SOUTH ASIAN ASSOCIATION FOR REGIONAL COOPERATION

Proceedings of SAARC Expert Group Meeting on **Adaptation to Climate Change Impacts and Risks To Different Forest Types of South Asia**

22 – 24 October, 2013

Rain Forest Research Institute, Jorhat, India

Organized by

SAARC Forestry Centre, Thimphu, Bhutan

and

Rain Forest Research Institute, Jorhat, Assam, India

For copies, write to:
SAARC Forestry centre
PO Box # 1284
Taba, Thimphu
Bhutan

Tel: (975-2) 365 260/365 148/ 365 181
Fax: (975 2) 365 190
Email: karmatp@yahoo.com

Printed and published in Thimphu, Bhutan
SAARC Forestry Centre Office
Thimphu, Bhutan

SOUTH ASIAN ASSOCIATION FOR REGIONAL COOPERATION

Proceedings of SAARC Expert Group Meeting

on

Adaptation to Climate Change Impacts and Risks To Different Forest Types of South Asia

22 – 24 October, 2013

Rain Forest Research Institute, Jorhat, India

Organised by

SAARC Forestry Centre, Thimphu, Bhutan

and

Rain Forest Research Institute, Jorhat, Assam, India

Mountain Ecology Division

SAARC Forestry Centre

2013

FOREWORD

The SAARC region is richly endowed with a variety of forest types and associated biodiversity. However, the threat of Climate Change is affecting the characteristics of forests and thereby the livelihoods of millions of dependent people. Hence, the SAARC Forestry Centre was keen to identify the vulnerable forest types, the impacts and the measures that could be taken in the South Asian region to address the situation.

It was in this context that the Expert Group Meeting on the 'Adaptation to Climate Change Impacts and Risks to Different Forest Types of South Asia' was held at Jorhat, Assam, India from 22 to 24, October, 2013 in technical collaboration with the Rain Forest Research Institute, an institute of the Indian Council for Forestry Research and Education (ICFRE). Experts from Bangladesh, Bhutan, India, Maldives, Nepal and Sri Lanka presented papers on the theme and discussed on related issues. A Field trip to study the Impacts of Climate Change on the forest-grassland floodplain ecosystem of the Kaziranga National park was organized on 23rd October, 2013 and this was greatly appreciated by the Experts.

I am also very happy to note that an intense group discussion on the topic was held during the concluding session on 24th October and the important outcome has been presented as 'Conclusions and Recommendations of the Expert Group Meeting' in the Proceedings. This elaborates the most critical issues faced by the various SAARC countries in connection with 'Climate Change and Forests', the steps already taken in this regard and the future steps that need to be taken.

On behalf of the SAARC Forestry Centre, I would like to thank Mr. Kantharaj Jude Sekar, Director General. ICFRE, Dr. N.S. Bisht, Director, Rain Forest Research Institute, Mr. Gautam Banerjee, Coordinator (facilities), Rain Forest Research Institute and their team for hosting as well as technically collaborating with us in holding this event. I would also like to thank Mr. N.K. Vasu, CCF and Director, Kaziranga National Park for organizing the excellent field trip to the Kaziranga N.P, a World Heritage Site. I would like to credit to the various Experts for having prepared and presented very important papers and for their active participation during the discussions.The team from SAARC Forestry Centre worked very hard in organizing this event and also in bringing out this proceedings and I appreciate their efforts.

We hope that the papers as well as the 'Conclusions and Recommendations' in the Proceedings would be useful to the Member States.

Dr. Sangay Wangchuk
Director
SAARC Forestry Centre,
Thimphu, Bhutan

Table of contents

I INAUGURAL SESSION

Lighting of Lamp

The Inaugural Session started at 09.15 AM on 22.10.2013 with the self introduction of participants. This was followed by lighting of the lamp by the Chief Guest, Shri A.K. Wahal, IFS, PCCF and HoFF, Arunachal Pradesh and other dignitaries. Dr. N. S. Bisht, Director RFRI felicitated the Chief Guest, Director, SAARC Forestry Centre and all the participants in the traditional way of presenting the Phulam Gamosa.

Welcome address by Dr. N.S. Bisht, Director, Rain Forest Research Institute, Jorhat

The meeting was attended by the experts from six SAARC countries viz., Bangladesh, Bhutan, India, Maldives, Nepal, and Sri Lanka, and the Scientists and officers from SAARC Forestry Centre, Rain Forest Research Institute, Jorhat and officials from Assam Forest Department (Annexure – II). In his welcome address, the Director, RFRI pointed out that RFRI is organizing such an International meeting for the first time and appreciated the kind support given by Director, SAARC Forestry Centre and his team. While briefing about the significance of the proposed SAARC expert group meeting, he provided the examples of the recent Kedarnath disaster, water scarcity in the Cheerapunjee region and the lack of regeneration of *Pinus khasiyana* in the lower elevations to emphasise the challenges due to environmental degradation and climate change and stressed the need for the collaborative efforts between all SAARC Countries to mitigate the problems.

Technical statement by Dr. Sangay Wangchuk, Director, SAARC Forestry Centre, Thimphu, Bhutan

Dr. Sangay Wangchuk, Director, SAARC Forestry Centre, Bhutan, welcomed the participants and briefed the participants about the functioning of the SAARC Regional Centres and the organizational set up, mandate and achievements of the SAARC Forestry Centre. He also explained the objectives of the meeting and expressed hope about the outcome of the meeting in meeting the most immediate challenges faced by the forestry fraternity in SAARC.

Inaugural address by Shri A.K. Wahal, Principal Chief Conservator of Forests and Head of Forest Force, Arunachal Pradesh

Mr. A.K. Wahal, Chief Guest of the function in his inaugural address appreciated the efforts of Director, SAARC Forestry Centre and the Director, RFRI for organizing such an important International event in the North Eastern State of India, which has 25% of India's forest cover, harbors three important world heritage sites – Kaziranga National Park, Assam; Namdapha National Park, Arunachal Pradesh and Loktak Lake, Manipur, a Ramsar site and has significant biodiversity resources. He then mentioned that in general, the forests of South Asia faces severe human pressure from the people eking out a living and that the situation is being compounded by the impacts of Climate Change. He explained the factors of mass tourism, unmindful interference with nature and the influential people causing destruction and untold suffering to the wildlife and forests of the region. The Chief Guest elaborated on the different impacts that could be faced by residents of cities and those of remote forest areas. He emphasized the need for collection of data on the extent of vulnerable communities in the region and suggested that GIS could play a major role in this effort. He mentioned that there is an urgent need to develop robust regional climate change impact models and identify the most vulnerable forest types and subtypes in the region. Only such an effort would lead to the implementation of effective mitigation and adaptation measures.

He further briefed the participants of the efforts taken by India to deal with Climate Change and mentioned the key components of the Green Indian Mission. He also emphasized the importance of awareness amongst all sections of the region and the need to bridge the gap between the political leaders and foresters to further the cause of forests and wildlife conservation. He mentioned the need for the Forestry sector to have a Charter of Action on Climate Change just as the U.S. Forest Service has done. He then pointed out the need for more capacity building programmes to be conducted and the exchange of data between SAARC Nations as this would help the policy makers to a great extent. He concluded by mentioning that the SAARC member states need to learn from each other as there have been outstanding examples of conservation in the region and mentioned that the new concepts like Payment for Ecological Services need to be used for conservation of the rich forestry and biodiversity resource in the Region.

Vote of Thanks

Mr. Udhayan, IFS, Specialist, SAARC Forestry Centre then concluded the session by thanking Mr. A.K. Wahal, Chief Guest for having kindly consented to present the inaugural address for the meeting. He then thanked Dr. N.S. Bisht, Director, RFRI, Mr. Gautam Banerjee, Coordinator (Facilities), RFRI and the entire team of RFRI having spared no efforts in hosting the meeting. He also thanked the Forest Department and officials of the Assam Forest Department for support in arranging the field trips to Kaziranga National Park and the Gibbon Wildlife Sanctuary. He also thanked Dr. Sangay Wangchuk, Director, SAARC Forestry Centre, Mr. Pasang W. Norbu, Specialist and other officials of the Centre for guidance and support.

A Group Photo of all the participants was taken and the session concluded with High Tea

The Chief Guest Mr. A.K. Wahal being felicitated by Dr. N.S. Bisht, Director, RFRI

Dr. N.S. Bisht, Director, RFRI lighting the lamp in the presence of Dr. Sangay Wangchuk, Director, SAARC Forestry Centre

The Chief Guest Mr. A.K. Wahal, Dr Sangay Wangchuk and Dr. N.S. Bisht during the inaugural session

The Chief Guest Mr. A.K. Wahal delivering the inaugural address to the Expert group

II CONCLUSIONS AND RECOMMENDATIONS

Expert Group Meeting on Adaptation to Climate Change Impacts and Risks to different forest types of South Asia

During the Expert Group Meeting, in order to facilitate the final group discussion session held on 24th October, 2013, a questionnaire was circulated amongst all the Experts to elicit their written responses to the following three questions:

1. **List out at least three critical issues in connection with the Impact of Climate Change on the forests of your country**
2. **List out at least three steps taken in your country for mitigation and adaptation of forests to Climate Change**
3. **List out at least three steps that need to be taken in future for adaptation and mitigation of forests in your country to Climate Change**

The written responses were put on power point slides country wise and displayed to all the Experts and based on the discussion that followed, the responses were refined and the country wise responses to the above questions are provided below:

1. **At least three critical issues in connection with the Impact of Climate Change on the forests of each SAARC country**

Bangladesh

- Increase in salinity, sea level rise and uncertainty of rainfall affecting mangrove forests (especially Top Dying of Sundri and Heart Rot disease of Passur species)
- Some indigenous species have become extinct and spread of invasive species
- Increase in forest fire, droughts and loss of biodiversity of the country
- Fragmentation of forest areas, density and forest areas have been decreasing
- Loss of wildlife habitats
- Decrease in ground water levels due to destruction of forests and catchment area

Bhutan

- Climate data and biome data are not available for many places
- Willingness to pay for services
- Research fund and capacity building

India

- Forest degradation and fragmentation
- Change in boundaries of forest types and species composition
- Habitat degradation and loss of biodiversity
- Adverse impacts on livelihoods of forest dependent communities
- Spread of fires, droughts and invasive species
- Flow of ecosystem goods and services from forests

Maldives

- Sea level rise, submersion of islands and the littoral forests also being affected
- Expansion of agriculture sector in order to achieve food security and livelihood and thereby could lead to clearing of forest land

- Invasive species of plants as well as insects threatening the forest
- Littoral forest degradation and loss due to soil erosion
- Salt water intrusion to the inner forest areas resulting in reduction in productivity and NWFP
- Soil erosion due to severe wind and sea swells
- Reduction in biodiversity like less migratory birds visiting the country and related changes

Nepal

- Glacial Lake Outburst Flood (GLOF)
- Unsustainable and unscientific collection of wood and Non-Timber Forest Products
- Low level of implementation

Sri Lanka

- Degradation of forests due to extreme weather conditions as well as changing climatic parameters, which could result in increase of fire incidences and forest dieback etc
- Difficulties encountered in restoration efforts due to unfavourable conditions such as droughts, soil erosion associated with high rainfall, invasive species etc.
- Increased pressure on forests as well as land resources from the peripheral communities due to loss of livelihoods (result of loss in agricultural productivity, water scarcity etc.)
- Increase in the extent of Forest fire in dry zone forests, Intermediate zone forest and montane forests
- Increase in Invasive species and die back in forests
- Illegal encroachment in forest land especially for slash and burn cultivation

2. At least three steps taken in each SAARC country for mitigation and adaptation of forests to Climate Change

Bangladesh

- Protection of wildlife and conservation of biodiversity has been included in the Constitution of Bangladesh
- Necessary amendments to the forest laws, other related laws and policy have been carried out
- Extraction of trees from government forests has been stopped
- Several protected areas have been declared for the protection of wildlife, biodiversity, flora and fauna
- Government is advocating to popularize green jobs
- Effluent treatment plant for every factory has been made compulsory
- Climate change trust fund, Climate change resilience fund and REDD plus cell established

Bhutan

- National Adaptation Programmes of Action (NAPA) adopted
- Sectoral Adaptation Programmes of Action (SAPA) adopted
- The Climate Change issues have been main streamed in all National programmes
- REDD plus cell established

India

- Implementation of National Action Plan on Climate Change through eight Missions; Green India Mission in forestry sector deals with mitigation and adaptation issues
- Formulation of State Action Plans on climate change including forests
- REDD Plus cell established in the Ministry of Environment and Forests
- Indian Network on Climate Change Assessment (INCCA) publishing findings on climate change in India including impacts of climate change on forests of India
- Methodology of estimating forest carbon stocks in India's forests established; National inventory of forest carbon stocks in India's forests prepared

Maldives

- Forest restoration activities
- Implementation of 'Safe island' concept where soft and hard mitigation measures are put in place to combat sea swells and soil erosion
- Creation of Buffer zone littoral forests in all the islands
- Allocation of island as protected areas and Biosphere Reserves
- Promotion of Agro Forestry to minimize forest clearance for agriculture
- Changing of law to lease islands for longer period of time so as to lease islands for forestry uses
- Environmental Impact Assessment to be done before any projects in islands to reduce impact of projects to natural environment
- Awareness creation amongst NGOs, CBPOs, policy makers, Government organizations etc on impact of Climate Change
- Forest policy has been developed addressing the impact of Climate Change
- The efforts to achieve the aim of whole of Maldives to become a Biosphere Reserve by the end of 2020

Nepal

- Establishment of REDD Forestry cell under the Ministry of Forests and Soil Conservation
- National Adaptation Programmes of Action (NAPA) handled by Ministry of Environment, Science and Technology
- In 2013, the National Pride Programme (a special priority programme by the Government) was 'President Chure Siwalik Conservation Program' for integrated conservation and development

Sri Lanka

- A National Climate Change Adaptation strategy has been developed for the period from 2011-2016 to adapt to the Climate Change impacts in different sectors
- The Sri Lankan National Policy 'MAHINDA CHINTHANA' has declared the intent to increase the National Forest cover upto 35% at the end of 2016 (from 29% to 35%). According to that policy, the targets and the necessary action to achieve this has been described
- Networking with other organisations
- Pilot level projects have been initiated in selected areas which are expected to be more vulnerable to climate change utilising the funds made available from the Adaptation Fund

- A Special Division has been established under the Ministry of Environment to deal with Climate Change issues especially to coordinate different institutions working on this subject
- Good network has been established between different organizations like Forest Department, Disaster Management Centre, Armed Forces, Police Department, village community organizations for early detection and control of forest fires
- REDD plus cell established

3. At least three steps that need to be taken in future for adaptation and mitigation of forests to Climate Change in each SAARC country

Bangladesh

- ❖ Increase research and funding support for identification of plants having more adaptability to Climate Change
- ❖ Increase Indigenous species plantations. There must be wide spread campaign for plantation of all indigenous varieties
- ❖ Make the best use of land by planned plantation
- ❖ Decrease biotic and abiotic pressure on the forests directly and indirectly
- ❖ Involve community based organizations for social afforestation with appropriate benefit distribution systems
- ❖ Develop digitized national database on biodiversity and prepare inventory of all flora and fauna by ecosystems in Bangladesh
- ❖ Introduce regulatory measures to protect biodiversity of nature
- ❖ Study possibilities of reintroduction of extinct species in selected areas

Bhutan

- ❖ Calibration and prediction models to Climate Change
- ❖ Experimentation of forest species
- ❖ Instrumentation and establishment of weather generating data for forest areas
- ❖ Expansion of permanent plots in all eco-regions
- ❖ Improve mapping capability of carbon stocks in forests under different climate change scenarios

India

- ❖ Revisit National Forest Policy of 1988 in the light of climate change relevant issues in the forestry sector; and, formulation of flexible and context sensitive forest policy and its integration to wider National Climate Change Framework
- ❖ Enhanced funding support to programmes like Green India Mission supporting adaptation and mitigation measures in forestry sector
- ❖ Capacity building of forest department in technical and institutional issues related to forest management in view of risks, vulnerabilities and impacts of climate change on forests along with awareness and capacity building programmes for all stake holders including forest dependent communities
- ❖ Enhanced funding to support capacity building and training activities in forestry sector
- ❖ Climate change modeling at regional and local levels for vulnerable areas to assess the likely impacts of climate change on forests and wildlife
- ❖ More research on climate change in forestry sector to bridge the data gaps

Maldives

- Forestry needs to be given a high priority and recognition at policy level
- Greater Budget allocation for forestry
- Forest assessment need to be carried out to determine the actual extent of the resource
- More forests need to be allocated as Protected Areas and conserved forests
- Research activities needs to be carried out to find out the damages to resource due to Climate Change
- Capacity building and institutional development
- Legislations
- Sustainable Forest Management plans
- Identifying the forest areas, vegetation mapping, identifying the vulnerable, endemic, rare and endangered taxa of the country to take necessary steps

Nepal

- Ecotourism and Payment for Ecosystem Services with emphasis on Fair and Equitable sharing of benefits
- Low cost access to Hydropower so that forests can be protected by reducing consumption of fuel wood
- Monitoring and providing emphasis to herbs and not trees and timber alone

Sri Lanka

- Filling the Data gaps in relation to climate parameters which are necessary for future analysis
- Studies to identify most vulnerable forest types using the latest technology available for modeling
- Create awareness among all the stake holders about possible impacts of Climate Change and issues related to forests
- Strengthen the capacities of communities living adjacent to forested areas so that their livelihoods are improved and better prepared for adaptation.
- Further research and modeling to identify areas for forest fire vulnerability
- Early detection of forest fire and warning system through satellite monitoring with collaboration with Research institutes
- Increase the awareness on forest fire, adaptation and mitigation measures among the most vulnerable people and the general public

III SESSION 1: AN OVERVIEW OF FOREST TYPES IN THE SAARC REGION

The session was chaired by Dr. Rajiv Kumar Garg.

Following presentations were made during this session:

1. Forest Types of Bhutan - Dr. Purna Bdr. Chhetri

A presentation on the Forest types of Bhutan was made and Dr. Purna Bdr. Chhetri highlighted the importance of altitude and precipitation as determining factors in forest types in the country. He also elaborated on the floral assemblage, diversity of flora and fauna, water resources and different land use types of Bhutan. He also explained about the importance of forests and the need for conserving the biodiversity in this region.

Discussion: Mr. Ramesh Basnet, Nepal enquired about the causative factor for Chir Pine mortality and whether it was due to dieback disease or due to climatic factor. Dr. Chhetri informed that this is covered in his paper.

2. Forest types of India- Dr. Renu Singh, IFS.

Dr. Renu Singh made a detailed presentation on the different forest types of India, classification of forests, mapping of forest types of India and also about current status of forest resources in India.

Discussion: Dr. Purna Bdr. Chhetri wanted know about the missing of certain forest types during forest type mapping and how it would be ascertained. Dr. Renu Singh and Dr. Rajiv Kumar Garg, chairman explained that this was due to land use change and degradation of forest land and this was ascertained during recent forest type mapping exercise done by FSI (1:50000 scale), which was confirmed by ground truthing.

3. Forest types of Maldives - Ms. Aishath Najath

Ms. Aishath Najath made a presentation on different forest types of Maldives.

Discussion: Dr. Renu Singh of India enquired about the reason why so far no forest type mapping was done and that accurate data was not available on the total forest cover of Maldives. Ms. Aishath Najath informed that Forestry in Maldives is still in its infant stage and there is no separate Forestry Ministry and that Forestry is being looked after by Ministry of Agriculture and Fisheries. She further mentioned that the Department is however gearing up to tackle the lack of expertise and financial crunch and that the task of assessing the forest area would be undertaken soon.

To a query from Dr. N.S. Bisht regarding the manner in which Maldives is meeting out their timber requirement, Ms. Aishath Najath informed that timber is primarily being imported from Malaysia and Indonesia.

Dr. Mohit Gera asked about their preparedness to sea level rise and Mr. Hussain Faisal, Maldives informed that some measures have been taken in the main city by construction of cement bunds to overcome sea bank erosion but in other islands only mangroves, coconut plantation and timber trees belt are used as a three layer blanket to protect from water current.

4. Forest types of Nepal - Mr. Ramesh Basnet

Mr. Ramesh Basnet made a presentation on Forest types of Nepal. He informed that Nepal has a total of 29% forest cover and delineated the various forest types according to the different classifications. He also mentioned that the annual forest degradation rate is about 1.7%.

5. Forest types of Sri Lanka - Mr. Wasantha Dissanayake

Mr. Wasantha Dissanayake made a presentation on Forest types of Sri Lanka. He explained about climatic factors, seasonal variation, different land use systems and vegetation of Sri Lanka.

Discussion: The chair, Dr. Rajiv Kumar Garg queried about how Sri Lanka meets out the timber requirement.

Mr. Dissanayake informed that since 1990, Sri Lankan government has completely banned extraction of timber from natural forest. For fulfilling their requirement they are importing timber from Malaysia and other neighbouring countries and also sourcing it to a great extent from 'Trees outside forests' in Sri Lanka.

6. Forest types of Bangladesh - Mr. Mozammel Choudhury

Mr. Mozammel Choudhury made a presentation on overview of Forest and its types in Bangladesh. He also explained about the conservation sites and measures taken for conservation of wildlife and conservation policies.

Dr. R.K. Borah, Group Co-coordinator (Research), RFRI presented the overview of the Rain Forest Research Institute and its activities.

The Chairperson then concluded the session by appreciating the important measures taken by the different SAARC countries to protect the forests and biodiversity. He emphasized the need for sharing of knowledge through such meetings.

IV PAPERS

Session 2 - Overview on Impact of Climate Change on forest types in South Asia

The session was chaired by **Dr. Purna Bdr. Chhetri** and four papers were presented.

Discussion

1. An Assessment of Climate Change Impacts and Risks to Different Forest Types Associated with Coal Mining in India

Dr. Rajiv Kumar Garg made a detailed presentation on coal mining, role of coal in the Indian Economy, impact of coal mining on climate change and on forests. He elucidated the issues and challenges involved in coal sector and stressed the need for the formulation of robust regulatory frame work for checking the diversion of forest land for non-forestry purpose and need for proper utilization of fund allotted to different state governments for the improvement of forest wealth. He advised Scientists and officers of RFRI to take up Ecorestoration of coal mining area at Margareta of upper Assam region.

Discussion: Mr. Mohan Heenatigala from Sri Lanka enquired about the effect of open and close mining and its effect on forest and also about Ecorestoration. Dr. Rajiv Kumar Garg explained both open and close mining and informed that in case of close mining the chances of fire damage are more. He explained about the Ecorestoration programme undertaken in Assam in coal mining area.

2. Climate Change and Forests in Nepal

Mr. Ramesh Basnet in his presentation briefed about the forest and climate change, current forest management practices, policy and guidelines available for conservation of biodiversity and efforts made on documentation of rare plants and medicinal plants of Nepal.

Discussion: To a query from Mr. Udhayan from SAARC Forestry Centre about the Climate Change vulnerable forest types of Nepal, Mr. Ramesh Basnet informed that the Sal and Oak Forests are the most vulnerable forests in Nepal.

3. Influence of Climate Changes on forest fires in Sri Lanka

Mr. Mohan Heenatigala mentioned about the forest resources and climatic conditions of Sri Lanka. He mentioned about increasing incidences of forest fire in recent past and also the most vulnerable forest types for fire damage. He elucidated the impact of climate change on the incidence of forest fire in last two decades with statistical data.

Discussion: Dr. Purna Bdr. Chhetri asked the presenter as to how he attributes forest fire incidence to climate change. The presenter explained about the recent incidences of forest fire, frequency and extent of fire damage directly related to wind velocity and dry weather etc and this was supported by data.

4. Climate Change and Island Forestry

Mr. Hussain Faisal mentioned that Maldives being a fragile, low lying Small Island is very vulnerable to climate change and its associated impacts especially the predicted sea level rise. He further elaborated the irony that although the contribution of Maldives to Green House gases is very negligible it is most susceptible to the effect of climate change. He also mentioned about how adverse climatic condition is affecting the forests and country’s food security. He also mentioned about the invasive species and reserving of uninhabited islands for cultivation purpose.

Discussion: Mr. Basnet from Nepal suggested the use of hydroponics system in agriculture to increase the productivity. Dr. Mohit Gera, from India explained the members how cultivation is being done in Dal Lake, Kashmir and mentioned that the increase of cultivable area in Maldives could be explored.

The Chairperson concluded the session by appreciating the presenters for the detailed information they have provided in the meeting. He also mentioned that the forest fires are the important indicator of climate change.

