effect on forest health**

This has reference to your application dated 3rd October 2003 on the above subject.

In this regard, I am happy to convey the approval of the CCM of the Council of Ministers to your proposal to undertake the above study subject to the following conditions:

1. This study should be carried out jointly with the officials of the NEC and Ministry of Agriculture (Forests Department).

2. Technology transfer should be given due importance i.e. the Professors from Harvard University may be asked to teach the methods of such study to Bhutanese members of the study team.

3. The study should be carried out only in the areas mentioned in your application, forests around Paro, Thimphu and Bumthang for high altitude coniferous forests and along the Thimphu-Phuentsholing highway and the East-West highway for landslides prone areas.

In the mean time I shall appreciate if you could submit the CVs of the Professors from Harvard University who would be joining to assist in the study.

Thanking you,

Yours Sincerely,

Nado Rinchhen
Deputy Minister

Copy to:
H.E. Lyonpo Kinzang Dorji
Chairman NEC
Ministry of Works and Human Settlement, Thimphu

Appendix B
List of Participants at the January 5th Seminar

Attendance Presentation by Havard visiting Researchers
Jan 5, 2004 "Global Carbon Cycle & the Carbon Budget for Bhutan"

SL NO	Name	Desig.	Orgn.	Date Signature
1.	G.K. Pradhan	J.D.	NEC.	
2	Yeshey Penjor	EA Officer	NEC	
3.	Chado Tshering	Offg JD	SFD, DOF	
4.	Chukey Wangchuk	Prg. Off.	BTFEC	
5.	Karma Tshering	EE	DOE, MTI	
6.	Karma C. Nyedrup	Deputy Director,	NECS	
7.	Tandin Wangdi, NBC			
8.	Tigme, Prog. Officer,	NECS		
9.	Durga Devi Sharma	National Coordinator	UNDP/GEF-SGP	
10.	Gopal Mahat	J.D	DOF.	
11.	P.B. Dhital	JD	DOF	
12.	Kelzang Wangchuk	ADF	FRDD/DoF	
13.	V.Y. (Victoria Y.) Chow	Research Assistant ~~Harvard~~	Harvard	
14.	Lucy Hutyra	PhD. student	HARVARD	
15.	Loseng Dorji	DFO	Thimphu, DoF	
16	Deelen Dorji	PPO-PPD.		
17	Mincha	WANGDI, EED, RSPN		
18.	Tigme Tobgyel	Programme Associate, UNDP		
19	Sonam Tobgyel	ADF, NCD/DOF		
20	Ngawang Gyeltshen	ADF, FRDD/DOF		
21	Tsheding Tashi	J.D.,	NEC	
22	Tsherin Lham	PO.	RSPN	
23	Scott Saleska	Research Scientist	Harvard	
24.	Karma C Rapten	Prgm. officer.	NEC.	
25.	Deki Pema	Planning Officer	PPD, MoA	
26.	Peldon Tshering	EIA Officer	NEC	
27.	Kunzang Dorji	Dy Director	NEC	
28.	Kunzang Dukpa	Prog. Officer	-"-	
29.	Sherab Lhendup	Sr. Legal officer	-"-	
30	Thinley Namgyel	Prog Officer	NEC	