AN ASSESSMENT OF CLIMATE CHANGE IMPACTS AND RISKS TO DIFFERENT FOREST TYPES ASSOCIATED WITH COAL MINING IN INDIA

DR. RAJIV KUMAR GARG
Advisor (Environment & Forest), Coal India Limited, New Delhi
Email: advisor.cil@gmail.com
Mobile: +91-9717466448

Summary
Coal plays an important resource in achieving energy security especially for countries, which have rich resource of this fuel. Coal reserves are found both under forest as well as non-forest lands. Coal mining has adverse impact on environment and fugitive emission of methane enhances concentration of greenhouse gases in atmosphere. Coal extraction leads to destruction of forests and can cause risks to different forest types. Efforts have been and are being made by State Forest Departments and coal companies to mitigate coal mining induced risks to different forest types. This paper examines the current status of coal mining and its impact on forest lands in India. Based on current practices, future scenario has been estimated. The paper then elaborates on issues and challenges associated with coal mining and the way forward. Findings and estimations can be helpful to SAARC countries especially India, Bangladesh and Pakistan where dependency on coal is bound to increase.

Keywords: climate change, energy security, environmental security, forest type groups, fugitive emission, SAARC nations

Introduction
SAARC is a diverse conglomerate of nations, mostly developing ones, where the demand for power has soared, propelled by the inexorable growth in population and aspirations for higher quality of life. Energy availability will be central to the development agenda in SAARC. India, Pakistan, Bangladesh, Sri Lanka and Afghanistan have energy demand surpassing their domestic supply while Bhutan and Nepal have energy resources in hydropower far in excess of their domestic needs. The role of coal in the current and future energy landscape in SAARC, especially with reference to Bangladesh, India and Pakistan has gained significance. An estimate of proved recoverable coal resource at end-2005 (*WP, 2013*) and coal production in 2005 for these three countries (*WEC, 2013*) is given below in Table 1.

India has already witnessed an ever-increasing dependency on coal and in most likelihood, Bangladesh and Pakistan will follow suit.

TABLE 1: Status of coal reserves and coal production amongst SAARC nations

	Proved Recoverable Coal Reserves at end-2005 (Million Tons)	**Coal Production in 2005 (Million Tons)**
Bangladesh	2221	0.87
India	92445	428.43
Pakistan	3300	4.59

Role of coal in Indian economy
In India, coal is the critical input for major infrastructure industries like Power, Steel and Cement. Coal meets around 52% of primary commercial energy needs in India (*MoP 2013*) against 29% the world over. India is the 3rd largest coal producing country in the world after China and USA (*ICC 2012*). Around 66% of India's power generation is coal based.

According to the Integrated Energy Policy prepared by the Planning Commission of India, even under a least coal usage scenario, coal will supply more than 40% of the primary commercial energy even in 2031-32. Secondly, policymakers regard coal as being very important to India's energy security. It is the most abundantly domestically available fossil fuel, while about 80% of oil has to be imported. Thirdly, policymakers tend to view coal as a key element in increasing energy access in India, as over a quarter of the country does not have access to electricity and coal will remain the cheapest source of electricity for at least another two decades.

A total of 293.50 billion tons (BT) of geological resources of coal has been estimated in the country. State-wise geological resources of coal (*MoC 2013*) are given in Table 2.

TABLE 2: State-wise geological resources of coal in India

State	**Geological Resources of Coal (in million tons)**			
	Proved	**Indicated**	**Inferred**	**Total**
Andhra Pradesh	9566.61	9553.91	3034.34	22154.86
Arunachal Pradesh	31.23	40.11	18.89	90.23
Assam	464.78	45.51	3.02	513.31
Bihar	0.00	0.00	160.00	160.00
Chhattisgarh	13987.85	33448.25	3410.05	50846.15
Jharkhand	40163.22	33609.29	6583.69	80356.20
Madhya Pradesh	9308.70	12290.65	2776.91	24376.26
Maharashtra	5667.48	3104.40	2110.21	10882.09
Meghalaya	89.04	16.51	470.93	576.48
Nagaland	8.76	0.00	306.65	315.41
Odisha	25547.66	36465.97	9433.78	71447.41
Sikkim	0.00	58.25	42.98	101.23
Uttar Pradesh	884.04	177.76	0.00	1061.80
West Bengal	12425.44	13358.24	4832.04	30615.72
Total	**118144.82**	**142168.85**	**33183.48**	**293497.15**

India has set a target to produce 615 million tons (MT) of coal in 2013-14. Targets for coal production for 2016-17 and 2021-22 have been fixed at 715 MT and 950 MT respectively. CAGR for Indian coal production has been estimated at 5%-6% in medium term (*E&Y, 2013*).

For the next 20 years, with CAGR of 5%, production targets for Indian coal have been estimated as shown in Table 3.

TABLE 3: Estimates for coal production target (in MT) from 2013-14 to 2032-33

Year	Coal Production Target (MT)
2013-14	615.00
2014-15	645.75
2015-16	678.04
2016-17	711.94
2017-18	747.54
2018-19	784.91
2019-20	824.16

Year	Coal Production Target (MT)
2020-21	865.37
2021-22	908.64
2022-23	954.07
2023-24	1001.77
2024-25	1051.86
2025-26	1104.45
2026-27	1159.67

Year	Coal Production Target (MT)
2027-28	1217.66
2028-29	1278.54
2029-30	1342.47
2030-31	1409.59
2031-32	1480.07
2032-33	1554.07

Climate Change and its impact on forests

The Intergovernmental Panel on Climate Change (IPCC) has emphasized that there is enough evidence to show that the world is warming and that action needs to be taken. CO_2 makes up almost 80% of anthropogenic (human-induced) GHG emissions. Over the last century, the amount of CO_2 in the atmosphere has risen, in large part driven by fossil fuel use but also because of other factors such as land-use change and deforestation. Coal use is one of many human activities that generate GHG emissions. The United Nations Framework Convention on Climate Change (UNFCCC) has estimated that GHG emission from fossil fuels and other sources (*UNFCCC 2013*) as below:

1. Oil and gas 37%
2. Coal 25%
3. Rest 38%

Forests are highly sensitive to climate change. This has been shown by observations from the past, experimental studies, and simulation models based on current eco-physiological and ecological understanding. In particular, the following was concluded (*CMGR et al 2013*):

1. Sustained increases of as little as 1°C in mean annual air temperature can be sufficient to cause changes in the growth and regeneration capacity of many tree species. In several regions, this can significantly alter the function and composition of forests; in others, it can cause forest cover to disappear completely.
2. Suitable habitats for many species or forest types are likely to shift faster with climate change than the maximum natural rate at which many species can migrate and establish. Consequently, slow-growing species, such as late successional species, or those with restricted seed dispersal will be replaced by faster-growing, highly adaptable or more mobile species.
3. Forests are particularly vulnerable to extremes of water availability (either drought or water-logging) and will decline rapidly if conditions move toward one of the extremes.
4. Forced by a doubled carbon dioxide (2 x CO_2) climate, global models project that a substantial fraction of the existing forests will experience climatic conditions under which they do not currently exist; eventually, large forested areas will have to change from the current to new major vegetation types.
5. Although net primary productivity may increase, the standing biomass of forests may not increase because of more frequent outbreaks and extended ranges of pests and pathogens and increasing frequency and intensity of fires.

6. Mature forests are a large store of terrestrial carbon. Because the maximum rate at which carbon can be lost is greater than the rate at which it can be gained, large amounts of carbon may be released transiently into the atmosphere as forests change in response to a changing climate and before new forests replace the former vegetation.

The challenge

India faces two challenges:

1. Achieving energy security, which is needed not only for higher GDP growth but also for assuring inclusive growth to all her citizens and ensuring environmental security. Coal meets not only commercial energy needs but also ensures lesser dependency on nearby forest areas for collection of firewood.
2. Coal mining and coal consumption are environmental unfriendly. Production, transportation and consumption of coal result in severe negative environmental impacts such as air, water and land pollution. There are negative social impacts as well such as displacement and lost livelihoods. Coal usage in India also has impacts beyond India. In 2011, though India's annual per-capita CO_2 emissions at 1.6 tons was considerably lower than the global average of 4.9 tons, India was the world's third largest emitter of CO_2 with 1,970 million tons. Of this, coal usage contributed about 970 million tons, or about 49.24% of India CO_2 emissions (*SA 2013*).

India needs coal but coal mining and subsequent usages of coal have adverse impacts on climate, which may risk various forest types.

Fugitive methane emissions in coal mining

Fugitive emissions are unintended emissions, including both carbon dioxide and methane that arise during the production, processing, transportation, storage and distribution of fossil fuels such as coal, oil and natural gas or liquefied natural gas (LNG). Fugitive emissions arise during the coal production / extraction process whereby previously trapped methane and carbon dioxide gases are released into the atmosphere as coal seams are mined. The level of fugitive emissions from coal mines varies from mine to mine.

Fugitive emissions are inherently difficult to accurately calculate and estimates remain subject to large uncertainty. The estimation of fugitive emissions from open cut mining operations is particularly problematic. IPCC recommends using mine-specific data as a first best option where possible. In the absence of this, then coal production is multiplied by an emission factor, often established by the Government dependent on the characteristics of the mine and the geography where it operates.

Methane emission factors (*SAK, 2010*) for Indian coal mines and associated post mining activities have been shown in Table 4.

TABLE 4: Methane emission factor for Indian coal mines and associated post mining activities

Operation	**Methane Emission Factor (m^3 / ton)**			
	Surface Mining	**Underground Mining**		
		Degree-I	**Degree-II**	**Degree-III**
Mining	1.18	2.91	13.08	23.68
Post Mining (Handling)	0.15	0.98	2.15	3.12

Indian coal production from underground coal mines have stagnated at around 40 MT per annum. For underground coal mines, mean values for methane emission factor (m^3 / ton) for mining and post mining (handling) is 13.22 and 2.08 respectively. Emission of fugitive methane from Indian coal mines for the next 20 years has been estimated in Table 5.

It is estimated that emission of fugitive methane will rise from a present level of 1376.75 million m^3 in 2013-14 to 2625.71 million m^3 in 2032-33.

In some cases it is technically and economically feasible to progressively pre-drain coal seams prior to mining and this rich methane gas can be utilized for power generation on site. Typically however the majority of fugitive emissions from underground operations arise from methane having very low concentrations, which are technically very difficult to abate or harness. Mitigation is currently a costly option for the coal mining industry.

TABLE 5: Estimated fugitive methane emission from Indian coal mines from 2013-14 to 2032-33

Year	Projected Coal Production (MT) from Open Cut Mines	Projected Coal Production (MT) from Under Ground Mines	Total Projected Coal Production (MT)	Fugitive Methane Emission from Open Cut Mines (million m^3)	Fugitive Methane Emission from Under Ground Mines (million m^3)	Total Fugitive Methane Emission from Coal Mining (million m^3)
2013-14	575.00	40.00	615.00	764.75	612.00	1376.75
2014-15	605.75	40.00	645.75	805.65	612.00	1417.65
2015-16	638.04	40.00	678.04	848.59	612.00	1460.59
2016-17	671.94	40.00	711.94	893.68	612.00	1505.68
2017-18	707.54	40.00	747.54	941.03	612.00	1553.03
2018-19	744.91	40.00	784.91	990.73	612.00	1602.73
2019-20	784.16	40.00	824.16	1042.93	612.00	1654.93
2020-21	825.37	40.00	865.37	1097.74	612.00	1709.74
2021-22	868.64	40.00	908.64	1155.29	612.00	1767.29
2022-23	914.07	40.00	954.07	1215.71	612.00	1827.71
2023-24	961.77	40.00	1001.77	1279.15	612.00	1891.15
2024-25	1011.86	40.00	1051.86	1345.77	612.00	1957.77
2025-26	1064.45	40.00	1104.45	1415.72	612.00	2027.72
2026-27	1119.67	40.00	1159.67	1489.16	612.00	2101.16
2027-28	1177.66	40.00	1217.66	1566.29	612.00	2178.29
2028-29	1238.54	40.00	1278.54	1647.26	612.00	2259.26
2029-30	1302.47	40.00	1342.47	1732.29	612.00	2344.29
2030-31	1369.59	40.00	1409.59	1821.55	612.00	2433.55
2031-32	1440.07	40.00	1480.07	1915.29	612.00	2527.29
2032-33	1514.07	40.00	1554.07	2013.71	612.00	2625.71

Fugitive methane emission from open cut coal mining and coal handling – 1.33 m^3 / ton
Fugitive methane emission from underground coal mining and coal handling – 15.30 m^3 / ton

Impact of coal mining on land

Coal bearing areas span over both forest as well as non-forest lands. Data available for selected coal companies (*CIL 2013*) for the year 2010-11, specifying coal production vis-à-vis extent of coal mining and allied activities over forest and non-forest lands is given in Table 6.

TABLE 6: Coal production vis-à-vis type of land under coal mining

Coal Company	Coal Production (MT)	Land Held by the Company (ha)		
		Forest Land	Other Lands	Total
Bharat Coking Coal Limited	29.00	86.41	18366.52	18452.93
Central Coalfields Limited	50.00	16989.00	51739.00	68728.00
Eastern Coalfields Limited	33.00	996.61	21519.43	22516.04
Mahanadi Coalfields Limited	116.75	18900.00	6000.00	24900.00
Northern Coalfields Limited	72.00	7837.21	8757.00	16594.21
North Eastern Coalfield	1.25	4489.82	1064.84	5554.66
South Eastern Coalfields Limited	112.00	6474.12	25587.60	32061.72
Western Coalfields Limited	46.50	1085.35	19901.62	20986.97
Total	**460.50**	**56858.52**	**152936.01**	**209794.53**

In the absence of other data, following first hand indicative inferences can be drawn:

1. Breakup of land used for coal mining between forest and non-forest lands is 27.10% and 72.90% respectively.
2. For producing 1 MT of coal, land requirement is 455.58 ha (123.47 ha of forest land + 332.11 ha non-forest land)
3. For 2013-14, India's coal production target is 615 MT. This production will come from 280,182 ha land (75,934 ha of forest land + 204,248 ha of non-forest land).

It is assumed that lands for meeting coal production target for 2013-14 is already under coal mining and allied activities.

Additional land requirement for meeting coal production targets for the next 20 years has been estimated in Table 7.

Since the advent of commercial mining in India, not even 0.10% of land under coal mining and allied activities has been returned back thus coal mining will expand over forest land from the level of 75,934 ha (2013-14) to 191,881 ha (2032-33). Similarly coal mining will expand over non-forest land from the level of 204,248 ha (2013-14) to 516,122 ha (2032-33).

Impact of coal mining on forests

Coal is mined in 12 States of India (*CG 2013*) and is present below all the 16 forest type groups, as classified by Champion & Seth Classification, but more than 98.50% coal comes from mines operational in 8 States viz. Andhra Pradesh (9.60%), Chhattisgarh (21.05%), Jharkhand (20,22%), Madhya Pradesh (13.48%), Maharashtra (7.45%), Odisha (19.60%), Uttar Pradesh (2.85%) and West Bengal (4.30%).

TABLE 7: Total and incremental land requirement for meeting coal production targets from 2013-14 to 2032-33

Year	Coal Production Target (MT)	Forest Land (ha)	Non-forest Land (ha)	Total Land (ha)	Annual Additional Requirement of Land (ha)		
					Forest	Non-forest	Total
2013-14	615.00	75934	204248	280182	0	0	0
2014-15	645.75	79731	214460	294191	3797	10212	14009
2015-16	678.04	83718	225184	308901	3987	10724	14711
2016-17	711.94	87903	236442	324346	4186	11259	15444
2017-18	747.54	92299	248266	340564	4396	11823	16219
2018-19	784.91	96913	260676	357589	4614	12411	17025
2019-20	824.16	101759	273712	375471	4846	13035	17882
2020-21	865.37	106847	287398	394245	5088	13686	18774
2021-22	908.64	112190	301768	413958	5343	14370	19713
2022-23	954.07	117799	316856	434655	5609	15088	20697
2023-24	1001.77	123689	332698	456386	5890	15842	21731
2024-25	1051.86	129873	349333	479206	6185	16635	22820
2025-26	1104.45	136366	366799	503165	6493	17466	23959
2026-27	1159.67	143184	385138	528322	6818	18339	25157
2027-28	1217.66	150344	404397	554742	7160	19259	26419
2028-29	1278.54	157861	424616	582477	7517	20219	27736
2029-30	1342.47	165755	445848	611602	7893	21232	29125
2030-31	1409.59	174042	468139	642181	8287	22291	30579
2031-32	1480.07	182744	491546	674290	8702	23407	32109
2032-33	1554.07	191881	516122	708003	9137	24576	33713

Group 2 Tropical Semi-Evergreen Forests
Group 3 Tropical Moist Deciduous Forests
Group 4 Littoral & Swamp Forests
Group 5 Tropical Dry Deciduous Forests
Group 6 Tropical Thorn Forests
Group 7 Tropical Dry Evergreen Forests
Group 8 Subtropical Broadleaved Hill Forests
Group 11 Montane Wet Temperate Forests
Group 12 Himalayan Moist Temperate Forests
Group 14 Sub-Alpine Scrub

State-wise distribution of forest type groups (*FSI 2013*) has been shown in Table 8.

TABLE 8: Distribution of forest type groups in major coal producing states (area in sq. km.)

	AP	CG	JH	MP	MH	OR	UP	WB
Recorded Forest Area	63814	59772	23605	94689	61939	58136	16583	11879
Group 2					7.72	0.68	0.21	2.86
Group 3	4.08	47.89	2.66	8.97	29.85	39.88	19.68	11.04
Group 4	0.57				0.09	0.48	2.35	17.00
Group 5	88.78	51.65	93.25	88.65	57.40	57.87	50.66	28.64
Group 6	4.52			0.26	1.02		4.61	
Group 7	0.97							
Group 8					1.54			2.72
Group 11								1.60
Group 12								2.36
Group 14								0.11
ToF / Plantations	1.08	0.46	4.09	2.12	2.38	1.09	22.49	33.67

Legend –

AP	Andhra Pradesh	MH	Maharashtra
CG	Chhattisgarh	OR	Odisha
JH	Jharkhand	UP	UttarPradesh
MP	Madhya Pradesh	WB	West Bengal
ToF	Trees outside forests		

The above mentioned 8 States, together, hold 99.50% of the proved coal reserve, thus we can say that even in next 20 years these 8 States together will be producing coal almost close to their existing share in coal production in the country.

Forest lands and Forest Type Groups coming under coal mining and allied activities for producing coal from major 8 States for 98.55 MT (out of 100 MT at national level) has been shown in Table 9.

Major Forest Type Groups affected by coal production and their percentage is as follows:

Group 2	Tropical Semi-Evergreen Forests	0.85
Group 3	Tropical Moist Deciduous Forests	23.64
Group 4	Littoral & Swamp Forests	0.97
Group 5	Tropical Dry Deciduous Forests	69.50
Group 6	Tropical Thorn Forests	0.69
Group 7	Tropical Dry Evergreen Forests	0.09
Group 8	Subtropical Broadleaved Hill Forests	0.24
Group 11	Montane Wet Temperate Forests	0.07
Group 12	Himalayan Moist Temperate Forests	0.10
ToF / Plantations		3.85
	Total	100.00

TABLE 9: Forest lands and forest type groups coming under coal mining and allied activities for producing coal from major 8 coal producing States for 98.55 MT (out of 100 MT at national level)

	AP	CG	JH	MP	MH	OR	UP	WB
For producing 100 MT at national level, production from each State (in MT)	9.60	21.05	20.22	13.48	7.45	19.60	2.85	4.30
Forest land needed to achieve this production (ha)	1185.31	2599.04	2496.56	1664.38	919.85	2420.01	351.89	530.92
State-wise Distribution of Forest Type Groups Over Coal Mining Areas								
Group 2	0.00	0.00	0.00	0.00	71.01	16.46	0.74	15.18
Group 3	48.36	1244.68	66.41	149.29	274.58	965.10	69.25	58.61
Group 4	6.76	0.00	0.00	0.00	0.83	11.62	8.27	90.26
Group 5	1052.32	1342.40	2328.04	1475.47	527.99	1400.46	178.27	152.06
Group 6	53.58	0.00	0.00	4.33	9.38	0.00	16.22	0.00
Group 7	11.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Group 8	0.00	0.00	0.00	0.00	14.17	0.00	0.00	14.44
Group 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.49
Group 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.53
Group 14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58
ToF / Plantations	12.80	11.96	102.11	35.28	21.89	26.38	79.14	178.76

For producing 100 MT of coal, forest type group-wise requirement of forest land is estimated as follows –

Forest Group Type		Area (ha)	%
Group 2	Tropical Semi-Evergreen Forests	103.39	0.85
Group 3	Tropical Moist Deciduous Forests	2876.29	23.64
Group 4	Littoral & Swamp Forests	117.73	0.97
Group 5	Tropical Dry Deciduous Forests	8457.01	69.50
Group 6	Tropical Thorn Forests	83.51	0.69
Group 7	Tropical Dry Evergreen Forests	11.50	0.09
Group 8	Subtropical Broadleaved Hill Forests	28.61	0.24
Group 11	Montane Wet Temperate Forests	8.49	0.07
Group 12	Himalayan Moist Temperate Forests	12.53	0.10
ToF / Plantations		468.32	3.85

An assessment of various Forest Type Groups coming under coal mining form 2013-14 to 2032-33 have been shown in Table 10.

TABLE 10: Various forest type groups coming under coal mining and allied activities from 2013-14 to 2032-33
Area in ha

Year	Forest Type Groups									ToF / Plantations
	2	3	4	5	6	7	8	11	12	
2013-14	636	17689	724	52011	514	71	176	52	77	2880
2014-15	668	18574	760	54611	539	74	185	55	81	3024
2015-16	701	19502	798	57342	566	78	194	58	85	3175
2016-17	736	20477	838	60209	595	82	204	60	89	3334
2017-18	773	21501	880	63220	624	86	214	63	94	3501
2018-19	812	22576	924	66380	655	90	225	67	98	3676
2019-20	852	23705	970	69699	688	95	236	70	103	3860
2020-21	895	24891	1019	73184	723	100	248	73	108	4053
2021-22	939	26135	1070	76844	759	104	260	77	114	4255
2022-23	986	27442	1123	80686	797	110	273	81	120	4468
2023-24	1036	28814	1179	84720	837	115	287	85	126	4691
2024-25	1088	30255	1238	88956	878	121	301	89	132	4926
2025-26	1142	31767	1300	93403	922	127	316	94	138	5172
2026-27	1199	33355	1365	98073	968	133	332	98	145	5431
2027-28	1259	35023	1434	102978	1017	140	348	103	153	5703
2028-29	1322	36775	1505	108126	1068	147	366	109	160	5988
2029-30	1388	38613	1580	113533	1121	154	384	114	168	6287
2030-31	1457	40544	1660	119209	1177	162	403	120	177	6601
2031-32	1530	42571	1742	125170	1236	170	423	126	185	6931
2032-33	1607	44700	1830	131428	1298	179	445	132	195	7278

From Table 10 it is evident that Forest Type Group-5 is most vulnerable followed by Forest Type Group-3. It is estimated that diversion for Forest Type Group-5 will increase from 52,011 ha in 2013-14 to 131,428 ha in 2032-33. Similarly diversion for Forest Type Group-3 will increase from 17,689 ha in 2013-14 to 44,700.32 ha in 2032-33.

For diversion of forest land for coal mining purpose, following provision exists:

1. Central Government Public Sector Undertaking (CPSUs) engage in coal mining have to provide funds to concerned State Forest Department for carrying out plantation over double the degraded forest land. It means that for every 1 ha of forest land diverted for coal mining, CPSUs have to provide funds for carrying out afforestation over 2 ha of degraded forest land.
2. Non-CPSU coal mining companies have to make available equivalent non-forest land to concerned State Forest Department, which will be notified as forest and also to provide funds to State Forest Departments for carrying out afforestation over such lands.
3. In both cases afforestation is carried out by concerned State Forest Department. Further more in most of the cases such plantations are carried out either in the same forest division or in the same circle where diversion of forest land takes place.

Since independence, 85% coal production in country is carried out by CPSUs and rest 15% comes from non-CPSU entities. It is assumed that same trend will continue for the next 2 decades.

Coal companies carry out afforestation over coal mine areas from where coal has been taken out. Coal mines span both over forest as well as non-forest lands. Data available for selected coal companies for the year 2011-12 and 2012-13 specifying status of biological reclamation for coal mines producing more than 5 million m^3 of overburden and coal states that on an average over 27.56% of mine lease area afforestation is carried out by coal companies on their own (*CMPDIL 2013*). This is over and above the funds made available by them to State Forest Departments for carrying out afforestation over degraded / non-forest land. Mined out lands are highly refractory, water regime is lost and human is non-existent and thus are only fit for plantation of very few selected species.

An assessment of forest lands likely to be lost to coal mining, non-forest lands along with funds made available to State Forest Departments for carrying out afforestation in-lieu of forest land diverted for coal mining, degraded forest lands for which coal mining companies have to make funds available for carrying out afforestation and afforestation to be carried out by coal companies on their own on coal mining lease area has estimated in Table 11.

From the table it is evident that while loss of forest land will increase from a present level of 75,934 ha to 191,881 ha, availability of non-forest land for developing and declaring forest lands will increase from the present level of 11,390 ha to 28.782 ha. Opportunities for improving degraded forests land will increase from the present level of 129,088 ha to 326,198 ha. Coal companies have the potential to create plantations over land areas always more than the diverted forest lands. Plantations carried out by coal companies should also increase from the present level of 77,218 ha to 195,126 ha

Issues and challenges

Coal mining in organized commercial sector is in operation in India for the last more than 100 years. Issues and challenges, with reference to coal mining and associated climate change impact and forest lands, are listed below:

1. Robust regulatory framework for diversion of forest land for non-forestry (coal mining and allied activities) exists which has directed coal companies to look at non-forest lands for carrying out coal mining.

TABLE 11: Forest lands converted to coal mining, non-forest lands for carrying out afforestation, areas for density improvement in degraded forest lands and afforestation over mine lease area by coal companies from 2013-14 to 2032-33

Year	Forest Land Converted to Coal Mines (ha)	Afforestation by State Forest Departments		Afforestation by Coal Companies on Their Own
		Non-forest Land Available for Afforestation	Degraded Forest Lands for Density Improvement	
2013-14	75934	11390	129088	77218
2014-15	79731	11960	135543	81079
2015-16	83718	12558	142321	85133
2016-17	87903	13185	149435	89390
2017-18	92299	13845	156908	93859
2018-19	96913	14537	164752	98552
2019-20	101759	15264	172990	103480
2020-21	106847	16027	181640	108654
2021-22	112190	16829	190723	114087
2022-23	117799	17670	200258	119791
2023-24	123689	18553	210271	125780
2024-25	129873	19481	220784	132069
2025-26	136366	20455	231822	138672
2026-27	143184	21478	243413	145606
2027-28	150344	22552	255585	152887
2028-29	157861	23679	268364	160531
2029-30	165755	24863	281784	168558
2030-31	174042	26106	295871	176985
2031-32	182744	27412	310665	185834
2032-33	191881	28782	326198	195126

2. With the Land Acquisition and Resettlement & Rehabilitation Bill 2013 becoming an Act, taking agriculture and tenancy lands will become more expensive and time consuming as compared to forest lands and this may put pressure on forest lands for diversion to non-forestry (coal mining and allied activities) purposes.
3. Non-forest lands and funds for carrying out afforestation in-lieu of forest lands diverted for coal mining and allied activities are available but their utilization is far from satisfactory both in terms of money spent and quality of plantations carried out. This is true both for State Forest Departments and coal companies.
4. Furthermore, no correlation exists between the Forest Type Group devastated due to coal mining and the afforestation carried out. Instead of plantations, eco-restoration will be more useful in ensuring replacement of same Forest Type Group.
5. Involvement of local communities in creating and managing plantations is very little. As a result survival of such plantations is poor. Real degradation takes places once State Forest Departments and coal companies stop maintaining these areas. State Forest Departments are still able to insulate their plantations from biotic

pressure due to force of law with them. Coal companies do not have such authority and hence plantations carried out by them suffer the most.

Way Forward

Learning from our past experience and seeing that the dependency on coal especially in India, Bangladesh and Pakistan is going to increase in years to come, the following way forward is suggested:

1. Experience sharing amongst SAARC countries especially India, Bangladesh and Pakistan on coal mining, its impact on climate change and associated risk to various Forest Type Groups.
2. Initiate quantification of impact of coal mining and associated mitigation efforts on release of methane gas in atmosphere and Forest Type Groups.
3. Initiate development of models for assessing tolerance limit for climate change due to coal mining and associated activities.
4. Initiate development of models for assessing tolerance limit for change in Forest Type Groups due to coal mining and associated activities.

There are no easy answers, but in order to have a meaningful dialogue between development enthusiasts and environmentalists there is a need to do this exercise.

Conclusion

This paper is an attempt in experience sharing with reference to impacts of coal mining on climate change and risk to various Forest Type Groups. Present and estimated future scenario from India has been discussed. This paper can be a starting point for taking forward this discussion.

References

Central Mine Planning and Development Institute Limited (CMPDIL) 2013 Land Restoration / Reclamation Monitoring of 50 Opencast Coal Mines of CIL producing more than 5 mcm (Coal+OB) based on Satellite Data for the Year 2012-13

Coalguru (CG) 2013http://www.coalguru.com/india/indian_state_wise_production_and_supply_of_coal/6763 as viewed on 30.08.2013

Coal India Limited (CIL) 2013Website http://www.coalindia.in as viewed on 14.05.2013

Cannel M.G.R., UK; R.V.O. Cruz, Philippines; W. Galinski, Poland; W.P. Cramer , Germany (CMGR et) 2013 Climate Change Impacts on Forests

Ernest and Young (E&Y) 2013 http://www.energyglobal.com/news/coal/articles/ Ernst_and_Young_review_the_Indian_coal_industry.aspx as viewed on 01.08.2013

Indian Chamber of Commerce (ICC) 2012 The Indian Coal Sector: Challenges and Future Outlook

Forest Survey of India (FSI) 2013 India State of Forest Report 2011

Ministry of Coal, Government of India (MoC) 2013 Annual Report 2012-13

Ministry of Power, Government of India (MoP) 2013 Website http://powermin.nic.in as viewed on 14.05.2013

Singh, Ajay Kumar (SAK) 2010 Fugitive Methane Emissions from Coal Mining and Handling Activities and Oil and Natural Gas Systems in India

Sreenivas Ashok (SA 2013) Black and Dirty: The Coal Challenge in India http://www.in.boell .org/web/113-912.html as viewed on 04.09.2013

United Nations Framework Convention on Climate Change (UNFCCC) 2013 http://unfccc.int/ghg_data/items/3800.php as viewed on 02.09.2013

World Energy Council (WEC) 2013, 2007 Survey of Energy Resources

Wikipedia (WP) 2013, http://en.wikipedia.org/wiki/Coal_by_country as viewed on 01.09.2013

CLIMATE CHANGE AND FORESTS IN NEPAL

Ramesh Basnet
Department of Plant Resources (DPR)
Ministry of Forests and Soil Conservation
Nepal
E-mail: basnetbt@yahoo.com

Summary

Due to altitudinal and climatic variation, Nepal has rich and unique biodiversity. Forests derivatives (one of the important types of plant resources) definitely cover environmental, ecological, economical (livelihood and industry) and socio-cultural values. Poverty, increasing population, illegal and unsustainable harvesting, habitat fragmentation, fires, overgrazing, wide spread invasive species and diseases, improper water, land and technology use, weak information management system and low level of political commitment threaten the biodiversity. Holding fourth position in Climate Change Risk country in the world, the forest sector has a great role in adaptation and mitigation measures. However, the southern Chure/Siwalik and Terai tropical Sal (*Shorea robusta*) and Bijaya Sal (*Pterocarpus marsupium*) forest have high deforestation rates than in the hill and mountain. Sometimes, here the people become highly sensitized during the silviculture operation and management for growing forests production and productivity and ignore useful herbal plants as well.

In this regard, meaningful public participation is required in both the conservation and sustainable utilization of resources and that can be only achieved by fair and equitable sharing of benefits through Good Governance. Moreover, landscape level conservation and trans boundary cooperation is equally important.

Background/Rationale

The United Nations Framework Convention on Climate Change (UNFCCC), which defines "climate change" as *'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability (temperature and rainfall) observed over comparable time periods.'* Nepal holds about 0.4% of world's population and produces 0.025% of Green House Gas emission. The average temperature increase per year is 0.06 degree Celsius since last 35 years. Likewise, there are 20 glacial lakes with high risk of outburst among 2323. Besides, it holds fourth position in Climate Change Risk country in the world.

Nepal being the country of Hindu Kush Himalaya region (*Geologically Young Mountain*, water tower of Asia) with world's highest peak Sagarmatha is vulnerable to climate change primarily due to its fragile mountain ecosystem, marginality and inaccessibility. Besides, low level of institutional and economic capacity is equally worrying. Once malaria was eradicated in 1960, the people have been continuously clearing forests to make room for increasing population, farming and infrastructural development. Recurring fire, overgrazing, both legal and illegal wood harvesting have led to increasing degradation of forest stock over time. In this regard, the National Adaptation Program of Action (NAPA) program under the Ministry of Environment, Science and Technology has prioritized the following given areas:

a. agriculture and food security b. wetlands and water resources c. Human health and population d. vegetation shift and ecosystem and e. livelihoods and economics of vulnerable groups.

The 10th position in biodiversity richness held by Nepal is because of its Phytogeographic situation. Nepal lies on the crossroad of six floristic provinces of Asia: (i) the Sino-Japanese, (ii) the South-East Asiatic, (iii) the Indian, (iv) the African-Asian desert (Sudano-Zambian)

(v) the Irano-Turranean and (vi) the Central Asiatic provinces. The verticality of the mountains further diversifies the bioclimatic features of Nepal. All types of global bioclimatic zones ranging from the tropical to the nival zone are juxtaposed along the slopes of the Nepalese mountains. Thus phytogeographic delimitation and habitat classification face serious problems of interpenetration and mutual overlaps.

Although six floristic provinces of Asia influence the flora of Nepal, it is the Sino-Japanese province whose features dominate the Himalayan region. The humid east Himalayan flora and the drier west Himalayan flora show considerable interpenetration.

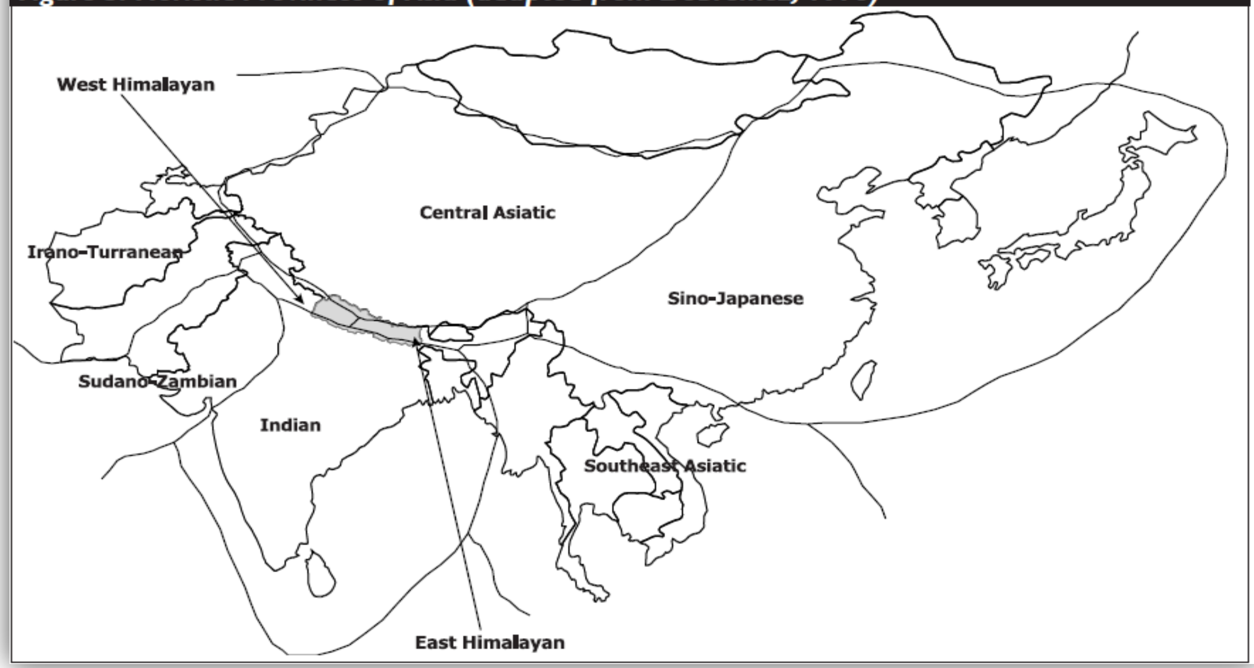
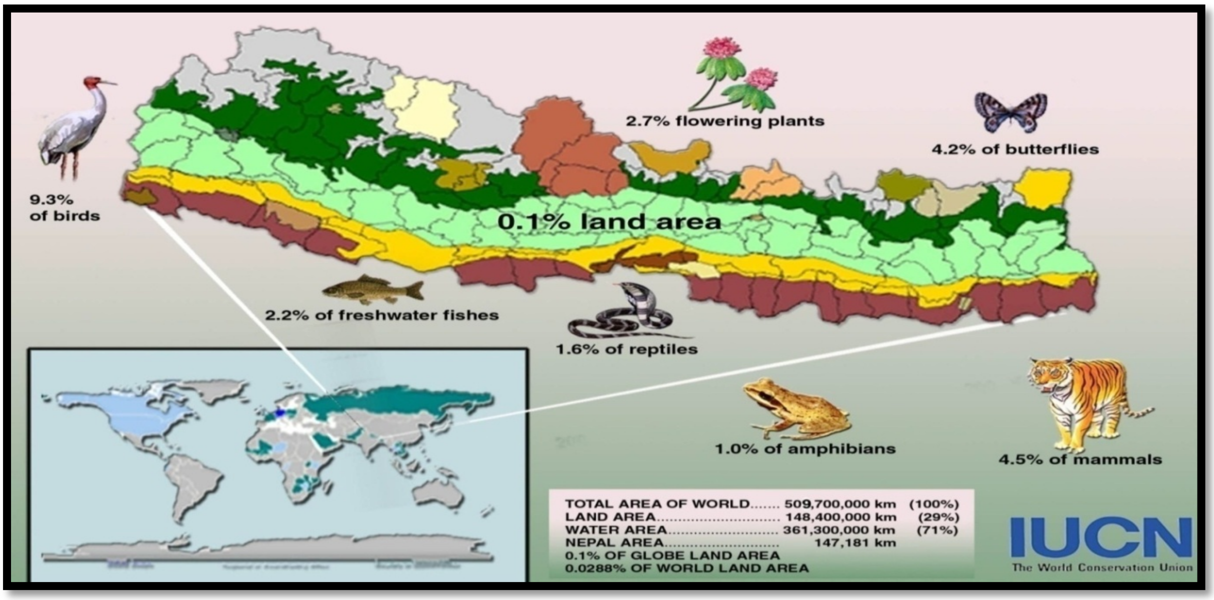


Figure 3: Floristic Provinces of Asia (adapted from Dobremez, 1976)

The land use pattern (%) in Nepal is Forest 29, Agriculture 21, Grassland 12, Shrub 10.6, Water 2.6, Non-cultivated 7 and others 17.8 (National Biodiversity Strategy/NBS, 2002). About 24% of its land area is covered with protected areas (10 National Parks, 3 Wildlife Reserves, 1 Hunting Reserve, 6 Conservation Areas and 12 Buffer Zones). Moreover, 11 Botanical Gardens including the World Peace Biodiversity Garden Kaski, Pokhara (approx. 182 ha.) hold approx. 299 ha for *in-situ* and *ex-situ* conservation. Likewise, it contains 35 forest, 118 ecosystem and 75 vegetation types. The Ministry of Forests and Soil Conservation (MFSC) has targeted to achieve 40% coverage of forest area. But, the annual average deforestation rate is 1.7% (Subedi, 2006).According to NBS, 2002 it has identified six ecosystems as the sectoral strategies are; a. Protected areas b. Forests c. Rangelands d. Agro biodiversity e. Wetlands f. Mountain biodiversity.

The Nepal Government has regulated the following Forest Management Models: National Forests that includes Government, Community(about 18,000 Community Forest User Groups/CFUGs and 35% population benefited especially in hills and mountain), Protected (7), Leasehold, Religious(36 Districts) and currently Collaborative Management for the Terai and inner Terai districts. The other category is Private Forest.



Some Related Institutions & Agencies

Ministry of Environment, Science and Technology (MoEST), Ministry of Forests & Soil Conservation (MoFSC) having REDD Forestry and Climate Change Cell/National Biodiversity Coordination Committee (NBCC), Ministry of Agriculture Development (MoA), Ministry of Federal Affairs & Local Development (MoFALD), Ministry of Tourism and Civil Aviation (MoATC), Ministry of Urban Development, Civil Society, Universities (T.U./ RECAST, K.U., P.U.), NAST/Pyramid Lab at 5050 m at Sagarmatha, NTNC, UNDP, GEF, WWF, IUCN, ICIMOD, ANSAB etc., are some relevant (national, multinational and international) agencies involved in sustainable development in Nepal.
Moreover, Global Observation Research Initiative in Alpine Environment (GLORIA) is working at Rasuwa, Taplejung, Manang and Humla on tree line ecotones with Central Department of Botany/TU/Nepal and Missouri Botanical Garden, USA since 2009 (Anonymous, 2013).

Challenges and Opportunities

Impact on NTFP and MAPs: Due to drought and rise in temperature, unpredictable rainfall in high altitude grass land, local communities have experienced availability of less herbs and NTFP. Though anthropogenic factor is prominent, however Climate Change effects on the life cycle, distribution of plant species and secondary chemical production as in Yarsagumba (*Ophiocordyceps sinensis*), Panchaule (*Dactylorhiza hatagirea*), Atis (*Delphinium himalayai*), Satuwa (*Paris polyphyla*), orchids and lichens (it is known as indicator of air pollution) as well. So, it has influence on losses of endemic and high altitude plants (like *Stellaria decumbens* at 6,130 m asl) that both an integral part of traditional medicine and solid area of Intellectual Property Rights (IPR). Among 285 endemic flowering plant species, the rich areas are Annapurna 55, Sheyphoksundo 36, Dhorpatan 30 (Anonymous, 2013).


Satuwa/*Paris polyphyla*) Red Fruit & Rhizome *Photo: DPR, 2013*



Photo: M.D.Joshi

Yarsagumba/*Ophiocordyceps sinensis* Atis/*Delphinium himalayai* (root & seed)

Impact on Forest Ecosystems

- ***Increased dryness and fire*****:** One of the strong impacts of climate change experience in Nepal is drought during the spring season. Although, forest fire is started by humans, dryness of forest floor and winds are great contributing factors to spread fires and increase damage of all forest (Sal, Satisal, Bijayasal and subtropical Sal) and its products like timber, fuel wood, NTFP, wildlife, plants and small micro-organisms.
- ***Physical disturbance from erratic rain, landslides and erosion*****:** Heavy rains results in landslips and landslides. Once there is land disturbance, additional rain cause erosion in the forest ecosystems. These physicals disturbance also cause damage to overall forest ecosystems.
- ***Degradation of species diversity*****:** Degradation of forest ecosystems from physical disturbance, erosion, and rise in temperature, short dormant season, forest fire, encroachment by alien species, insects and pests cause damage to existing species diversity in forest ecosystems.
- ***Altered natural life cycles*****:** Short winters due to increase in temperature results in reduced dormancy period for plants. As the result, there has been early sprouting, flowering and fruiting. This makes impacts to species, which depends upon flower and fruits of the particular species. For example, early flowering of *Rhododendron sp* (Ericaceae) and *Myrica esculanta* monotypic family (Myricaceae) may not be compatible to the pollinators and birds that directly or indirectly lead to the biodiversity loss.
- Moreover, unsustainable stone, sand and gravel mining from the Chure/Siwalik Hill region seriously threaten human life, water source and biodiversity as well. Hopefully, the

‘President Chure Conservation Program’ launched as **‘National Pride Program’** since this fiscal year 2013/14 will provide the desired results.

Chure/Siwalik Region (developmental works, mining for stones, gravels) *Photo: R.Basnet*

Mountain Ecosystems

- ***Risk of glacial lake outburst flood:*** There are 20 glacial lakes, which are at risk of bursting and 6 have been identified as critical.
- ***Damage due to landslide and flood:*** In last ten years, more than 4000 persons died and properties worth $ 5.34 billion are lost, which include loss of land and crops, livestock etc., (NAPA, 2010).
- ***Migration of species:*** It loses the species by moving from the original habitat as it requires both adaptation and competition. Some studies show that the tree line shifts to higher altitude in case of *Abies spectabilis,* but have not proved yet as due to climate change only.

Vulnerable forests of Sub-Tropical to Temperate region

- (Kaulo – *Machilus odoratissima* Nees in Wall (Lauraceae), distribution at subtropical 1000-2500 m asl, evergreen, broad leaved tree, mainly from mid and far western Nepal gets unscientific and unsustainable collection (*bark*; even from tree felling). Moreover, it is declining day by day due to excessive fodder use and recalcitrant seeds as well (Basnet, 2013).

Photo: R.Basnet

Kaulo/*Machilus odoratissima* Fruiting Twig and Bark Harvesting (Dhanbang-3, Salyan)

- Unsustainable tapping **resin** from (*Pinus roxburghii*) in the mid hills (subtropical, mainly Central to Western) adversely affect the survival of the population.
- Unsustainable felling of the Oak (*Quercus semicarpifolia* - Fagaceae) for firewood, charcoal, fodder (as it contains 7.3% crude protein) and litter collection; the another challenge in high hill (approx. 2400-3000m) for its low regeneration rate (Subedi, 2006).It is one of the oldest vegetation types in the Himalaya as Beech forests are known to be climax forest typein cool temperate zone of Japan and other countries of the northern hemisphere.

Natural Oak Forest & pole like tree by over lopping (Photo: M.N.Subedi)

- *Taxus baccata* (CITES- 2 Plant) leaf (source of **taxol**) is unsustainably collected in hills of Central Nepal; however, it is less exploited in Western Nepal.
- *Talauma hodgsonii* (CITES-3 Plant) (Magnoliaceae) excessive utilization for timber value from the Eastern midhills.

- Severely, decreasing population of *Gnetum montanum* (Gymnosperm/Climber and - CITES- 3 Plant) from Sankhuwasava (approx. 300-1800m), Eastern Nepal by excessive and unsustainable fodder use, slow growth and dioecious nature. Besides, seeds used in cough locally.

Gnetum montanum (Female Cone) *Photo: NHPL, 2013*

Vulnerable Tropical forests

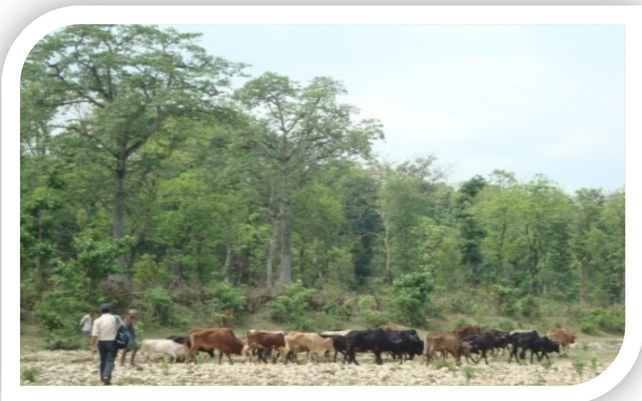


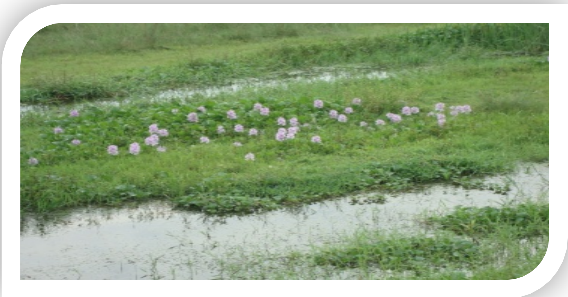
Photo: R.Basnet

Simal (*Bombax ceiba*- a 'key stone' species is in decreasing from tropical riverine forest)

  Photo: KrisnaRam Bhattarai

Bijaya Sal (*Pterocarpus marsupium* (tree and seed from Kanchanpur District far Western Nepal) *Now in vulnerable status based on local experience as it is excessively utilized for timber and medicine.*

***Encroachment by alien species*:** Due to rise in temperature, drought and other unknown climatic factors, certain alien species are spreading rapidly in forests such as *Mikania micarantha*, *Chromolaena odorata* species in the Terai forests, *Lantana camera, Bidens pilosa, Ageratina adenophora*in hill forests. *Eichhornia crassipes* (Water hyacinth) is prominent in both the hillside and terai wetlands. The beautiful lake, Fewa in Pokhara Valley is suffering from this plant by every year.



Eichhornia crassipes (Water Hyacinth) *Photo: R.Basnet*

Nepal has about 217 naturalized alien plant species belonging to 46 families of the flowering plants. The various ecosystems of the Terai, Chure/Siwaliks and midhills are seriously threatened by Invasive Alien Species /IAS (Siwakoti, 2012).

Mikania micrantha (mile-a-minute*)* is fast growing climbing herb having wide range of distribution in forests, agriculture, grassland and wetlands that displaces the habitat of indigenous flora and fauna in the tropical area Jhapa to Dang district. It results mainly in the loss of both endangered species wild buffalo in Koshi Tapu Wildlife Reserve (KTWR) and one horned Rhinoceros in Chitwan National Park (CNP), which could lead to serious ecological and economic consequences.

- ***Disease and pests:*** Due to extension of rainfall after conventional monsoon period, rise in temperature, and other unknown factors various pest and diseases are seen increasing in forest ecosystems. For example, Die back diseases in Sisso in the Terai region, farmers are not keen to start plantations.

Case of Tinjure, Milke, Jaljale (TMJ), Eastern Nepal

The capital of Rhododendron forests, TMJ harbors 28 species among the 32 in Nepal. Since 2 years, unidentified insects cause its wilting, make it a serious problem (NTV, 24.8.2013).

Some potential forests

However, the religious tree Rudrachha (*Elaeocarpus sphararicus*) mainly in the mid hills of Eastern part is going on mass cultivation due to increasing its trade demand. Likewise, Vadrachha/Bodhimala (*Zizyphus sativa*) in the mid hills of Central region (Kavreplanchok District) has great public interest for mass production in marginal land.

Bodhimala (*Zizyphus sativa*) at flowering stage *Photo: NHPL, 2013*

Way Forward

Climate Change is not only the concern of one country but it is also the most challenging global issue. Indeed, the fact is that, the nature may exist without human but the human cannot exist without nature. In this regard, the vital component is plant as being in autotrophic nature.

It is essential that the political commitment and trust be for equitable benefit sharing from all the resources including forests that supports long term conservation and sustainable utilization efforts effectively. Therefore, it needs periodic Geographic Information System (GIS) based forest resources inventory and assessment, monitoring the herbs (lichens, orchids, endemic plants) along with tree species, incentive based conservation and trade, education and the law enforcement (as the part of Good Governance) in order to secure the Himalayan biodiversity, fresh water and livelihood for future. For this, Hydropower and transportation development, Ecotourism and Good Information& Communication System should be developed.

At the same time, we have to point out the adaptation and mitigation measures, which should be treated as the part of development and trade respectively. For this, meaningful local participation and transboundary cooperation is essential (LFP, 2009).

Finally, there is considerable direction and inspiration in the famous saying of Mahatma Gandhi '**there is enough for everyone's need but not for their greed.'**

References

Anonymous, 2013HamroSampada (National Monthly) Banaspati Special Issue 12(10) Kathmandu, Nepal ISSN 2091-2048.

Basnet, R.2013Multipurpose Plant-*Machilus odoratissima*, Waiting for Conservation HamroSampada(National Monthly) 2013 (June, Environment Special Issue) 13(1) Kathhmandu. Nepal ISSN 2091-2048.

DPR, 2013 BanaspatiSrot (Newsletter) November Issue Department of Plant Resources, Kathmandu, Nepal.

Government of Nepal/Ministry of Forests and Soil Conservation 2002, Nepal Biodiversity Strategy/NBSKathmandu, Nepal.

Government of Nepal/Ministry of Environment 2010, National Adaptation Program of Actions to Climate Change (NAPA), Nepal.

NHPL, 2013 National Herbarium & Plant Laboratory (KATH)/Brochure Lalitpur, Nepal.

LFP, 2009 Impact of Climate Change on Forests and Livelihoods: Issues and Options for Nepal Livelihood and Forestry Program Nepal.

NTV, 2013 Nepal Television/News (24.8.2013), Kathmandu, Nepal.

Siwakoti, M. 2012, Threats and Opportunity of Invasive Alien Plant Species in Wetlands Conservation of Nepal Proceedings, International Wetland Symposium (IWS), 7-9 November, Pokhara, Nepal organized by Ministry of Forests and Soil Conservation/Conservation and Sustainable Use of Wetlands in Nepal.

Subedi, M.N. 2006, Conservation and Sustainable Utilization of Oak (*Quercus semecarpifolia* Sm) Bull.Dept. Pl. Res. N. 27 Plant Resources Department of Plant Resources, Kathmandu, Nepal.

INFLUENCE OF CLIMATE CHANGE ON FOREST FIRES IN SRI LANKA

M. Heenatigala
Assistant Conservator of Forests,
Forest Department, Sri Lanka
mohanhee@gmail.com

Summary

Forests play a vital role in the environment. Specially, improve soil properties and regulate the balance of water, defining the interaction of soil and climate at the local level and supporting the flora and fauna. The balance between these factors is essential for development. Human involvement is a major contributor for forest fires in Sri Lanka. Forest fires can be attributed to human activities such as animal husbandry, agriculture and land-conversion burning. Human carelessness is a major cause of forest fires in Sri Lanka. Threats for forest fires in natural forests as well as plantation forest are increasing with time because of the climate change impacts. Intensity of forest fire increases due to dry weather and high wind speed. Rapid climate change will affect tree growth rates, mortality rates, disturbance patterns and the distribution of tree species. Impacts will be cumulative and interconnected. For example, the risk of Forest fire combined with drought can stress trees making them more susceptible to forest fires. However, prevention policies must consider the role that humans play in Forest fires. There is a marked fire season from June to September in the eastern and northern region. Moderate to strong winds can be expected, blowing mainly from south – West. Fire seasons in the up country occur normally in February – March. But this duration seem to change with time as a result of effects of climate change.

Background

The total area of natural closed-canopy forests of Sri Lanka in 2010 is estimated at 1.4 million ha or 22.3 percent of the total land area while the total extent of well established forest plantations amount to 85217 ha,1.3 percent of the land area. There are about 1.2 million ha of lands classified as "Sparsely used crop lands" that are comprised of scrub and grasslands.

Table 1: Forest resources of Sri Lanka

Forest Type	Area(ha)	Share of total land Area (%)
Montane Forest	44758	0.68
Sub- montane forest	28513	0.43
Lowland rain forest	123302	1.87
Moist monsoon forest	117885	1.79
Dry monsoon forest	1121392	17.09
Riverine Dry forest	2425	0.03
Mangrove	15669	0.23
Open & Sparse forest	429485	6.54
Savannah	68043	1.03
Forest plantation	76559	1.16
Total	**2028031**	**30.91**

Source: Forest inventory & Management unit, Forest Department (2010)

Fires are an integral part of many ecosystems. Forest fires create public health and water quality problems. Also forest fires now increasingly burn with intensities that reduce or eliminate habitat for threatened species. The ecological disasters that a wooded area could suffer at risk from fire are very high.

Estimation of the fire risk can be made by analyzing the main causes. An Internationally agreed classification of causes indicates natural, carelessness, incendiary, accidently and unknown as the causes. The problem of forest fire in Sri Lanka can be summarized by examining weather conditions, fuel types in the forest and human attitudes in the area. The agent causing natural forest fires such as dry thunderstorms or volcanic eruptions are not present in Sri Lanka, so all fires have a human origin. Carelessness seems to be the main cause. For example, almost all of forest fires in Sri Lanka are related to human involvement. Sources of human-caused fire may include arson, accidental ignition, or the uncontrolled use of fire in land-clearing and agriculture such as the slash-and-burn farming. Main negligence are by smokers who throw cigarette butts when walking through the forest or when travelling by train, burning of debris by workers maintaining highways and railway tracks without taking proper precautionary measures, burning of degraded forests for shifting cultivation, setting fire to the forest by hunters to drive animals out, burning dead grass in order to obtain fresh grass for cattle. These fires often spread to nearby forests.

Forest fire generates ash, destroys available organic nutrients, and cause an increase in water runoff, eroding away other nutrients and creating flash flood conditions. Forest fires can also have an effect on climate change, increasing the amount of carbon released into the atmosphere and inhibiting vegetation growth, which affects overall carbon uptake by plants.

Four weather factors have an influence on forest fire behavior: Rainfall, Relative humidity Temperature and Wind. The climate of Sri Lanka is a monsoon climate. That is, weather conditions are mainly determined by the prevailing winds. There are two major monsoons, the Southwest monsoon from May to September and the Northeast monsoon from December to February. The Southwest monsoon is stronger than Northeast monsoon and lasts longer. During the Southwest monsoon rainfall is concentrated on the windward slopes of the central highlands, so on the lee side the winds are very dry. The contrary happens during the Northeast monsoon, but this monsoon is weak and shorter compared to the southwest monsoon.

Although the rainfall figures are quite high in the dry zone (around 1000mm) the distribution of rainfall is very uneven. Much of the rainfall in the dry zone come with the northwest monsoon during a three-month period from October to December leaving seven to eight months virtually dry. This considerably increases the fire hazard during the dry period.

The wind pattern and topography create two marked fire seasons. There is a short but important fire season from February to March in the wet zone and a longer fire season from June to September in the dry zone. In the Central highlands, only a short dry season prevails during the first three months of the year but the risk of fire is often high due to low humidity and the topography of the area.

Considering the extent of fire hazards, there is no significant fire hazard in most of the native vegetation of the country except intermediate and dry zones of Sri Lanka. The climax vegetation of the south and central highlands is tropical rain forest and sub-tropical montane forests. In the intermediate zone it is mainly evergreen forests, while in the dry zone it is semi-deciduous forests. Lands not occupied by the permanent agriculture are mainly covered with grasses. Fuel loads in this area are between 4-12 tons/ha (dry weight). Mean height of the grass is about one meter and grasslands are ready to burn during the dry season. Fire hazard is very high in forest plantation, especially in eucalyptus and pine plantations. Over the past 40 years, 18000 ha of Pines and 19000 ha of eucalyptus have been planted. Most of the pine plantations are situated on the steep slopes of the central highlands. This situation creates a very high fire hazard/ Fire risk.

The number of fires reported annually range from 50-200 depending on the weather conditions. Most of fires reported are in forest plantations. The area burnt by a single fire varies from 0.2 to 150 ha with an average of 10ha. Nearly 2 percent of newly planted areas are burnt annually. Most of the forest plantations are of small size and scattered over the country. Therefore, the risk is also scattered. Almost all fires are surface fires and crown fires are very rare. But with time, the risk of fires in natural forest has increased due to climate change happenings and human involvement.

Until recently fire was not a priority concern in Sri Lanka. With changing land use patterns, relocation programs and the replacement of moist native forests with more productive but flammable eucalyptus and pines, the forest fire problems in Sri Lanka are reaching serious proportions.

There is no significant health hazard associated with forest fire due to the small size and relatively short burning period. The direct economic losses are mainly due to damage to forest plantations. Environmental damage caused by forest fire is often much greater and takes many forms.

Thus fire protection and fire management strategies become essential to ensure the survival and maintain productivity of current forestry initiatives. In assessing the fire problems we must look at the types of fire behavior we need to handle and their causes, both physical and social.

Fire prevention is the main strategy used in forest fire control in Sri Lanka, especially in regard to forest plantations. This is mainly done by creating firebreaks around the plantations. Interior fire breaks are also used if the fire risk is relatively high. The current forest policy clearly states that all forests are brought under sustainable management. Management plans have been developed for both natural forests and forest plantations and forest fire prevention is one of the activities in these plans. Depending on the status of each forest, these plans contain different strategies to be used in forest fire management.

Due to lack of transport facilities and poor quality minor roads the unimpeded access response times, which could be achieved will be slow by normal standards. The development of competent and responsive fire fighting groups with the community is basic to the use of fire as a tool of management.

Training is required in fire fighting and in controlled burning. Initial training should consist of practical exercise in safe areas or areas where controlled burning is required and should take place at the beginning of the season.

As a signatory to the UN framework Convention on Climate Change (UNFCC), Sri Lanka is committed to address the threat of human induced climate change through all sectors both by increasing the resilience of its people and its ecosystem through adaptation measures. Therefore, the Government of Sri Lanka is developing strategy for reducing emission from deforestation and forest degradation plus conservation, sustainable management of forests and enhancement of forest carbon stock (REDD+).

The North East (NE) monsoon is shorter and weaker than the South west (SW) monsoon and hence the rainfall is never high on the NE slopes, and drought is never serious on the SW side. Mean rainfall in the SW is around 2000mm, while on the other side of the island it is around 1000mm. Although this is not small in extent, distribution in the Eastern region reaches to a minimum from June to September. Then relative humidity drops below 50% for most of the days. Fresh fuel get dry and hazard reaches it maximum.

Regeneration in fire ravaged sites is generally quick in Sri Lanka because of its high mean temperature and high average rainfall. Therefore, when the fire is over, nature begins at once in restoring the site. But when the frequency of fires increases, natural restoration slows down and in some cases it cannot take place. Then the eco-system productivity decreases and less biomass accumulation can be expected. The Sri Lanka climate makes possible the easy and fast regeneration of vegetation after fire. So a cover is laid on the soil preventing erosion. However, some time elapses between the end of the fire and the moment when the full soil protection is accomplished by the vegetation. In other wet zones in the world, it has been calculated that erosion rate amounting up to 50 tons/ha a year happens during the first year after fire. The process nearly stops in the second year, but a repeated fire can start it again.

Most of the fires in Sri Lanka are small in areas but the accumulative effects can occur. So erosion consequences should not be forgotten. Especially in the up country patina grass normally grows in the burned area and it gives poor protection against erosion.

The present policy is that no fires are allowed in the forests except in the certain seasons and under license. Helping to prevent and to suppress the fire is compulsory for people connected with and in the vicinity of the forest. This is rational basis for a national wide policy concerning protection against fire.

Challenges

Climate change effects for forest fires

Steeper trend line on Figure 1 shows that the occurrences of forest fires have increased with the years from 2002 to 2012. From 2006, the highest forest fires were reported in year 2009 followed by 2012. Metrological data shows that (Table 3) rainfall is having good relationship between the forest fires, when the dry period is increased the forest fire occurrence and the extent of damages are increased.

Table 2: Forest fires and area damaged in Sri Lanka

Year	No. of fires reported	Area burned (ha)	Estimated Damage (SLR)
2002	88	449.55	973,990
2003	47	145.00	484,375
2004	44	573.35	1,762,225
2005	82	982.25	441,292
2006	58	230.98	1,093,280
2007	15	92.30	388,742
2008	15	108.80	33,000
2009	111	1073.30	1,701,607
2010	63	748.10	1,299,432
2011	63	436.67	613,800
2012	81	785.1	2,843,740

Source: Forest inventory & Management unit, Forest Department

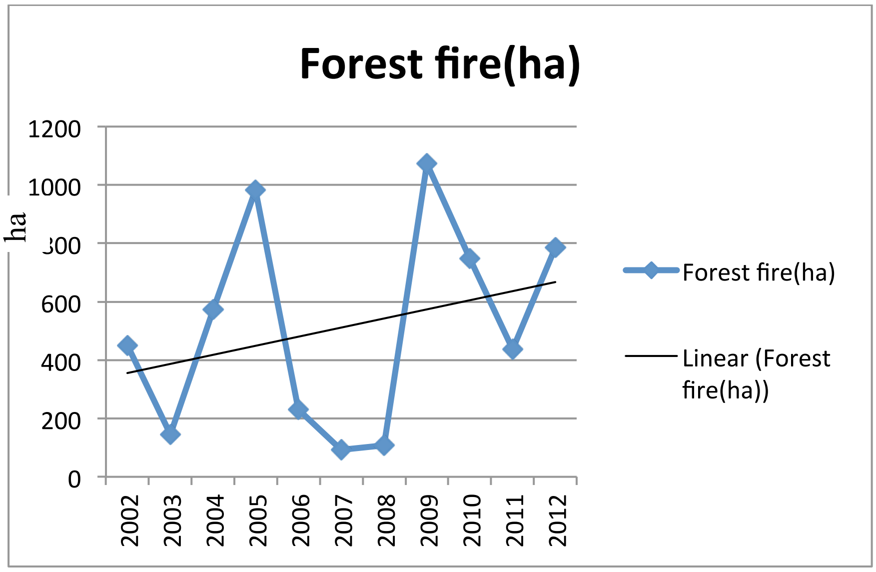


Figure1: Occurrence of forest fires from year 2002 to 2012

Source: Forest inventory & Management unit, Forest Department

The intensity of forest fires (the areas damaged by the one forest fire) also shows an increase from 2006 to 2012. Wind and the relative humidity are also having increasing relationship with the forest fires. Due to climatic changes, the occurrence of extreme weathers events has increased such as drought duration, high intensity of rainfall (for shorter period of time), high velocity of winds. Due to weather pattern change, unexpected forest fires were reported in last few years. At the same time the intensity of forest fires also increased in last few years. It happened mainly due to increase of drought period and wind velocity.

Table3: Annual rainfall(mm) – Sri Lanka

Year	Annual Total(mm)
2003	1419
2004	1945
2005	1607
2006	1921
2007	1640
2008	2020
2009	1711
2010	1992
2011	2027
2012	1776

Source: Meteorological Department, Sri Lanka.

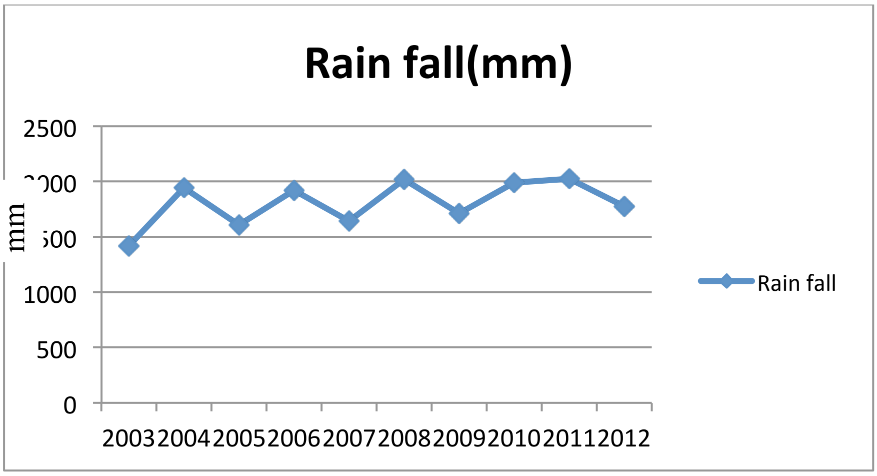


Figure 2: Annual rainfall (mm) from 2003 to 2012.

Table 4: Extent (ha) of Monthly Forest fire from year 2008 to 2012(only in Main forest fire occurrence months)

	Year				
Month	2012	2011	2010	2009	2008
March	12.7	1	101.1	70	0
May	36.5	0	0	0	0
June	170	123	2	159.5	27.5
July	76	168.6	330.4	213.5	12.5
Aug	487.5	114.5	189.75	117	0.5
Sep	74.5	16.5	111.8	8	14
Oct	0	13.4	90	395.6	0

Source: Forest inventory & Management unit, Forest Department

Table5: Extent of Forest fires in different forest types.

	Year-Extent of Damage (ha)						
Forest type	2006	2007	2008	2009	2010	2011	2012
Montane Forest	42	12.1		48		103	48
Sub- montane forest	33.48	15.1		163.5	138	36.4	12.5
Lowland rain forest				74			
Dry monsoon forest					108	155	184.5
Savannah	54.3				367	5	
Forest plantation	101.2	65.1	109	787.8	136	138	540.1
Total	230.98	92.3	109	1073	748	437	785.1

Source: Forest inventory & Management unit, Forest Department

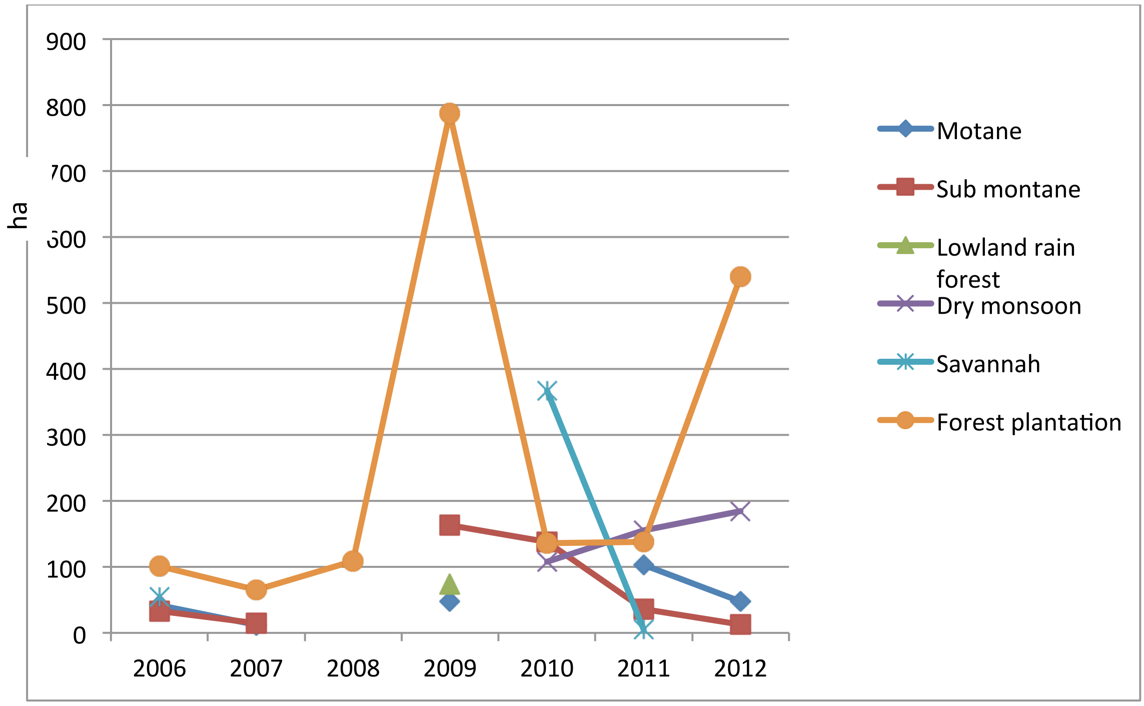


Figure3: Forest fire occurrence in different forest types

According to the Table5 and figure3, the highest forest fires occur in Forest Plantations. But after 2010, the dry zone forest (Dry monsoon forest) fire damages have also increased with time. It may be due to changes with probability of occurrence of rainfall from North East monsoon, high solar radiation, and wind velocity.

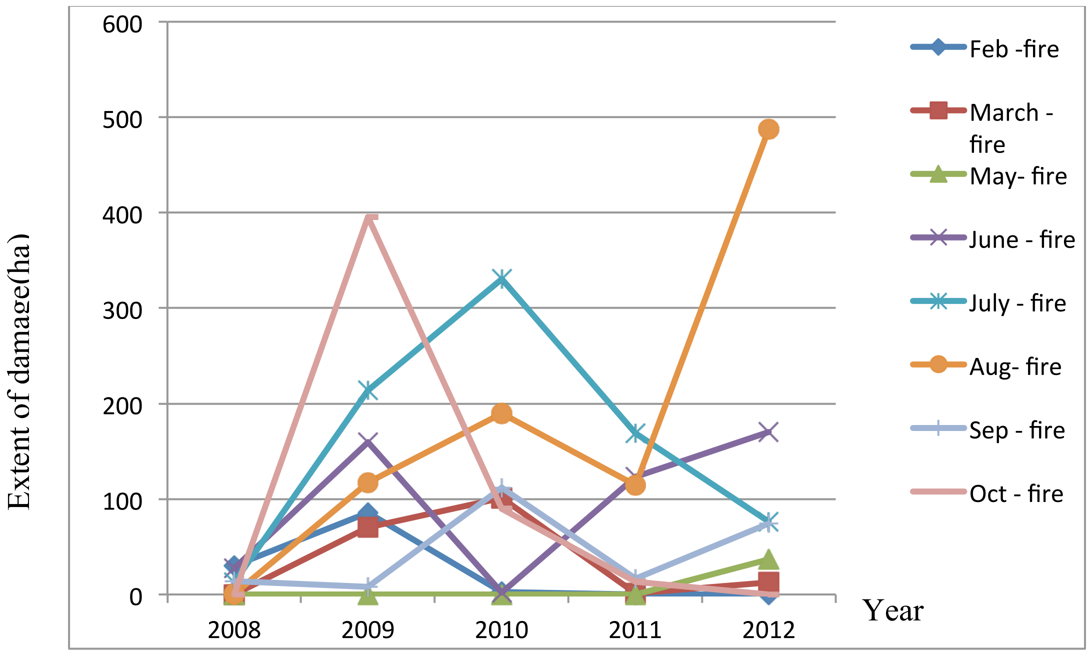


Figure4: Distribution of forest fires in different months of the year (2008 to 2012)

Table4 and the Figure4 show that the highest forest fire can be seen in July every year, except 2009, but in 2012, August the extent of damage from the forest fires was extremely high. This may have happened due to extreme dry period from July to August (2012) and the high wind velocity, followed by lower relative humidity (according to Metrological data, Metrological Department, Sri Lanka). So it may be assumed that the extent of damages from forest fires in month is dispersed to July and August.

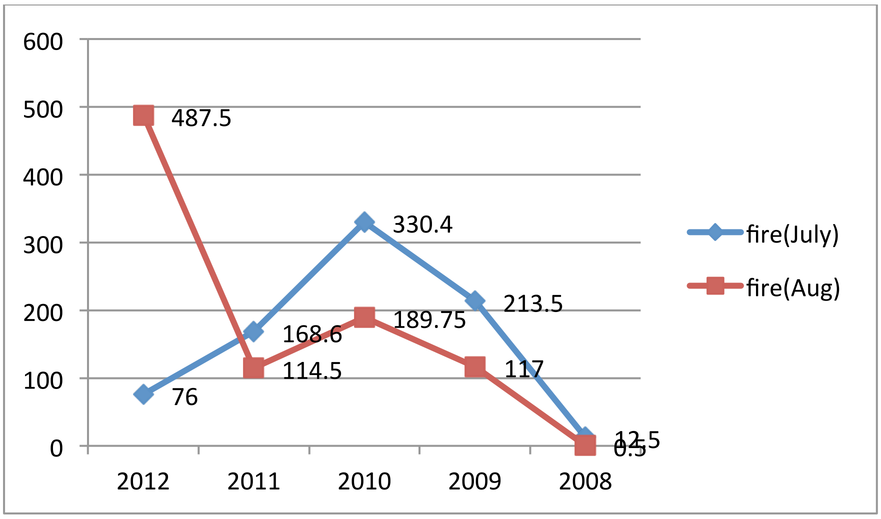


Figure5: Extent of forest fires on July, August from 2008 to 2012

According to the figure5 the extent of damage by the forest fires on August increased from 2008 to 2012. Most of the forest fires in Sri Lanka (about 75%) occur in Badulla, Nuwara Elliya, Matale and Monaragala District. Out of these districts Badulla, Mattale falls into up country intermediate zone (IU), Nuwala Elliya is the Up Country wet zones (WU), and Monaragala district is in low country dry zone (DL). Forest fires occurrence in Dry zone and intermediate zone are increasing in last few years. These may be happening due to increase of dry period, high wind velocity and the lower relative humidity, which may be happening mainly due to climate changes. Intensity also increases during daytime hours. Burn rates of smoldering logs are up to five times greater during the day due to lower humidity, increased temperatures, and increased wind speeds. Sunlight warms the ground during the day, which creates air currents that travel uphill. At night the land cools, creating air currents that travel downhill. Wildfires are fanned by these winds and often follow the air currents over hills and through valleys.

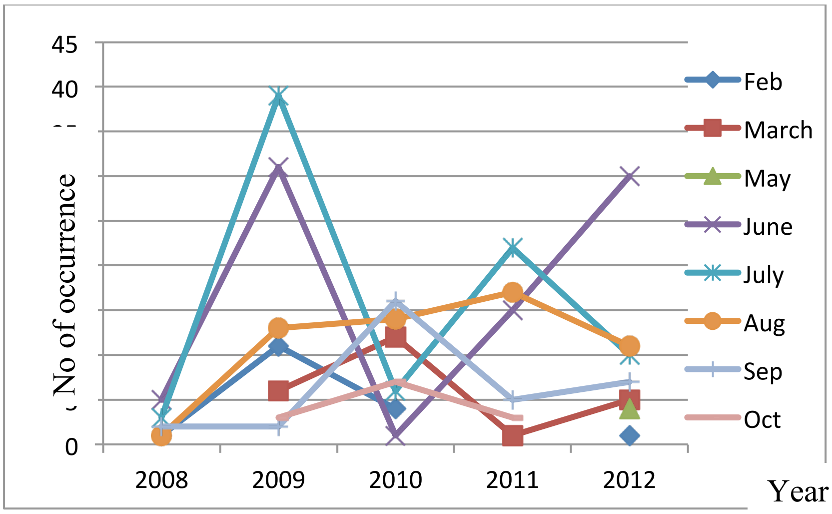


Figure6: No of occurrence of forest fires from 2008 to 2012

According to figure4 and figure6 the intensity of forest fire damages was extremely high in August 2012. (Comparatively, number of occurrences is low but the extent of damages were higher in August 2012)

Table6: Maximum Day Temperature in Badulla District

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	24.6	26.6	27.5	28.6	30.2	29.7	29.9	30.1	30.0	28.3	26.6	25.0
2009	24.8	26.8	29.2	29.1	30.5	31	31.3	30.2	30.6	29.8	26.1	25.1
2010	24.9	26.8	29.4	29.1	30.1	30.2	29.8	30.0	29.0	28.8	26.5	24.8
2011	23.3	25.0	27.6	28.9	30.1	30.8	30.5	30.5	31.2	28.9	26.2	24.9

Source: Meteorological Department, Sri Lanka

Table7: Monthly average rainfall in Badulla District (Intermediate Zone)

	Month											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2009	185.4	53.4	172	328.9	175	91.4	66.9	63.3	106	170.6	440	322
2010	68	17.4	171	223.6	35.9	18.2	10.3	149	7.9	253.7	291	337
2011	579.7	538.0	118.1	256.7	148.7	5.4	25.5	18.1	38.9	334.5	225.4	236.1
2012	57.4	105.0	50.8	268.1	0.4	69.0	33.2	38.4	103.1	214.5	262.5	313.8

Source: Meteorological Department, Sri Lanka

Heat waves, droughts, cyclical changes such as El Niño, and regional weather patterns such as high-pressure ridges can increase the risk and alter the behavior of Forest fire dramatically. Years of precipitation followed by warm periods can encourage more widespread fires and longer fire seasons. Forest fires are common in climates that are sufficiently moist to allow the growth of vegetation but feature extended dry, hot periods. Fires can be particularly intense during days of strong winds, periods of drought, and during warm months. Global warming may increase the intensity and frequency of droughts in many areas, creating more intense and frequent Forest fires.

Table8: Maximum Day Temperature in Monaragala District (Dry Zone)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	-9.9	-9.9	33.4	32.9	33.8	34.7	35.5	34.4	34.9	34.2	29.8	29.5
2010	29.6	31.3	34	33.7	33	33.5	33.9	33.8	32.6	32.6	30.8	29
2011	28.0	29.5	31.5	32.6	33.7	35.2	34.3	34.8	34.4	32.2	30.0	29.2

Source: Meteorological Department, Sri Lanka

Table9: Monthly average rainfall in Monaragala District

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	-9.9	-9.9	105.4	112.8	123.3	20	1.8	136.3	15.3	220.8	108.9	268
2010	96.9	23.8	168.8	178.3	315.3	49.8	23.9	156.4	165.5	165.5	370.8	129.6
2011	301.6	235.7	250.1	289.5	60.6	8.7	67	11.8	128.1	179.3	126.7	138.7
2012.0	68.9	129.5	66.0	289.9	25.7	tr	34.8	8.5	70.1	231.1	332.6	237.0

Source: Meteorological Department, Sri Lanka

Comparatively higher forest fires can be seen in Badulla district followed by Monaragala District, Matalle, and Nuwara Elliya District. Table 6and Table7, show that (for Example), Maximum day time temperature and monthly rain fall distribution for several years, according to those figures the Maximum temperature on the year can be seen on months of June and July. But towards the year 2011 – 2012, the Maximum temperature time duration is disperse August and September also dry period(less rainfall period), increase with the time(Table7, Disperse to August, September from July). As a result of that, the vulnerability of Forest for fires are increase (the data of forest fires in Badulla District also well fit with that time duration/ June, July period were disperse in to August and September).This occurrences are same for the almost all of the districts in Sri Lanka (Dry period increase, higher wind speed, lower relative humidity), which create forest in dry zone, more vulnerable to fires. These happenings are seen for the most forest fire areas. So it can be assumed that those things may be happen due to the climate change in the world.

Table10: Monsoonal and Inter-monsoonal Rainfall receiving variability

Monsoon	1931 to 1960(30 year period)	1961 to 1990 (30yr)
1st Inter-monsoon (March – April)	23%	27%
South West Monsoon (May – September)	21%	16%
2nd Inter-monsoon (Oct – Nov)	22%	23%
North East Monsoon (Dec – Feb)	31%	42%
Total	11%	14%

Source: Agriculture Department, Sri Lanka

Table10 show that the Annual rainfall receiving variability (There is more variability on rainfall in recent time). According to those figures, North East monsoon receiving variability is the higher variability, which received more rainfall in dry zone of Sri Lanka. According to the data of table 8 and 9 considerably dry period get increased and the sudden rainfall (very high intensity for shorter period) also happen , which create dry zone natural forest and forest plantation more risky for fires. Agriculture Department in Sri Lanka has Indentified, Climate change vulnerable district in Sri Lanka. According to this identification, Dry zone has more vulnerable for the climate change.

Forest fire vulnerable areas and forest types

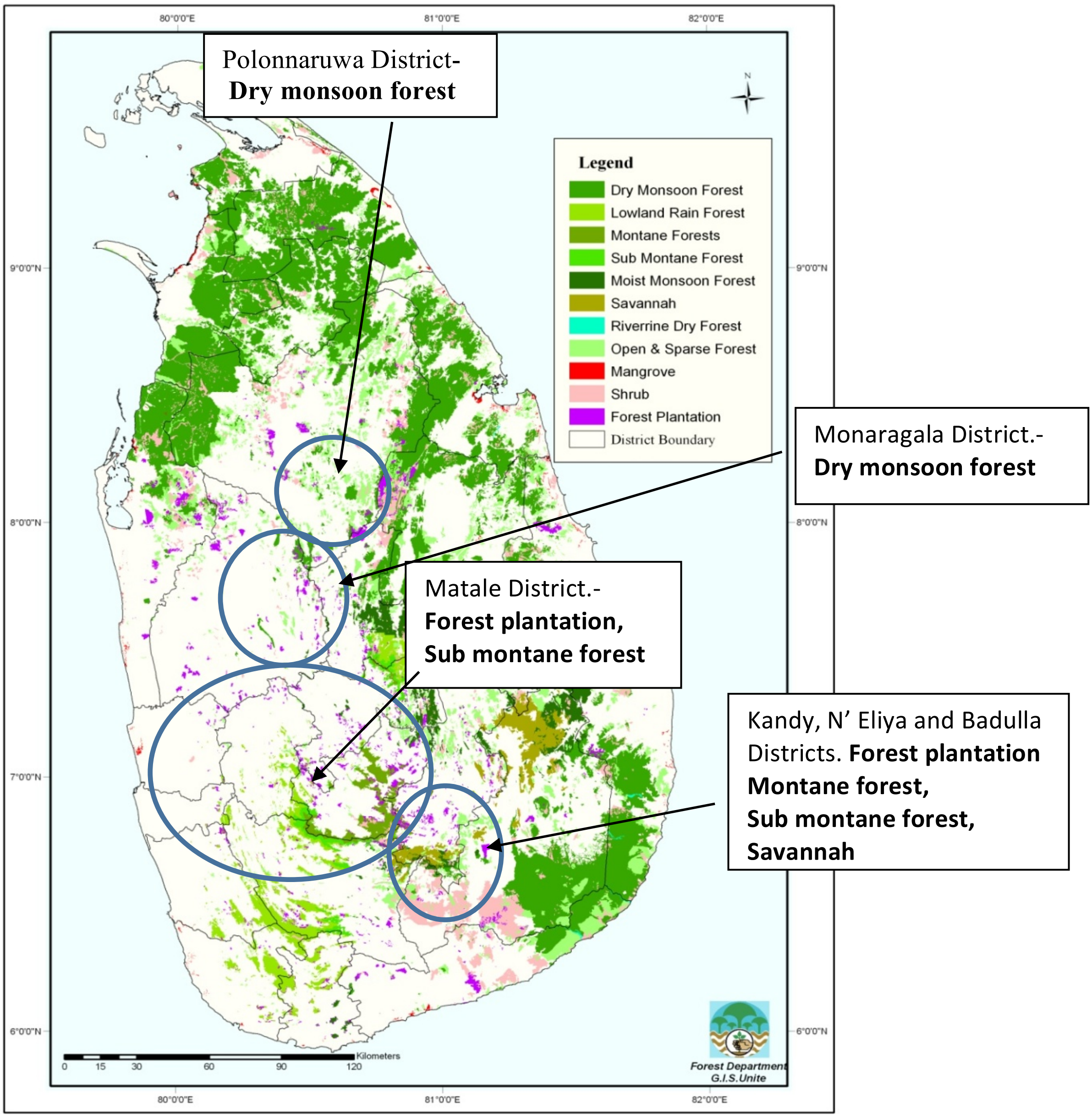


Figure7: Forest fire vulnerable areas and forest types

According to the forest fire data and metrological data, the highest forest fire vulnerable districts and the forest types are described on figure7.

According to the forest fire data and metrological data the highest forest fire vulnerable districts and the forest types are described on figure7.

Figure10: Forest fire in Central Highland, (2012

Adaptation for forest fires

- Forest fire prevention programs around the world may employ techniques such as wild land fire use and prescribed or controlled burns. Forest fire use refers to any fire of natural causes that is monitored but allowed to burn. Controlled burns are fires ignited by government agencies under less dangerous weather conditions. However, controlled burns are reportedly "the most effective treatment for reducing the rate of spread, fire line intensity, flame length, and heat per unit of area.
- Maintaining the existing fire belt and make new fire belts for the risky areas.
- Establish fire protection unit from the community who are more vulnerable from the forest fires.
- Maintain good network with the stake holder agencies such as Forest Department, Department of wild life conservation, Disaster Management Center, Forces (Army, Air Force) Pradeshiya Shaba, Divisional Secretariats, Non Government organizations, and Village Organizations. So it may be helpful for early detections of forest fires, uses for control measures, and finally to minimize the extent of damages of forest and other things (human beings, households, animal husbandry, Infra structures)
- Public awareness towards the forest fires and related activities should be increase by using field activities, training class.
- Punishment for the peoples who are involved for the forest fires by using existing rules and regulation. According to the statements of the Forest Ordinance, It is a punishable offence if the peoples are damage to the natural forest–Damage to the Conservation or Reserved Forest; the Offence is Fines judge by the judiciary and two years to five years jailed. For the other forest – Rs. 2500 to 25000 fines and one year to 4 years of jailed.

- Fast and effective detection is a key factor in Forest fire fighting. Early detection efforts were focused on early response, accurate results in both daytime and nighttime, and the ability to prioritize fire danger.

Prevention:

- Influencing on human behavior in order to prevent wrong uses of fire in the forest. This can be obtained by persuasion, through education, extension and information, co-operate between forest and agriculture aims and with law enforcement when necessary.
- Reducing the flammability of the forest in order to get self protection by decreasing ignition probability and spread of fire. This can be obtained by a set of silviculture activities known as fuel management.

Warning activities:

- Fire danger rating on meteorological data to make aware the protection organization of when, where and how the fires will burn, make public warnings, forbid or allow burnings.

Table11. For Forest type specific prevention/adaptation measure

Forest type	specific prevention/adaptation measure
Montane Forest Sub- montane forest Dry monsoon forest Savannah Forest plantation	Maintaining the exiting fire belt and make new fire belts, Establish fire protection unit from the community who are more vulnerable from the forest fires, Maintain good network with the stake holder agencies, Increase the awareness among the peoples by field activities, trainings. Punishment for the peoples who are involved for the forest fires, usage of Volunteers form youth groups to control of fires (University students, schools children's, youth senanka, etc), Strong and effective fire prevention campaign. Prevention implies public awareness, equipment and infrastructure preparation, enforcement and fire fuel management. Improve capacity and capability to prepare for forest fires, that have gaps in these attributes such as laws, policy, plans, practices and monitoring.
Sub- montane forest	Fire belts
Dry monsoon forest	Control burns,
Savannah	Control burns
Forest plantation	Selective thinning

Mitigation Measures:

Planting of fire resistant forest plant varieties where the places are more vulnerable for fires. (Replanting, enrichment planting).

Conclusion:

- Threat of forest fires in Natural forests as well as plantation forest are increasing with time because of the climate change occurrence, (specially dry zone and intermediate zone forest)
- Intensity of forest fire increase with the time, Due to dry weather, high wind speed, Lower Relative humidity.
- Fire seasons in the up country occur normally in February – March. But this duration seem to change with the time, as a result of happenings of climate change. Before 1990, Fire seasons in the up country occur normally in February – March but after 2000 this time period were disperse in to July to September.

References

Ministry of Lands and Land Development. Forest Resources Development Project, 1996, Forestry Master Plan for Sri Lanka, Annex III, Forest Fire Protection ,in Collaboration with Sri Lanka Authorities.

Pathirana.N.R., (1998) WanaWidhurawa, Forest Science article. 1998, May(page82 to 86)., Survey on Sri Lankan Forest Fires.

MaddhumabandaraS.W.L.,(2005) Ruk Article, 10th Episode 2005, 1st order , 23rdZone, page9 to12, Protection of forest from fires and strength the community experiences form the Nikawewa Reserved forest.

*en.wikipedia.org/wiki/Wild**fire**,* From Wikipedia, the free encyclopedia. This article is about uncontrolled outdoor fires.

Ariyadasa.K.P.,International Forest News, No 26, January – June 2002(Pages 96 to 100), Food and Agriculture Organization of the United State.

CLIMATE CHANGE AND ISLAND FORESTRY

Hussain Faisal
Assistant Director
Ministry of Fisheries and Agriculture
Maldives
hussfaisal@gmail.com

Summary

Climate Change and its changes are being felt around the world. An island nation that is merely just above sea level, Maldives faces and feels the changes more than some other countries. Changing weather patterns brings more torrential rain and sea swells. This encompassing with high winds is ideal situation for island erosion and destruction to the island dwellers. For centuries coral reef barrier and littoral forest has played vital role in the protection of the islands. Coral reefs are the first natural line of defence against the force of sea waves. Littoral forest is the second line of defence against waves and wind force. As the country develops, we have forgotten the important role that these factors have been playing in the protection of the island that we live on. In the name of development we have been cutting down the littoral forest and damaging the coral reefs. But as the world faces the climate change phenomenon, ironically we are back to protecting the natural barriers that once were important for protection. Littoral forest with other structures can play instrumental role in the protection of the island from the changes whilst keeping the natural environment and serenity of the islands.

Background

The Republic of Maldives is comprised of 1,192 small, low-lying coral islands in the Indian Ocean. Some 200 islands are inhabited, another 105 islands are tourist resorts, and 80 are reserved for industrial use. Only 28 inhabited islands have land area of more than 100 ha. Eighty percent of islands have an elevation of less than one meter above the sea level, and the average elevation of all the islands is 1.5 meters above the sea level.The islands exist as a chain of coral atolls, stretching 900 km from latitude 706’35”N, crossing the Equator to0042’24”S, and lying between 72032’19”E and 73046’13”E longitude. The total land area of the Maldives is estimated at around 30,000ha. The islands are surrounded by coral reefs, which protect these islands from the impacts of strong waves and other such effects. The Maldives enjoys a warm and humid tropical climate, with the weather mainly being dominated by two monsoon periods: the southwest monsoon (the wet period, from May to November); and the northeast monsoon (the dry period, from January to March).

The islands of the Maldives have been known to be inhabited for up to 2,500 years. The population of the Maldives, according to the latest census, is 350,000 with an annual growth rate of 1.96%. About 25% of the total population resides in the capital, Malé, where most of the economic and commercial development activities take place. The main contributors to the economy are tourism, fisheries, constructions and commercial sectors. The tourism and fisheries sectors are very much dependent on the coastal environment of Maldives.

The forest area of Maldives is not known. The Global Forest Resources Assessment of 2010 estimated the forest area at 1,000 ha, and the Agricultural Development Master Plan (2006-2020) of Maldives quotes an estimate of 3,716 ha of forests. These estimates do not apparently include coconut groves that are by far the most common formations of woody vegetation in Maldives. Coconut groves in Maldives are typically mixed formations of various trees and bushes dominated by coconut palms. Littoral forests and bushes have an important role in coastal protection.

"The planet's warming is unequivocal, its impact is clearly noticeable and it is beyond doubt that human activities are contributing to it... We cannot afford to ignore or underestimate this existential threat. Failure to combat climate change will increase poverty and hardship" UN SG Mr. Ban Ki- Moon

The Maldives today is faced with unprecedented challenges unwitnessed by previous generations of Maldivians. One such challenge is the impact of climate change. Climate change threatens the very existence of the low-lying small coral islands which we call home, and poses significant threats to the survival of our society, cultures and traditions which have since time immemorial co-existed harmoniously with the fragile island ecosystem. Furthermore, climate change threatens to remove the very lifeblood of our economy; our treasured coral reefs and oceans on which our most important sectors- the tourism and fisheries industries are based on. In this regard, the Maldives is among the most vulnerable and least defensible countries to the projected impacts of climate change and associated sea level rise.

The Maldives being a fragile low lying small island ecosystem, it is very vulnerable to climate change and its associated impacts especially the predicted sea level rise. Although the Maldives contributes minimally to the global greenhouse gas emissions: 0.001% (MHAHE 2001), it is among the most susceptible to impacts of the changes in climate.

Maldives is located at the equator and experiences monsoonal climate. Maldives has two distinct seasons; dry season (northeast monsoon) and wet season (southwest monsoon). In these two seasons, the temperature varies hardly. Northeast monsoon extends from January to March. Since Maldives consists of small islands and are surrounded by seas, hot days are often tempered by cool sea breezes and balmy evening temperatures. Throughout the year, temperature remains almost same in the Maldives. However, daily temperature ranges from around 31 degrees Celsius in daytime to 23 degrees Celsius in nighttime. The mean daily maximum temperature for Central parts (Hulhule) of the Maldives is 30.5 degrees Celsius and minimum temperature is 25.7 degrees Celsius. On the other hand, mean daily maximum and minimum temperature for South (Gan) is 30.9 and 24.5 degree Celsius, respectively. Furthermore, mean daily maximum and minimum temperature for North (Hanimaadhoo) is 30.7 and 25.2 degrees Celsius, respectively. The highest temperature ever recorded in the Maldives was 36.8degree C recorded on 19 May 1991 at Kadhdhoo Meteorological Office. Likewise, the minimum temperature ever recorded in the Maldives was 17.2degree Celsius, recorded at the National Meteorological Centre on 11th April 1978. The wet season- southwest monsoon runs from mid-May to November. In this season Maldives experiences torrential rain. Central, Southern and Northern parts of the Maldives receive annual average rainfall of 1924.7mm, 2277.8mm, and 1786.4mm, respectively. The highest rainfall ever recorded in the Maldives within 24 hour period was recorded on 9th July 2002 at Kaadedhdhoo Meteorological Office and amounts to 219.8mm of rainfall. The fact that the Maldives is located at the equator, Maldives receives plentiful of sunshine throughout the year. On average Southern atolls (Gan) of the Maldives receives 2704.07 hours of sunshine each year. Furthermore, on average central (Hulhule) parts of the country receives 2784.51 hours of sunshine per year.

Islands forest of Maldives

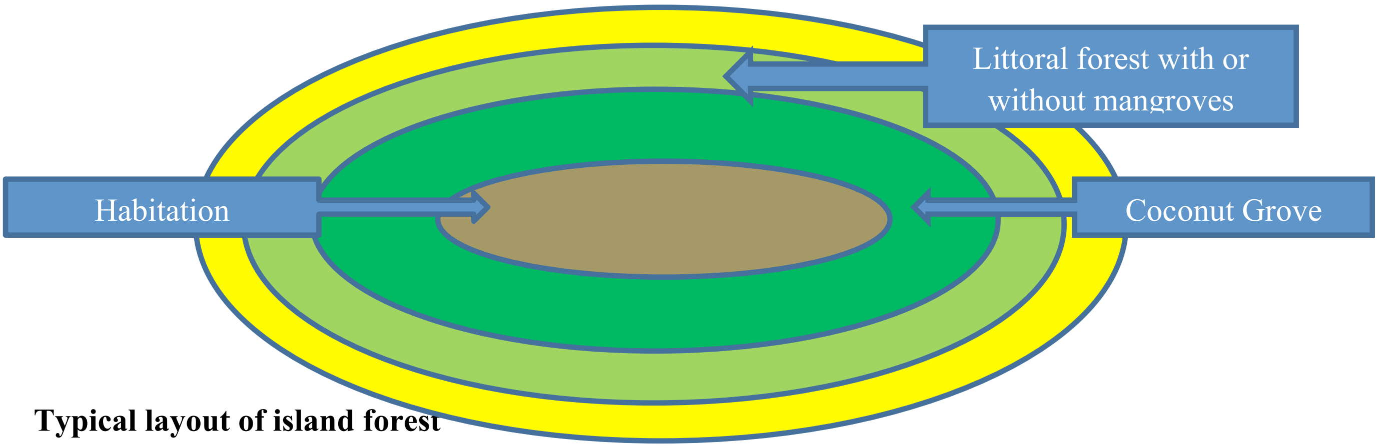
Island Forestry

The main types of forests in the Maldives are littoral forests and mangroves and some inland forests (locally referred to as "jungle") with larger trees. The littoral forests are dominated by species in the *Scaveola* and *Suriana* group, which are saline tolerant. Mangroves occur only in some of the islands and are dominated by species in the Rhizophoraceae family.

The littoral forests and mangroves are used by local communities to supply wood for boat building and other needs. There is considerable demand for wood for boat building, particularly in the northern islands. Species used in boat building include: *Hibiscus tiliaceous* (sea hibiscus, known as "dhigga" in Dhivehi, the local language), *Ochrasia barbonica* (cork wood; dhunburi) *Calophyllum inophyllum* (Alexander laurel; funa), and *Diospyros ebenum* (ebony; kalhuvakaru) and *Tectona grandis*(teak; haivakaru). Some of the wood is available from local forests in the north, but this is supplemented by wood imported from outside the Maldives. In the southern islands, there is less demand for boat building wood, as the islanders prefer fiber reinforced plastic (FRP) boats. Some wood is used even for building the FRP boats, some of which is sourced locally. Demand for firewood is comparatively low, since coconut refuse is widely used for fuel, and kerosene and cooking gas are easily available in many places. The country is heavily dependent on imports to meet most of its timber needs for construction, furniture and other uses.

The forest area of the Maldives is not known. The Global Forest Resources Assessment of 2005[1] estimated the forest area at 1000 ha, and the Agricultural Development Master Plan (2006-2020)[2] of the Maldives estimates 3716 ha of forests. These estimates do not apparently include coconut groves that are by far the most common formations of woody vegetation. Coconut groves in the Maldives are typically mixed formations of various trees and bushes dominated by coconut palms.

Maldives forests, although not distributed extensively given the limited land area, comprise littoral forests along with mangroves, coconut groves, ponds and lagoons. The littoral and mangrove forests perform multiple functions by acting as shelterbelts and windbreaks, preventing soil and beach erosion and lessening the effect of flooding during tsunamis and storm surges. Extensive coconut groves provide livelihood security for islanders. All the islands have a tapering beach on one flank and an abrupt coral beach on the other. The vegetation pattern is described in Figure 1. Mangroves are not found on all the islands.



Typical layout of island forest

Challenges

Coastal forests

The island vegetation is characterized by the presence of littoral forest for a width of 15 to 20 meters followed by small-scale mangrove on a few islands and coconut forests and home gardens. However, depending on the width of the island, these profiles differ. If the island is wider, the protection by forests is also relatively greater. The coastal forests are more or less uniform in their composition and structure throughout the Maldives. There is a dense growth of forest vegetation along the coasts with clear zonation in the distribution of different species. *Scaevola taccada*(Magoo) is a common and dense thicket-forming plant species, which is widely distributed. *Pemphis acidula*(Kuredhi), *Thespesia populnaea*(Hirundhu), *Pandanus tectorus*, *Guettarda speciosa*(Uni), *Calophyllum inophyllum*(Funa), and *Suriana maritima*(Halaveli) together form a dense shield protecting the islands from salt spray, storms, monsoon winds and beach erosion and played a critical role in mitigating the 2004 tsunami's damage. In some areas, pandanus forms a thick network with *Guettarda speciosa* and *Calophyllum inophyllum*to the landward side. Coconut groves are distributed like forest with dense growth across the islands. Mangroves are confined to a second line in the coast and are distributed in small swampy areas.

Causes and issues for littoral forest erosion

Coral and sand mining for urbanization and house construction are the main causes of coastal area/beach erosion. This is disturbing the littoral vegetation. Local people are aware of the consequences but the economic situation and the high cost of importing sand and lack of suitable low cost material forces them to practice sand mining.

Availability and supply of wood for boat building

There is high demand for boat building wood, particularly in the northern islands. *Hibiscus tiliaceous, Ochrasia barbonica,* (Dhunburi) *Calophyllum inophyllum* (Funa), *Diospyros ebenum* (Kalhuvakaru) and *Tectona grandis* (Haivakaru) are used. In addition to harvesting wood from locally available trees, wood demand, particularly for ebony and teak, is met from imported wood. There is less demand for boat building wood in the southern islands, as the islanders prefer Fibre Reinforced Plastic (FRP) boats. However, even for building FRP boats, wood from the forests is used. In Foamullah, trees are felled for boat building purposes.

Forests and climate change
The 7th National Development Plan has addressed the issue of climate change and the predicted sea level rise which is of grave importance to the Maldives. The estimated predicted sea level rise of 0.09 m to 0.88 m in the period between 1990 and 2100, combined with increased extreme weather events like the recent tidal wave and storm surges that affected large numbers of islands, makes the Maldives one of the most vulnerable countries to climate change and sea level rise. The small size of the islands forces human settlements and vital infrastructure to be located near the coast and thus existing at high risk. There is a need to include climate change prediction in future land use planning and community development plans.

Also, their small size and low lying nature make the Maldives islands very vulnerable to environmental threats. At the same time the coastal environment is very sensitive to changes in the coastal area from any development activity. The Maldives is a party to the United Nations Framework Convention on Climate Change (UNFCCC) and is the first country to sign the Kyoto Protocol. The Maldives submitted the First National Communication to the UNFCCC in 2001. However as a non-Annex 1 party to the UNFCCC, Maldives is not obliged to implement mitigation measures. But there is a need for the Maldives to be exemplary in implementing mitigation measures. The Government of Maldives has taken steps by introducing the Safe Island concept for islands vulnerable to calamities like storm surges and monsoon winds and rare events like tsunamis.

Vulnerability of Climate Change
The Maldives is vulnerable to the following climatic hazards:

Rise of Sea level Rise
The observed long term trend in relative sea level for Hulhulé is 1.7mm/year. The maximum hourly sea level is increasing by approximately 7mm/year, a rate far in excess of the observed local and global trends in mean sea level. For Hulhulé an hourly sea level of 70cm above mean sea level is currently a 100-year event. It will likely be at least an annual event by 2050.

Decreasing the amount and increasing the intensity of Rainfall
Currently a daily rainfall of at least 160mm is a relatively rare event at Hulhulé, with a return period of 17 years. An extreme daily rainfall of 180mm is currently a 100-year event. It will likely occur twice as often, on average, by 2050. An extreme three-hourly rainfall of 100mm is currently a 25-year event. It will likely become at least twice as common, on average, by around 2050.

Increasing the Minimum and Maximum Temperature
There is relatively high confidence in projections of maximum temperature. The annual maximum daily temperature is projected to increase by around 1.5°C by 2100. A maximum temperature of 33.5°C is currently a 20-year event. It will likely have a return period of three years by 2025.

Increasing the intensity and frequency of the Extreme Events
The predicted return periods for cyclonic activity based on historical records of wind data: Currently an extreme wind gust of 60 knots has a return period of 16 years. It is estimated

that this will reduce to 9 years by 2025. Presently, the maximum storm surge height is reported to be 1.32m with a return period of 500 years in the Maldives. When storm surges coupled with high tide, it could generate a storm tide of 2.30m which is disastrous to islands which have a mean elevation of 1 – 1.5 m above the mean sea level. Increasing the frequency of such storms would put pressure on to the natural balance of the islands and would cause overtopping of the existing coastal structures on the island. The impact of climate change on the islands in terms of flooding increases from north to south (Jameel, 2006).

Impacts of Climate Change

The following key vulnerabilities have been identified as part of the NAPA process.

1. Land, beach, and human settlements

Maldives is the sixth smallest sovereign state in terms of land area, estimated to be approximately 235 sq km. This land is divided over some 1,200 coral islands, of which 96 percent are less than 1 square km in area. Only ten islands are more than 2.5 square km; and the largest island, Laamu Gan, has an area of 6.1 square km. At present, 44 percent of the settlement footprints of all islands are within 100 m of coastline. This translates to 42 percent of the population and 47 percent of all housing structures being within 100 m of coastline. Over the last six years more than 90 inhabited islands have been flooded at least once, and 37 islands have been flooded regularly or at least once a year (Shaig, 2006).

The beaches of the Maldives, which represent 5 percent of the country's total land area, are of an unconsolidated nature and naturally dynamic and unstable. More than 97 percent of inhabited islands reported beach erosion in 2004, of which 64 percent reported severe beach erosion. More than 45 percent of the country's 87 tourist resorts have also reported severe erosion (Shaig 2006).

The scarcity of land, the smallness of the islands, and their extreme low elevation all make retreat to inland or to higher ground impossible. Building setback has limited utility and beach replenishment may only be a temporary remedy for beach loss. Unless expensive coastal protection measures are undertaken, human settlements face the threat of inundation.

Decreasing area of littoral forest is a major challenge in combating beach erosion and climate change. As the islands are developed the littoral forests are being cleared for harbor and other infrastructure development. This is very clear in many islands.

Way Forward

Despite the challenges, as a country Maldives is moving ahead. As such we still see opportunities in the face of all the challenges.

Discussion about Climate Change and Global Warming is such a hot topic that everyone is aware of the brunt truth that is to be faced by Maldives. So much awareness has been created in the communities about these topics that everyone knows about it. Ironically communities are unaware or blissful about the role of forest especially littoral forest played in the protection of the island communities. Thus more awareness programs needs to be conducted in the island communities and pilot projects needs to be developed to scientifically compile the affects and role of littoral forest in climate change.

Under the costal management soft and hard adaptive structures are to be developed in the islands. In either case, littoral forest will play a vital role in the protection of the islands from natural calamities, especially erosion. More reforestation activities need to be undertaken using the naturally found varieties. This will ensure a more robust foundation to tackle island erosion with other structures.

Environmental policy: Section 3.8 of the National Biodiversity Strategy and Action Plan defines the vision and guiding principles for the environment sector, whose elements can be interpreted as an expression of forestry sector policy. The vision states that the Maldives is a nation which appreciates the true value of the natural environment, utilizing its natural resources in a sustainable manner for national development. Conservation of biodiversity, equitable sharing of the benefits, and building capacity for learning from the environment are also aspects of the vision. The guiding principles realize the dependence of the people on the nation's biological resources and the need to conserve them; the necessity to share the benefits equitably; economic cost-benefit assessment; the need to integrate environmental considerations as cross-cutting issues in the economic development policies and plans; and appreciation of community participation, accountability and transparency in plan implementation. Further, the principles state that ecological sustainability should be a major goal in national development; efficient and prudent management of natural resources is fundamental; an integrated ecological approach is needed; and finally, the action plan will be a part of an interactive process to be monitored and reviewed regularly. All the above principles appear to be conducive for sustaining forest cover.

Erosion in the islands

References

UNDP(2006).Developing a Disaster Risk Profile for Maldives. Male, United Nations Development Programme Maldives.

Shaig, A. (2006). Climate Change Vulnerability and Adaptation Assessment of the Coastal Infrastructure of Maldives. Technical Papers of Maldives National Adaptation Plan of Action for Climate Change. Male, Ministry of Environment, Energy and Water.

Shaig, A. (2006). Climate Change Vulnerability and Adaptation Assessment of the Land and Beaches of Maldives. Technical Papers to Maldives National Adaptation Plan of Action for Climate Change. Male′, Ministry of Environment, Energy and Water.

Dr. Ravishankar (2005), Forestry Assessment and Programme Planning Maldives

SESSION 3 – IMPACTS, VULNERABILITY AND ADAPTATION MEASURES

The session was chaired by **Dr. N.S. Bisht** and the two papers were presented.

Discussion

1. **Likely impacts of Climate Change on Forests of Western Himalayas and Adaptation Strategies**

Dr. Mohit Gera explained about climate change modeling studies conducted by IISc Bangalore, projected global average surface temperature changes, mean sea level rise, evidences and likely impacts of climate change on forest biodiversity. He stressed the need for establishment permanent plots for long term observation on the impact of climate change and also to take provenance trials to test the adaptability of the species, developing resistant varieties, rehabilitation of degraded forests and afforestation of waste lands to reduce the pressure on natural forests. He also pointed out the need for enhancing and strengthening of protected area network.

2. **Climate Change and Forests in India: Impacts, Vulnerability and Adaptation Options**

Dr. Renu Singh in her presentation explained about the contribution of forests to the national economy, wealth of biodiversity, vulnerability of the forest ecosystem to the climate change, emerging challenges and adaptive measures to be taken to integrate forest policy and planning, the Green India Mission and its role.

Discussion: Mr. Mohan Heenatigala from Sri Lanka enquired about the climate change modeling and Dr.Mohit Gera briefed about modeling procedure.

LIKELY IMPACTS OF CLIMATE CHANGE ON FORESTS OF WESTERN HIMALAYAS AND ADAPTATION STRATEGIES

Dr. Mohit Gera, IFS
Additional Professor, IGNFA
P.O. – New Forest, Dehradun, INDIA
mohitgera87@gmail.com

Abstract

The Fifth Assessment Report of Intergovernmental Panel on Climate Change concluded that the global surface temperatures have risen by almost 0.89°C over the period 1901–2012 and about 0.72°C over the period 1951-2012 and it is extremely likely that the human activities have caused more than half of the observed increase in temperature during 1951-2010. Since life cycles of forests range from decades to centuries, they are likely to be seriously impacted by the changing climate. The studies on likely impacts of changing climate on forests still remain inconclusive and there is a lack of certainty on a clear view of future climate and forests. Based on the scientific literature available, the likely impacts of climate change on forests of Western Himalayan region with special focus on state of Uttarakhand, India is presented here along with existing pressures on forests and suggested adaptation strategies.

Keywords: Climate Change, Vulnerability, Uttarakhand, Adaptation

Introduction

As per fifth assessment report of Intergovernmental Panel on Climate Change, the global surface temperatures have risen by almost 0.89°C over the period 1901–2012 and about 0.72°C over the period 1951–2012 and it is extremely likely that the human activities have caused more than half of the observed increase in temperature during 1951-2010 (IPCC, 2013). The report has predicted that relative to the reference period of 1986-2005, the global surface temperature by the end of 2100 is likely to be in the range of 1.5°C to 4.5°C and in the range of 0.3°C to 0.7°C for the period 2016–2035. This would cause further warming and induce many changes in the global climate systems during the 21st century that would very likely be more severe than those observed during the 20th century.

A scientific study from Indian Network for Climate Change Assessment (INCCA, 2010) for 2030s indicates an all round warming over Indian subcontinent associated with increasing GHGs concentrations. The study further indicates that the mean annual temperature is likely to increase in the Himalayan region from 0.9°C to 2.6°C with respect to the baseline, which is the average for the period between 1961 to 1990 and a rise in temperature is predicted for all seasons. The annual rainfall in the Himalayan regions is likely to vary between 1268 and 1604 mm, which is an increase by 5% to 13% with respect to the baseline. The extreme temperatures are also likely to rise by 2030s, which may be by 1°C to 4.5°C for minimum temperatures, and 0.5°C to 2.5°C for maximum temperature. The number of rainy days in the Himalayan region may also increase by 5 to 10 days on an average; and the intensity of rainfall is also likely to increase by 1-2 mm/day.

Forests provide a wide range of ecological, social and economic benefits, in the form of goods and services to society that are much less easier to quantify. In particular, forests provide livelihood and are especially important for the large number of forest-dependent communities.

Forests are the most vulnerable climate dependent systems especially in the tropics, boreal and mountain areas. The most recent report from the International Union of Forest Research Organizations (**Seppälä *et al.* 2009**) paints a rather gloomy picture about the future of the world forests in a changed climate, as it suggests that in a warmer world the current carbon regulating services of forests as carbon sinks may be entirely lost as land ecosystems could turn into a net source of carbon dioxide later in the century.

According to the IPCC, roughly 20–30% of vascular plants on the planet are estimated to be at an increasingly high risk of extinction as temperatures increase by 2–3°C above pre-industrial levels **(Fischlin *et al.* 2009)**. Even small changes in climate could affect phenological events such as flowering and fruiting that may escalate into major impacts on forest biodiversity. This is because co-evolution has produced highly specialized interactions among specific plant and animal species in natural forests. Overall, it is very likely that even modest losses in biodiversity would cause consequential changes in the ecosystem services that forests provide. Climate change affects forest ecosystems in their structure and morphology, thus causing an impact on their functionality. Vulnerability analysis of forest ecosystems in the national communications demonstrates that climate change can significantly affect the availability of forest goods and services in terms of quality and quantity **(MoEF, 2012)**. India is one of the key countries with respect to tropical region, with around 20% of the geographic area classified as forests (FSI, 2011). As per an earlier study using BIOME4 vegetation model under the climate projection for the year 2085, more than two-third forest vegetation in India is projected to be vulnerable to changing climate **(Ravindranath *et al.* 2006)**.

Adaptation measures are planned responses aimed at reducing the vulnerability of a system. It is an adjustment in human and natural systems in response to actual or expected climate stimuli or their impacts that moderate harm or exploit beneficial opportunities **(IPCC, 2007)**. The need to include adaptation into forest management and policies is becoming increasingly recognized, especially in tropical and temperate areas. In particular, forest stakeholders face challenges related to understanding vulnerability, identifying adaptation options, and implementing adaptation strategies.

Uttarakhand as a State

Uttarakhand is an Indian Himalayan State situated in the north of the country. It constitutes part of Western Himalayan ranges, which extend from Shivalik foothills to Great Himalayas. The State is strategically important as it shares its north-eastern border with China and two of the most important rivers of the subcontinent i.e. Ganga and Yamuna originate here. It covers 10.3% geographical area and represents 21.40% population of Indian Himalayan Region (IHR). Being the part of IHR, its geological formations are fragile and weak, which makes large area prone to earthquakes, landslides and other disasters. It is largely a mountainous region with an altitude range varying between 300 m to 7817 m. This altitudinal variation has resulted in diversity in topography, flora, fauna and occupational patterns in the State.

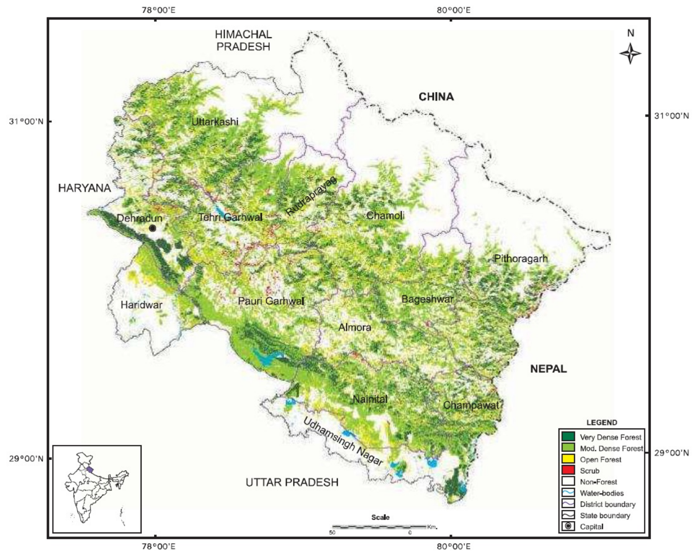


Fig. 1: Forest cover map of Uttarakhand (Source: ISFR, 2011)

The State is a rich repository of natural resources, forests being an important part of them. Recorded forest area is 3.47 million hectares, which constitute 64.79% of the total geographical area of the State (Fig.1). Out of the sixteen Major types of forests in India, eight types exist in the State, which indicate diversity of different ecological biomes in the State. Forests play a complimentary role to agriculture including animal husbandry, which is the major occupation and supports livelihood of 80% of the population.

Forests of the State provide various ecosystem services, which flow beyond the confines of the State and contribute to the welfare of the entire country. Some of the important services are climate regulation, water regulation and recharge, biodiversity conservation and carbon storage, which are relevant at regional and even at global level. One of the most critical functions of the forests in the State is protecting the upper catchments of Ganga and Yamuna. These rivers provide water to millions of people, used for drinking, irrigation, and industrial purposes. Forests are also ecologically important as they are home to a number of endemic plant and animal species.

Despite their utility and ecological importance, forests in Uttarakhand are degrading due to a number of pressures like diversion of forest lands for developmental purposes, unsustainable harvests of forest products, encroachments, forest fires and biotic interferences. The adverse impacts of climate change will be an additional pressure on the forest ecosystems of the State. This paper discusses the likely impacts of Climate Change on the forests of Uttarakhand in light of available scientific knowledge. It also highlights the pressures on forest resources and suggests strategies for reducing vulnerability and adapting to the likely impacts of changing climate on forests in the State.

Status of forests in Uttarakhand

The recorded forest area of Uttarakhand is 34,651 km^2, which constitutes 64.79% of its total geographical area. By legal status, Reserved Forests constitutes 71.11%, Protected Forests 28.52% and Un-classed Forests 0.38% **(IFSR, 2011)**. The major forest types are the moist alpine scrub, sub-alpine forests, Himalayan dry temperate forests, Himalayan moist temperate forests, sub-tropical pine forests, tropical dry deciduous forests, littoral and swamp forests, and tropical moist deciduous forest.

The total forest cover in the State is 24,496 km^2, which represents 45.80% of its total geographical area **(ISFR, 2011)**. The region is endowed with very rich flora and fauna. The forests are unique with spectacular plant groups such as conifers, rhododendrons, orchids, oak, maple and many other species. Forests of the State support a wide range of biodiversity. The region has six national parks, six wildlife sanctuaries, one biosphere reserve, one UNESCO world heritage site, and two elephant ranges.

Likely impacts of Climate Change on forests of Uttarakhand

Only a few studies are available, which address the likely impact of climate change on forests of India. However, there is no comprehensive study available for the State of Uttarakhand. The earliest study conducted on the forests of adjoining State of Himachal Pradesh by Stockholm Environment Institute in partnership with The Energy and Resources Institute (TERI) is relevant to Uttarakhand because of similar geography and vegetation patterns. This study has used BIOME model and the GCM based climate scenario prepared by University of East Anglia, UK. The study forecasts that even under moderate climate change conditions, many important biomes and forest types are expected to show significant changes in Himachal Pradesh **(Deshingkar *et al.* 1996)**. Time series projection of the model indicate that temperate deciduous, cool mixed and conifer forests are likely to migrate and undergo changes in area by middle of 21st century. By 2080, the meadows in higher part of Himachal Pradesh are expected to shrink drastically and the area under temperate deciduous and cool conifer forests is predicted to decrease over time, with temperate deciduous forests in the lower limits being replaced by evergreen warm mixed forests. Chir pine is likely to emerge as the dominant species in the temperate deciduous forests. The study also forecast changes in species composition, increased occurrence of fire, erratic rainfall and decline in socio-economic important species like deodar, fir and oak due to increased climatic and biotic interactions.

Another study by **Ravindranath *et al.* 2006** on analysis of the 35,190 forested grids at national level reports that more than two third forested grids are likely to undergo vegetation change by the year 2100. Almost all major forest types of Uttarakhand, viz., Fir-Spruce, Sal, Chir-pine, Fir, Blue pine, Mixed Conifers etc. are likely to be impacted by the projected climate change. The actual impacts may be more as different species respond differently to the changing climate. A few endemic species may show a steep decline in population and may even get extinct. These impacts are expected to have adverse socio-economic implications for the forest-dependent communities and the economy of the State. Moreover the impacts of climate change on forest ecosystems are likely to be long-term and irreversible. The study further reports that the average net primary productivity (NPP) is projected to increase by 1.5 times for tropical evergreen forests but the rate of increase is expected to be lower for temperate deciduous, cool conifer and cold mixed forests.

A study by **Singh, 2007** reports that increase in temperature would lead to shifting of many species to the higher altitudes, which will result in smaller populations of these species due to unavailability of soil and space at higher altitudes. Some of the plant species like Oak (*Quercus semicarpifolia*), Birch (*Betula utilis*), some of rhododendrons; and animal species like pikas, snow leopards and brown bears might even get extinct. Preferred fodder species like Bhimal (*Grewia optiwa*) and Kharik (*Celtis australis*) is likely to shift to higher altitudes. These changes would result in shifting of the human populations at higher altitudes as well, which will have a negative influence on the biodiversity of the ecosystem.

Another study conducted by **TERI, 2003** based on people's perceptions in Uttarakashi Forest Division of Uttarakhand reports a number of changes in the vegetation over the last 20 to 50 years. Major changes noticed are phenological and related to the composition of the forests. For example, it has been observed that Rhododendron has started flowering early by around 15 days over the last 15 years. Likewise early sprouting of leaves and fruiting has been reported in Oak (*Quercus leucotricophora*). There have been reports of changes in the species composition of forests in the area. It has been reported that Chir pine is replacing Oak in the division. Oak is a multipurpose tree, which is used for fuel wood, fodder and for making agricultural implements whereas Chir pine is primarily used for timber by local people. Also, Oak allows growth of under storey vegetation whereas Chir pine does not allow under storey vegetation because of excessive shedding of its needles on the forest floor. Hence, these slow changes are affecting biodiversity of the forests and are likely to adversely impact the livelihood of the forest dependent communities.

The climate modeling for likely impacts of climate change on natural ecosystems and biodiversity in Himalayan region by Indian Network for Climate Change Assessment has shown that out of the 98 vegetation grids covering the Himalayan region, 56% of the grids are projected to undergo change in vegetation by the 2030s indicating that more than half of the vegetation and biodiversity is vulnerable to the impacts of climate change. The Net Primary Productivity is, however, projected to increase in the region by about 57% on an average by the 2030s, as compared to the baseline. **(INCCA, 2010)**.

Another recent study has also reported that a significant part of the Himalayan biodiversity hotpots that stretches along the north-western part of India along the States of Jammu & Kashmir and Himachal Pradesh is highly vulnerable to the likely impacts of changing climate **(Gopalkrishnan *et al.* 2011)**. The study has shown that low tree density and biodiversity status as well as higher levels of fragmentation contribute to the vulnerability of forests. The mountainous forests of north-western Himalayan region are susceptible to the adverse impacts of climate change as likely climate change is predicted to be larger for regions with greater elevations.

Pressures on forest resources of Uttarakhand

It is estimated that 5,14,300 ha of forestland is highly degraded in the State of Uttarakhand **(UEPPCB, 2004)**. The degraded forest area actually may be higher than the official estimates in the State. There are a number of geographical, demographic and socio-economic factors responsible for this degradation. In addition to the fragile ecosystems, increasing population with low agricultural production, large and unproductive bovine population, degraded community forests and restricted means of livelihoods constitute a vicious cycle of poverty resulting in tremendous pressure on forests in the region. Some of the major drivers of deforestation and forest degradation, which play significant role towards increasing the vulnerability of forests, are discussed below:

i. **Unregulated removal of wood**

The population in the State is heavily dependent on the forests of the region for timber and fuel wood. Around 87% of the households use timber for house construction. This demand along with informal removals puts a tremendous pressure on forests of the State. Likewise, fuel wood accounts for 90% of the source of domestic energy and is especially important to rural people (UEPPCB, 2004). This dependence keeps on increasing with increasing altitude as cooler climate necessitates more fuel wood for heating. It is estimated that demand for fuelwood in the State is 2.50 million MT whereas forests can produce only 1.32 million MT of annual sustainable yield. Most of this gap is fulfilled through informal removal from forests.

ii. **Diversion of forestland for non-forestry purposes**

Forests are increasingly being diverted for purposes such as hydel power projects, industry, road buildings, and mining. Between 1981 and 2001, a total of 23,156 ha of land has been diverted for various developmental activities in Uttarakhand, of which a major part has been diverted for the hydel power projects (5,086 ha) and mining projects (8,359 ha). This is believed to have resulted in problems such as increased soil erosion and landslides.

iii. **Unregulated grazing**

Grazing and trampling of regenerated seedlings by livestock is the biggest threat to regeneration of vegetation in all forested areas of the State. The National Biodiversity Strategy and Action Plan **(GoI, 2002)** have estimated that the requirement for green fodder is 25.90 million MT per annum based on the State's livestock census of 1993. However, the total productivity from forests and pasture land is estimated at 4.35 million MT. Estimate of the fodder produce from agriculture lands is 0.85 million MT annually, and thus there is a huge deficit of 20 million MT per year in the State **(GoI, 2002)**. Most of this gap is filled by illegal removal such as heavy lopping of trees and cutting of saplings. The presence of Gujjars in Uttarakhand forests has also increased pressure on forests due to grazing.

iv. **Unregulated collection of NTFP including medicinal plant parts**

The other major pressure on forest resources is the unsustainable harvesting of NTFP. A serious consequence of the low productivity of agriculture and livestock is the over exploitation of NTFP including medicinal plant parts to supplement low income. Extraction of medicinal plant parts in alpine meadows for self-consumption and for sale has resulted in over-exploitation of several herb species. Pressures are particularly high on commercially important medicinal plants such as Salampanja (*Orchis latifolia*), Kutki (*Picrorhiza kurroa*), Dhup (*Cynodon dactylon*), Atis (*Aconitum heterophyllum*) and several others.

v. **Forest fires**

Uncontrolled fires have caused tremendous damage to the forest biodiversity of the State (UEPPCB, 2004). The forest fire generally spreads in two phases. The first phase occurs during late March and early April when fresh leaf litter especially in Chir pine forests gets accumulated and burnt. The second phase of fire, which occurs in May–June is more serious. It occurs under conditions of high temperature, extreme dryness, strong winds, and low moisture in the forest floor. The most sensitive fire prone area in Uttarakhand is Chir pine forests and its transition zone with Sal at lower altitude and Ban oak at higher altitudes.

vi. **Unregulated Tourism**

While tourism in Uttarakhand is an important source of livelihood for the people and revenue for the State, the environmental implications are many. Land degradation is the most common effect of tourism, particularly in hill resorts. The demand for fuelwood, the primary fuel for restaurants and road side shops is much higher during tourist season, especially in the higher reaches of the State, leading to further pressures on the forests **(UEPPCB, 2004)**. In addition expansion of tourist areas causes degradation of the adjoining vegetation, as most of the tourist centres are located in places with good natural forests.

Suggested Adaptation Measures

Forest ecosystems in Uttarakhand are already subject to heavy socio-economic pressures leading to forest degradation and Climate Change will be an additional pressure on its already vulnerable vegetation. This can significantly affect the availability of forest goods and services in terms of quality and quantity. Many non-timber forest products are likely to be more vulnerable to changes in climate system than timber and fuelwood production **(Robledo and Forner, 2005)**, and hence would have a more profound impact on those forest-dependent communities deriving their livelihood needs from such NTFPs. Uttarakhand being a '**Herbal State**' is likely to be severely impacted by these changes.

Despite availability of projections on future climate, there is no certainty about the likely impacts of the climate change on the forests in Uttarakhand, yet it is imperative to begin developing adaptation measures, based on the scientific literature elsewhere under similar ecological conditions. Some of the adaptation measures for the State could be:

i) Identification of critical forest ecosystems and species and initiating measures that would reduce pressure on such ecosystems and species and ensure their conservation either through in-situ and ex-situ means.
ii) Maintaining of proper health and hygiene of the forest ecosystems to reduce vulnerability to pests and diseases.
iii) The State forest department needs to strengthen the existing fire detection and management system and work towards reducing the response time. It would also be important to ensure proper sanitation measures to prevent incidences of fire.
iv) The State needs to come out with a policy on grazing, which should ensure no grazing in the plantation areas, natural regeneration areas and the Bugyals. Grazing should be regulated and communities need to be encouraged to keep only productive livestock, which could be stall-fed.
v) Incorporating climate concerns in the working plans/management plans prescriptions to ensure that the management interventions are in line with adaptation measures.
vi) To build the capacity of the forest department to understand the vulnerability of the forest ecosystems to the changing climate. In this context a State level capacity building programme focusing on forest ecosystems and their future management would be important.

Apart from the above-mentioned specific adaptation measures, State should adopt good practices of sustainable forest management, which would help in reducing vulnerability and increasing adaptive capacity of the forests and communities to cope with the likely impacts of climate change. Some of the strategies could be arresting forest degradation, rehabilitating degraded forests and wastelands to increase the forest cover and improving productivity of forests and plantations to meet the ever-increasing demand for forest products. Such strategies have to necessarily adopt a well-balanced approach incorporating all aspects of the forest sector. For instance, supply-side mechanisms must be augmented by demand-side management to ensure sustainable use of the State's forest resources. This may involve added investment and capacity building of the forest department and the communities to facilitate informed decision-making. The following strategies for sustainable forest management as also discussed in GREEN India document prepared by TERI **(TERI, 2006)** would be quite relevant.

a) **Rehabilitation of degraded forests and afforestation of wastelands**

25.7% of the total area in the State is covered by open forests and scrub-lands. The stocking level of this area can be improved through a combination of plantation and assisted natural regeneration interventions. While regeneration of scrub-land will require intensive plantation activities, open forests could be regenerated through a combination of plantation and assisted natural regeneration. The wastelands can potentially be brought under afforestation activities. The biggest hurdle to such an initiative is availability of the required financial resources, which mostly come from budgetary support of the government. Such areas can be taken up under on-going Green India Mission of MoEF, Govt. of India. Likewise, alternative sources such as funding under REDD-plus can be tapped for afforestation, reforestation and conservation projects. REDD-plus framework is evolving and there is likelihood of flow of funds for forests conservation, sustainable management of forest and enhancement of carbon stocks.

b) **Improving productivity of forests and plantations**

Improving the productivity of existing plantations and forest areas is another option to meet the ever-increasing demand from forests. The adoption of silvicultural practices and improved planting materials can increase the productivity of forests in the State. As per MoEF's estimates, productivity can be enhanced to 1.35 m^3 per ha per year in drier regions, 7.66 m^3 per ha per year in moist/wet regions, and 4–5 m^3 per ha per year in other parts of the country **(MoEF, 1999)**. Uttarakhand has combination of different forest types falling in these regions and accordingly productivity can be enhanced.

In case of plantations, productivity can potentially be increased manifold by planting of superior planting stock raised through tree improvement programmes as well as through clonal technology. For instance, the annual productivity of a seed-raised Eucalyptus plantation is only 4–5 m^3 per ha, which can increase to 20–40 m^3 per ha with the introduction of genetically improved clonal plants. However, tree improvement programmes have not received enough attention and funding. In this context, the State needs to strengthen its research facilities and also may collaborate with the forestry research institutions, agricultural universities, to intensify research activities on raising of superior planting materials and on silvicultural practices.

c) **Strengthening community forest management**

Strengthening community forest management could be another strategy for sustainable management of forests. There are around 10,000 JFM committees in the State, which are managing around 25% of the forest area, including Van Panchayat forests and civil soyam lands in the State **(FSI, 2008)**. Various studies across the country indicate that community forest management has had a positive impact on vegetation and income, and on the relationship between local communities and the forest department. Green Indian Mission also envisages empowerment of forest based communities which would be critical for the success of such interventions.

Women and marginalized sections of the communities also need to be empowered through self-help groups (SHGs) so that they can actively participate in such interventions. Further, possibility of introducing a mechanism on payment for environmental services also needs to be explored where the communities could be paid directly for protection and management of forests by the beneficiaries of these services.

d) Diverting pressures away from forests

Yet another opportunity to reduce the pressure on forests is agro-forestry and farm forestry wherein trees may be planted on and along farm boundaries and homesteads in a manner that does not affect crop productivity. Strategies for promoting farm forestry should focus on educating and motivating farmers, rationalizing legal barriers on felling and transport of produce, bringing about market reforms, and fostering farmer–industry linkages. The districts like Udham Singh Nagar have made good progress in agro & farm forestry but other districts like Dehradun and Haridwar should be able to promote agroforestry and farm forestry.

e) Demand-side management

The demand side management requires promoting use of wood as a 'carbon neutral material' in place of energy intensive metallic structural materials and development of technologies for efficient utilization of wood into long-term carbon traps. In case of fuelwood, augmenting the use of alternatives to fuelwood such as liquefied petroleum gas and kerosene as also efficiency improvements in use of fuelwood are some measures that can reduce the demand for fuelwood. For example, it has been estimated that an improved '*chulha*' (cook stove) reduces fuel wood demand by 400 kg per household per annum. This way, there is a potential of saving 0.024 and 0.032 million tonnes of fuel wood per annum at 60% and 80% adoption rates of improved '*chulhas'* respectively. Likewise other efficient technology options such as use of non-conventional energy sources like solar energy also would help in reducing the burden on forests.

f) Improving livelihoods of forest dependent communities

Ensuring better livelihood opportunities for forest-dependent people can reduce the over-exploitation of forest resources. Forest based interventions alone cannot fulfill the livelihood needs of the communities in question. Hence, initiatives to bolster their livelihood options need to be dovetailed with interventions in the agricultural sector and other income-generation activities. In the forestry sector, livelihoods can be improved significantly through NTFP oriented forest management in the State and creating the enabling conditions such as value addition and marketing.

g) Strengthening of Protected Area network

The State has six national parks and six wildlife sanctuaries, spread over an area of 0.71 million ha. However the fragmentation of wildlife habitats that have occurred over the years need to be reversed. Strengthening of wildlife corridors is also suggested as a measure to overcome the adverse effects of fragmentation. These would address the issues of large mammals like elephants and tigers and the human-wildlife conflicts arising as a result of shrinking and degraded animal habitats. Increasing the forest cover in areas that lead to enhancement of the potential role of designated protected areas would also be a step towards sustainable development.

h) Promoting ecosystem approach of management

Over the years environmental economists have tried to articulate the value of ecosystems and biodiversity so as to rationalize as well as to enhance budgetary allocation towards conservation. While the various studies are still debated, for the State to tread the path of sustainable development, forest ecosystems should be managed for their intrinsic values. Such a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable manner is called the ecosystem approach by the Convention on Biological Diversity. The conservation and restoration of ecosystem structures and functioning will result in the long-term maintenance of biodiversity.

i) Integrated watershed development approach

Watershed based development is a good example of ecosystem approach. Watershed development programmes have been implemented in Uttarakhand for long before its inception and have helped in treating catchments of rivers like Ganga and Yamuna, conserving biodiversity and improving livelihoods of local people. Recently concluded Uttarakhand Decentralised Watershed Development Project in the State has been able to achieve multiple objectives of improving vegetation cover, water availability, increasing incomes of local communities and enhancing administrative capacity of the *Gram Panchayats*. Various interventions related to agriculture, livestock improvement, horticulture, forestry, irrigation, soil and water conservation, development of market linkages, enterprise development, and income generation have been implemented in an integrated manner through *Gram Panchayats*. The project seems to have effectively addressed a number of ecological, economic and social issues but the challenge would be to ensure sustainability of these interventions. Watershed programme could be further strengthened and promoted for sustainable management of forest ecosystem in the State.

References

Deshingkar P, Bradley P N, Chadwick M J and Leach G. (1996). *Adapting to Climate Change in a Forest-Based Land Use System: A Case Study of Himachal Pradesh, India.* Stockholm Environment Institute.

Fischlin A, Ayres M, Karnosky D, Kellomäki S, Louman B,Ong C, Palttner G-K, Santoso H and Thompson I. (2009).Future environmental impacts and vulnerabilities. In: Seppälä, R. Buck, A. & Katila, P. (eds.). *Adaptation of Forests and People to Climate Change: A Global Assessment Report*. IUFRO World Series Vol. 22. IUFRO, Vienna. p. 53–100.

India State of Forest Report (2011). Forest Survey of India, Ministry of Environment and Forests, Government of India, Dehra Dun.

GoI. (2002). Draft Report of Working Group on Forests. Eleventh Five Year Plan (2007-2012). Planning Commission. Government of India. New Delhi.

GoI. (2002). Forests and Environment. Tenth Five Year Plan. Planning Commission. Government of India. New Delhi.

Gopalakrishnan R, Jayaraman M, Bala G and Ravindranath N H. (2011). Climate change and Indian forests: *Current Science*, 101 (3) 348-355.

INCCA (2010): "Climate change and India: A 4 x 4 Assessment by Indian Network for Climate Change Assessment. Ministry of Environment and Forests, Govt. of India, New Delhi.

IPCC, (2007): Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp.

IPCC, (2013): Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis. Final Draft Underlying Scientific-Technical Assessment.

Ministry of Agriculture 2005 in FSI. (2008). State of Forest Report 2005. Ministry of Environment & Forests. Forest Survey of India Dehradun 140 pp.

MoEF, (1999). National Forestry Action Programme – India – Volume 1 : Status of Forestry in India. New Delhi. Ministry of Environment & Forests.179 pp.

MoEF, (2012). India Second National Communication to the United Nations Framework Convention on Climate Change. Ministry of Environment & Forests, Government of India, New Delhi.

Ravindranath N H, Joshi N V, Sukumar R and Saxena A. (2006). Impact of climate change on forests in India. *Current Science* 90: 3. pp 354-361.

Robledo C and Forner C. (2005). Forest and Climate Change Working Paper 2. Adaptation of forest ecosystems and the forest sector to climate change. Food and Agriculture Organization of the United Nations, Swiss Agency for Development and Cooperation, and Swiss Foundation for Development and International Cooperation.

Seppälä R, Buck A and Katila P (eds) (2009a) Adaptation of Forests and People to Climate Change – A Global Assessment Report. IUFRO World Series volume 22, International Union of Forest Research Organisations, Vienna.

Singh S P. (2007). Carbon Dioxide Rise and Climate Change in Banskota Reducing Carbon Emissions through community managed Forests in the Himalaya. International Centre for Integrated Mountain Development, Nepal.

TERI. (2003). Vulnerability and Adaptation to Climate change in India Unpublished.

TERI. (2006). Forests: Looking Back to change track - GREEN India 2047. TERI Press New Delhi, Tata Energy Research Institute: 173pp.

UEPPCB. (2004). State of Environment Report for Uttaranchal, Government of Uttaranchal, Dehradun.

CLIMATE CHANGE AND FORESTS IN INDIA: IMPACTS, VULNERABILITY AND ADAPTATION OPTIONS

Dr. Renu Singh
ADG,ICFRE,
Dehradun, India
renusingh@icfre.org

Abstract

Acknowledging the important role of forests and their inextricable linkage to human survival in the face of significant impacts of climate change on the capacity of forests to provide ecosystem services, and to enable them to continue making contribution to climate change mitigation; vulnerabilities of forests and their adaptation to changing climate are getting prominence on the agenda of forest managers and policy makers worldwide. To meet the challenges of climate change, adaptation in forest sector needs context sensitive flexible approaches aiming at strengthening of sustainable forest management at national level. Future adaptation strategies need to focus on more systems-oriented and people centered approach emphasizing multiple interactive stresses including both climatic and non-climatic ones. Integration of forest adaptation to national climate change framework poses opportunities to promote sustainable development, and reduce the risks and vulnerability of forest dependent people. This paper presents an overview of the forest resources and biodiversity of India including the existing non climate pressures. It examines the adaptation strategies and options in the forestry sector in the context of climate change impacts and vulnerabilities of forest ecosystems, and attempts to identify the critical issues that require attention to effectively establish and implement adaptation actions.

Keywords: Climate change, impacts, adaptation, vulnerability, adaptive capacity, India's forests, sustainable forest management, forest policy

1. Introduction

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), a global assessment of data since 1970 has shown it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems. Adaptation will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions (IPCC 2007a). Forests are increasingly considered significant in meeting the challenges of climate change because of their unique ability to simultaneously reduce greenhouse gas (GHG) emissions, capture and store carbon, and reduce the vulnerability of people and other ecosystems to climate change. However, forests are increasingly becoming vulnerable to markedly changing climate regime as their resilient and adaptive capacity is exceeded.

The concept that the effective and efficient forest policies, conservation, and management, bringing a number of co-benefits often serving multiple purposes and actions to tackle deforestation and forest degradation, are compatible with efforts to adapt to changing climate, to check land degradation, to mitigate GHG emissions, and to protect biodiversity is gaining widespread acceptance. Acknowledging the important role of forests and their inextricable linkage to human survival in the face of significant impacts of climate change on the capacity of forests to provide ecosystem services, and to enable them to continue making contribution to climate change mitigation; vulnerabilities of forests and their adaptation to changing climate are getting prominence on the agenda of forest managers and policy makers worldwide.

Considering the long term and irreversible impacts of climate change on forests, long term planning for forest conservation, effective adaptation action, and policy responsive to a wide variety of economic, social, political, and environmental circumstances are the urgent need of the hour. Climate change adaptation strategies should be viewed as a risk management component of sustainable forest management practice and planning. National forest policy should focus on the future adaptation strategies and a flexible framework for adaptation in the forestry sector in the local context of climate change and vulnerabilities of forest ecosystems. Policies encouraging and integrating adaptation measures in the forest management would ensure and maintain the sustainability of forests and their services in the long run.

This paper presents an overview of the forest resources and biodiversity of India including the existing non climate pressures. It focuses on the adaptation strategies and options in the forestry sector in the context of climate change impacts and vulnerabilities of forest ecosystems. This paper examines the associated challenges, and attempts to identify the critical issues that require attention to effectively establish and implement adaptation actions.

2. State of Forest Resources in India

India is endowed with vast forest resources. The present recorded forest area, i.e., forest area as per government records, is 76.95 million hectare (Mha) which is 23.41% of the total geographical area of the country. Against the legally classified 76.95 Mha forest area, the actual forest cover as assessed by the Forest survey of India (FSI) in 2011 is 69.20 Mha constituting 21.05% of the total geographical area. On the basis of tree canopy density, the forest cover of the country has been classified into three classes - very dense forest, moderately dense forest, and open forest with tree canopy density of over 70%, between 40-70%, and between 10-40% respectively. Out of the estimated forest cover of 69.20 Mha, 8.35 Mha (70% of the total forest cover) is very dense forest, 32.07 Mha (46.2%) is moderately dense forest, and 28.78 Mha (41.7%) is open forest (FSI 2011b).

According to ITTO (2006), only 39.1 Mha of India' forests fall under the category of natural forests. FAO (2010) estimates that out of 68.43 Mha of total forest area, 15.70 Mha is primary forest, 42.52 Mha constitutes other naturally regenerated forest and 10.21 Mha comprises of planted forest area.

According to Global Forest Resource Assessment Report (2005) of Food and Agricultural Organization (FAO), India has been successful in stabilizing its area under forests against the prevailing global trend of decreasing forest cover. India has the world's tenth largest area of forests, and occupies third position among countries which have registered annual net gain in forest area from 1990 to 2010 (FAO 2010). According to FSI (2009) report, the increase in the forest cover between 1997 and 2007 is 3.13 Mha (4.75%). The FSI (2011b) report also states a net increase of 0.11 Mha in the forest cover as compared to 2009 assessment.

In terms of biodiversity, India is one of the world's 17 'mega-diverse' accounting for 7-8% of the recorded species of the world spread over 45,500 species of plants and 91,212 species of animals. In terms of plant diversity, India ranks tenth in the world and fourth in Asia. India represents nearly 11% of the world's known floral diversity. About 11,058 species are endemic to Indian region, 6,200 of which belong to flowering plants alone. Of the 34 globally identified biodiversity hotspots, India contains three hotspots, namely, Himalayas, Western Ghats and Sri Lanka, and Indo-Burma. The richness of the biodiversity of the country is largely due to the occurrence of rich diversity of species, genetic and ecological variabilities in different biogeographically and bioclimatically defined zones. Approximately 4.8% of the total geographical area of the country is under in situ conservation through a 'Protected Area' network of 99 National Parks, 515 Wildlife Sanctuaries, 43 Conservation Reserves, and 4 Community Reserves (MoEF 2009).

There have been various approaches to classify forests of the country. One of the most comprehensive and detailed classification of forests was given by Champion and Seth (1968) on the basis of climatic and edaphic features which is still in vogue in India. They adopted a hierarchical system with five major forest types - (1) Tropical Forests (Moist and Dry) (2) Montane Subtropical Forests (3) Montane Temperate Forests (4) Sub Alpine Forests (5) Alpine Scrub. These are in turn classified into 16 major forest type-groups and 221 minor forest type-groups. Recently, FSI has mapped forest types of India following Champion and Seth classification (1968) on 1:50,000 scale. For the first time, an extensive study in GIS framework with ground truthing, covering the entire country, was undertaken. The study has delineated 178 forest sub-types against 221 sub-types of Champion and Seth. Distribution of diverse forest types across the country is presented in Table 1.

Table 1: Diversity and Distribution of Major Forest Types in India

Major Groups	**Type-Groups**	**Area (km^2)**	**Percentage of Forest Cover***
I. Tropical Forests			
	Wet Evergreen Forests	20,927.31	2.92
	Semi-Evergreen Forests	98,668.93	13.79
	Moist Deciduous Forests	141,185.85	19.73
	Littoral and Swamp Forests	4,964.19	0.69
	Dry Deciduous Forests	299,574.25	41.87
	Thorn Forests	16,123.84	2.25
	Dry Evergreen Forests	928.01	0.13
II. Montane Subtropical Forests			
	Subtropical Broadleaved Hill Forests	19,217.04	2.69
	Subtropical Pine Forests	18,826.92	2.63
	Subtropical Dry Evergreen Forests	196.06	0.03
III. Montane Temperate Forests			
	Montane Wet Temperate Forests	4,963.88	0.69
	Himalayan Moist Temperate Forests	29,462.20	4.12
	Himalayan Dry Temperate Forests	5,976.21	0.84

IV. Sub Alpine Forests			
	Sub Alpine Forests	13,497.31	1.89
V. Alpine Scrub			
	Moist Alpine Scrub	1,675.38	0.23
	Dry Alpine Scrub	3,080.82	0.43
Sub Total		**679,268.20**	**94.93**
Plantation/Trees Outside Forests (TOF)		36,294.33	5.07
Total		**715,562.53**	**100.00**

* Area under forest cover as per State of Forest Report (2005)
(Source: FSI 2011a)

2.1 Carbon Storage and Sequestration Potential

Carbon stock is an important indicator of the state of forests in the context of climate change. There are varying estimates of carbon stock in biomass and mineral soils in India. Haripriya (2003) conducted a comprehensive study taking into account the carbon stored in both above and below ground biomass as well as in the soil. The total carbon stock in biomass and mineral soils were estimated to be 2,934 MT C and 5,109 MT C respectively for the year 1994 and 1995. The average biomass carbon of the forest ecosystem in India for the year 1994 was reported to be 46 T C/ha, of which 76 % was in above ground biomass and the rest in fine and coarse root biomass. The average mineral soil carbon was found to be 80 T C/ha.
Increase in annual productivity directly indicates an increase in forest biomass and hence higher carbon sequestration potential. Noting the annual productivity increase in India's forests from 0.7 m3 per ha in 1985 to 1.37 m3 per ha in 1995, Lal and Singh (2000) estimated the carbon pool for the Indian forests to be 2026.72 Mt for the year 1995, and concluded that India's forests and plantations had been able to remove at least 0.125 Gt of CO2 from the atmosphere in the year 1995. Assuming that the natural forest cover in India will sustain itself at an annual productivity of 1.37 m3 per ha while the plantations would have an annual productivity of 3.2 t/ha, the total annual carbon uptake of 55.48 Mt and 73.48 Mt for the years 2020 and 2045 respectively was also projected.

Kaul, Dadhwal, and Mohren (2009) observed that Indian forest sector acted as a small source of carbon during the period 1982–1992, and as a small carbon sink during the period 1992–2002. The cumulative net carbon flux from Indian forests due to land use change between 1982 and 2002 was estimated at 45.6 Tg C.

On the basis of analysis of forest cover, afforestation and reforestation, and other conservation measures, Ravindranath, Chaturvedi, and Murthy (2008) have projected an increase in Indian forests during the period 2006-2030, and occupation of 72 m ha of land under forests by 2030 under the current trend scenario of the afforestation rate of 1.32 mha/annum. The model based projection of carbon stocks in India's forests and tree cover reflects an increase in the carbon stocks from 8.79 GtC in 2005 to 9.75 GtC in 2030 (ibid).

According to GoI (2009), India's forests are a major sink of CO2, and serving an important role in GHG mitigation for India. From 1995 to 2005, the carbon stocks stored in forests and trees have increased from 6245 Mt to 6662 Mt with an annual increment of 38 Mt of carbon. The annual CO2 removals by India's forest and tree cover is enough to neutralize 11.25 % of India's total GHG emissions at 1994 levels, which is equivalent to offsetting 100% emissions from all energy in residential and transport sectors; or 40% of total emissions from the agriculture sector.

Ravindranath et al. (2007) estimated the national mitigation potential in forestry sector and noted that during the period 2005 to 2035, at a carbon price of $100 per tC, India's forests have the potential to sequester an additional 260 MtC through afforestation and reforestation activities. Another study by Ravindranath et al (2011) projects that the cumulative mitigation potential of India's forests is to increase by up to 14% to 21% between the years 2008 and 2108 using BIOME4 vegetation model. However, estimates obtained from IBIS, a dynamic global vegetation model, suggest mitigation potential increases by only 5% to 6% during the period 2008 to 2108.

2.2 Challenges of Forest Resource Use

India, having 2.5% of world's geographic area and 1.8% of world's forests, sustains 16% of global human population and 18% of livestock population. Per capita availability of forest area is only 0.07 ha against the world average of 0.62 ha (FAO 2010). Around 70 million tribal and 200 million non-tribal rural people have been defined as forest-dependent (MoEF n.d.). In the Indian context, forests are multipurpose resources, and work not only as a savings account but they also provide a range of products for subsistence to people living in and around them. Thus, understanding the existing challenges of forest resource use and their linkages to the nature and extent of resource use is crucial to inform the policy and planning process to reduce vulnerabilities of forests and support adaptation strategies in the country.

Forests have great potential for generating employment opportunities and boosting the local and national economy. It has been estimated that the current contribution of forests to national GDP is 1.2%. According to one estimate, value of annual flow of goods and services per hectare of forests in India varies from a minimum of Rs 24,664 to Rs 1,432,671 considering both tangible and intangible benefits (Manoharan 2000). A number of studies have attempted to highlight the important role of forestry in rural livelihoods. While Vedeld et al (2004) noted that forest products contribute between 20 to 40% of the total household income in forest areas others observed a range between 10 to 54% (Bhattacharya and Hayat 2004, Prasad 2006, Saxena 1999).

Forests offer a number of valuable products like leaves of commercial importance, bamboos and canes, gums, resins, oil seeds, essential oils, medicines, spices, fibres and flosses, tans and dyes, edible and mineral products which are commonly referred as Non Timber Forest Products (NTFPs). There are an estimated more than 3000 wild plant species that comprise NTFPs in India. The value of NTFPs in India is estimated to be in the range of US$ 60-100 billion. The collection of Non Timber Forest Products (NTFPs) is the main source of wage labour for 17% of landless labourers, and 39% more are engaged in NTFPs collection as subsidiary occupation (MoEF n.d.). It is estimated that nearly 400 million people living in and around forests depend on NTFPs for sustenance and supplemental income (ibid).

The Indian forest ecosystems are rich repositories of medicinal plants of high therapeutic value and considerable national and international demands. India has 15 Agroclimatic zones and 17000-18000 species of flowering plants of which 6000-7000 are estimated to have medicinal usage in folk and documented systems of medicine. About 960 species of medicinal plants are estimated to be in trade of which 178 species have annual consumption levels in excess of 100 metric tonnes. A larger percentage of known medicinal plants occur in the dry and moist deciduous vegetation as compared to the evergreen or temperate habitats. As per National Medicinal Plants Board study, the total value of raw material traded in India is around Rs.1000 crores (Ved and Goraya2007). Over exploitation of wild populations of some medicinal plants to meet ever increasing market demand has led to lowering of their population in wild habitats.

In rural areas, about 50% of the total fuel consumption is met from fuelwood. According to MoEF (n. d.) estimates, the annual fuelwood consumption is in the range of 250 to 300 million m3, which is mainly collected from forests in an unorganized way as only about 17 million m3 is recorded to be supplied from forests. About 75% of all forest production is said to be fuelwood and mostly collected from natural forests. Although most of the fuelwood is consumed domestically, it is also a major source of income for poor in forest fringe villages. It is estimated that fuelwood consumption would go up to 400 million m3 along with increase in industrial demand of wood from 58 in the year 2000 to 153 million m3 in the year 2020 (ibid). Traditionally, uncontrolled and unmonitored fuelwood collection is impacting growing stock and creates ecological imbalances leading to forest degradation.

India's 78% forest area is under grazing pressure (FSI 1995) with 270 million cattle grazing inside forests (MoEF 2006). Additionally 175 to 200 million tonnes of green fodder is also collected from forests through lopping and harvesting of grasses. This uncontrolled grazing results in over-grazing and over-extraction of green fodder causing forest degradation through compaction of top soil, damages to regeneration, loss of plant diversity and promotion of weeds, and increasing the vulnerability of forests to climate change.

Man-caused forest fire, predominantly for collection of certain NTFPs and land preparation for shifting cultivation, is adversely affecting 35 Mha of forest area (MoEF 2006a). As per FSI report (1995), 53.1% forest area is affected by fire. Out of this, 8.92% is affected by frequent fire and 44.25% by occasional fire. A total of 13,898 fire incidences have been reported by FSI (2011b) in the country in the year 2010-11. Himalayan forests are highly susceptible to fires. Forest fires are a major recurrent management problem in dry deciduous forests of Western Ghats and parts of South India. In India, ground fire is the most common type of forest fire which adversely impacts biodiversity, damages watershed services, soil fertility and productivity. Around 26 million people in the north eastern states are involved in shifting cultivation on 10 Mha leading to deforestation. According to Manhas et al (2006)shifting cultivation accounts for 23% of the total deforestation in India leading to an annual loss of 0.93 MtC per year.

3. Vulnerability of Forests and Forest Communities to Climate Change

Climate is one of the most important determinants of forest ecosystems and its biodiversity. Many ecosystems including forests are likely to be affected this century by an unprecedented combination of climate change, associated disturbances (e.g. flooding, drought, wildfire, insects) and other global change drivers (e.g. land use change, pollution, fragmentation of natural systems, over-exploitation of resources). There are projected to be major changes in ecosystem structure and function, species' ecological interactions and shifts in species' geographical ranges, with predominantly negative consequences for biodiversity and ecosystem goods and services if global average temperature exceeds 1.5 to 2.5°C in concomitant atmospheric carbon dioxide (CO2) concentrations (IPCC 2007c). Additional threats to forests will emerge as the climate continues to change and interacts with non climatic pressures like habitat fragmentation (Brook et al 2008).

The Fourth Assessment Report of the IPCC defines vulnerability as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and the variation to which a system is exposed, its sensitivity and its adaptive capacity (Parry et al 2007). Vulnerability assessments follow two main approaches – 'impact-based approaches' and 'vulnerability-based approaches'. Impact-based approaches involve the potential impacts of climate change on forest or forest people under different climate scenarios, and can facilitate decision-making when conducted at national or sub-national level. A vulnerability-based approach includes assessing social sensitivity and adaptive capacity to respond to stresses, and is determined by the existing capacity rather than by any predicted future impacts (Kelly and Adger 2000, Ribot 2009).

Some issues are important when assessing vulnerabilities of forest or forest communities to anthropogenic climate change and related adaptation responses. Firstly, we need to know the ability of forest ecosystem to adapt naturally. It is pertinent to understand whether the resilience of forest ecosystem (the disturbance forest can tolerate before it shifts into a different state) is sufficient to tolerate future anthropogenic climate change (Jump and Peñuelas, 2005). Secondly, India's forests are under huge human-induced pressures, such as extraction of goods for various purposes, increasing fragmentation and degradation of natural habitats. As an additional stress, climate change will increasingly exacerbate these human-induced pressures resulting in decline in biodiversity in forests. This complex relationship between climatic and non climatic existing pressures needs to be contextualized in local socio-economic scenario. Thirdly, we need to develop a better understanding of critical thresholds or breakpoints in forest ecosystems response that increases ecosystem's susceptibility to being triggered to enter an alternative state. A fourth important issue involves an understanding of time lags in ecosystem responses to develop effective adaptation responses at the appropriate time-scale. Because of this character, forest ecosystems would take a long time to respond to climate change, and it may be several centuries before responses including broad-scale biospheric responses or shifting species geographical ranges are observed. A fifth key issue relates to species extinctions that are critical for ecosystem functioning and maintenance of ecosystem services (Duraiappah et al 2005,Hooper et al 2005). Global extinction is distinct from local extinctions as represents irreversible change. Such extinctions are critical and reduce adaptation options and responses towards climate change.

Temperature and precipitation are the two main climate drivers affecting forest ecosystems. Significant warming trend of 0.56°C per 100 years during the period 1901–2007 has been observed in India's annual mean temperature. Mean temperature increased by about 0.2°C per decade for the period 1971–2007, with a much steeper increase in minimum temperature than maximum temperature. It is also predicted that the annual mean surface air temperature rise by the end of this century would range from 3.5°C to 4.3°C. It appears that there may not be significant decrease in the monsoon rainfall in the future except in some parts of the southern peninsula. However, the rainy days in future appear to be less in number than the present. The projections indicate positive change in rainfall in the 21st century, especially during monsoon months with increase in the rainfall intensity (MoEF 2012). According to one study undertaken by ICFRE (2013), changes in boundaries of forest types and areas along with changes in the composition of species and assemblages are already taking place in India's forests. It is noted that Alpine flora occurring in the higher elevations of Himalayas, one of the four biodiversity hotspots of India, is undergoing significant changes in the vegetation composition and distribution pattern. *Pinus gerardiana* preferring warmer climate is found in higher proportion and occupying new sites in Himalayas. The blue pine found in the elevations up to 2750 m is now reported in higher elevations up to 3400 m indicating the shift in the tree line and migration of species.

The change in the rainfall pattern in the north eastern India is also reported causing significant changes in the species composition resulting in the dominance of evergreen species in the semi- evergreen and deciduous forest types (ibid). Similar observations have been made in tropical Nilgiri hill top forests wherein *Myristica malabarica*, a low elevation evergreen type is found replacing *Themeda* and *Cymbophogon* due to increased wetness (ibid). As a result of climate change warming at high latitudes, upward shift of species from their current locations is likely to adversely affect the distribution and abundance of endemic species whose natural ranges are already confined to high elevations in both temperate and tropical ecosystems. As mountain peaks are smaller than the bases, upward shifting of species would result in the occupation of smaller areas by smaller populations, and species may become vulnerable to genetic and environmental pressures. Migration of species is very likely to result in large scale mortality, forest die-back and loss of biodiversity. New sites may not be suitable edaphically for the establishment. Unlike animals, plants are stationary and rely on dispersal of seeds from unsuitable areas to more favourable areas. Sometimes, because of natural barriers like mountains seed dispersal to new areas may not take place. When conditions become unfavourable for endemic/ native species, alien species would invade successfully.

Earliest observed responses to climate change include change in plant phenology which could lead to serious consequences for the plants and animals. Several studies have noted early flowering and fruiting of native trees like *Rhododendron* species and *Myrica esculenta* (MoEF 2010a) and longer growing seasons with increased growth rates as observed in Himalayan conifers (*Cedrus deodara* and *Pinus smithiana*) in Kinnaur and Gangotri regions (Borgaonkar et al 2010 cited in MoEF 2010a).

4. Potential Impacts of Climate Change on Forests

Ravindranath et al (2006) made an assessment of the impact of projected climate change on forest ecosystems in India based on climate projections of Regional Climate Model of the Hadley Centre (HadRM3) using the A2 (740 ppm CO2) and B2 (575 ppm CO2) scenarios of Special Report on Emissions Scenarios (SRES) and the BIOME4 vegetation response model. They conclude that under the climate projection for the year 2085, 77% and 68% of the total 35,000 forested grids in India are likely to experience shift in forest types under A2 and B2 scenario, respectively. A shift towards wetter forest types in the northeastern region and drier forest types in the northwestern region in the absence of human influence is also noted. A doubling of net primary productivity under the A2 scenario and nearly 70% increase under the B2 scenario is also reported noting the increase in atmospheric CO2 concentration and climate warming.

On the basis of Dynamic Global Vegetation Model, Chaturvedi et al. (2010) assessed the impact of projected climate change on forest ecosystems in India and projected that 39% of forest grids are likely to undergo vegetation type change under the A2 scenario and 34% under the B2 scenario by the end of this century. The study concluded that the impacts varied with the region and forest types.

Another study (MoEF 2010a) assessed the impacts of climate change on forests in India for 2030s using the dynamic model IBIS version 2 (Integrated Biosphere Simulator) under SRES scenario A1B (atmospheric CO2 concentration of 490 ppm by 2035). The "baseline" scenario represents the averaged climate, over the period 1961–91. The assessment is based on the changes in area under different forest types and shifts in boundary of forest types and net primary productivity (NPP) for four eco-sensitive regions for short-term period by 2035. The entire Western Ghats region is covered by 54 grids, out of which 10 (18%) of them are projected to undergo change and show vulnerability to climate change. The region is projected to have approximately 20% increase in NPP on an average.

The entire Himalayan region is covered by 98 IBIS grids, out of which 55 (56%) are projected to undergo change. Over half of the forests are likely to be adversely impacted in the Himalayan region by 2030's. NPP is projected to increase in the region by about 57%.

The entire coastal region is covered by 96 grids, out of which 29 (30%) of them are projected to undergo change. The NPP of coastal region is projected to increase by 31% on an average.

The Sundarbans (a part of the Indian coast) is a large block of tidal mangrove forests, covering about 10,000 square km. About 6,000 square km area of Sundarbans is in Bangladesh). The area has been declared as a UNESCO world heritage site in 1997. The entire Sundarbans is covered by 7 grids, out of which none are projected to undergo change within this short period. Thus vegetation or forest type shift may not be a major threat for the Sundarbans.

In the North-Eastern region only about 8% of (6 out of 73 grids) forested grids are projected to undergo change. The region is projected to witness a 23% increase in NPP on an average.

The forest ecosystems of the Himalayan eco-region have been found to be the most vulnerable to climate change. The coastal regions and Western Ghats are moderately vulnerable to climate change while forests in the North-Eastern region are projected to be minimally impacted by climate change in the short term (MoEF 2010a).

Climate change and modelling studies on *Shorea robusta* and *Tectona grandis*, dominant tree species of central India, have indicated that there would be a net increase in primary productivity with increase in temperature and rainfall, but this would also lead to a die-back with the induced stress to nutrient availability (MoEF 2012).

5. Adaptation Options

Forests are complex ecosystems and have resilience capacity to changes in their environment including climate change up to certain limits. Although uncertainty remains about the extent of climate change vulnerability and impacts on forest ecosystems, a number of studies indicate that the adaptive capacity of forests will not be sufficient to adapt to unprecedented rates of climate change (IPCC 2007c, Gitay et al 2002). Adaptation will be necessary to address impacts resulting from the climate change which is already unavoidable due to past emissions. Further there is sufficient evidence which indicate that some large-scale climate events have the potential to cause very large impacts on forests, especially after the 21st century (Parry et al 2007).

Adaptation refers to adjustments in forest systems in response to actual or expected climate change or their effects (Parry et al 2007). There are different types of adaptation, including autonomous, anticipatory, reactive or planned adaptation. Autonomous or spontaneous adaptation does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Planned/ reactive adaptation is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change, and that action is required to return to, maintain, or achieve a desired state. Reactive adaptation consists of 'soft' adaptation options that are cost effective and easier to implement. Currently, forest sector responses to climate change are mostly reactive. Anticipatory or proactive adaptation, on the other hand, is the adaptation that takes place before impacts of climate change are observed. Adaptive capacity of forest ecosystem, i.e. , their ability to adjust to climate change to moderate potential damages, to take advantage of opportunities, or to cope with the consequences is dynamic and influenced by national circumstances. Adaptation may be autonomous, reactive, anticipatory or planned (ibid). We need to develop a better understanding of economic, social, political, institutional, technological and environmental circumstances related factors that enhance or limit the adaptive capacity of forests. There is inertia and a lag period between climate change and impacts on forests due to very long gestation period involved in forest response to any changes. Many impacts (e.g., loss of biodiversity) are long term and irreversible. Rural population is heavily dependent on forest ecosystem goods and services for their livelihoods and any adverse impact on ecosystems would lead to negative impacts on livelihoods. Forest departments and communities are not adequately equipped in technical, institutional and financial capacity to adapt to climate change impacts.

Adapting to climate change need adjustments and changes at every level - from community to institutions and governments. Climate change adaptation strategies can be viewed as a risk management component of existing and future sustainable forest management and ecosystem policy, planning and practice (Ogden and Innes 2007, Spittlehouse and Stewart 2003). Policy planners and practitioners are required to establish objectives for the future forest ecosystems under climate change. A wide array of available adaptation options are needed to be considered carefully to reduce vulnerability of forests to future climate change. There are barriers and associated costs which are not fully understood. Some adaptation is occurring now as part of current management policy and practice to observed and projected future climate change, but more extensive adaptation strategies are required to reduce vulnerability to future climate change. A portfolio of adaptation options and measures can help diminishing the risks associated with climate change to reduce vulnerability of forest systems.

Adaptation Integration into Forest Policy and Planning

UNFCCC (2008) notes that as climate change increases the potential for climate related risk, it is also important that risk management and risk reduction is incorporated into adaptation planning at all levels. Thus, promoting the integration of risk reduction associated with existing climate variability and future climate change into forest policy strategies for the reduction of forest vulnerability and risks, and adaptation to climate change need to be strengthened to address the complexities of the implementation of adaptation action.

The country framework of forest policies is critical in increasing or decreasing the vulnerability of forests along with determining the adaptive capacity of communities to climate change. India has several conservation oriented forest policies and legislations which shape forest management practice in the country. Key policy instruments - Indian Forest Acts, Wildlife (Protection) Act 1972, Forest (Conservation) Act 1980, National Forest Policy 1988, June 1990 Guidelines for Joint Forest Management, Biological Diversity Act 2002, National Environment Policy 2006, Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act 2006, National Biodiversity Action Plan (NBAP) 2008, and Green India Mission 2010 – provide a conducive environment to design and adopt appropriate adaptation measures and options to overcome and cope with the adverse impacts of changing climate. These progressive policies and legislations have significant positive impacts on restoration of degraded forests, maintenance and conservation of forests and its biodiversity, increased availability of fuelwood, fodder, food and other NTFPs and participation of local communities in forest management.

In 2010, the Prime Minister's Council on Climate Change (PMCCC) has approved India's National Action Plan on Climate Change (NAPCC) aiming at achieving national growth objectives through measures that enhance climate change mitigation and adaptation. Adopting a mission approach, eight sectoral national Missions have been identified under the Plan (GoI n.d.). The Green India Mission (GIM), one of the eight Missions under the National Action Plan on Climate Change (NAPCC), recognizes that climate change will seriously affect the forest resources of the country, and the associated livelihoods of the people. The Mission puts the "greening" in the context of climate change adaptation and mitigation, and aims at addressing climate change by enhancing carbon sinks in sustainably managed forests and other ecosystems; enhancing the resilience and ability of vulnerable species/ecosystems to adapt to the changing climate; and, enabling adaptation of forest dependant local communities in the face of climatic variability (MoEF 2010b).

Places high importance on adaptation, the GIM proposes not only to increase the quantity of forest and tree cover on 5 million ha of lands but also the quality of forest cover on another 5 million ha of lands with involvement of revamped JFM committees and decentralized governance. The GIM aims at improving ecosystem services including biodiversity, hydrological services, and enhanced annual CO2 sequestration by 50 to 60 million tonnes in the year 2020 with increased forest-based livelihood income of about 3 million households living in and around the forests (ibid).

The GIM is the manifestation of India's support for the policy of conservation, sustainable management of forests, and increase in forest cover as important policy instrument of facilitating adaptation of both forests and communities to climate change. Various Mission activities would result in conservation and improving the health and vitality of forest resources, thus, enhancing the resilience and adaptive capacity of forests. This would result in continued supply of forest ecosystem services to forest dependent communities and widening their portfolio of adaptation options to cope with the climate change.

Adaptive Collaborative Forest Management

Adaptive management involves recognizing uncertainty of climate change and uses management as a tool not only to change the system but to learn about the system (Holling 1978, Lee 1993). Adaptive forest management enables forest managers to adjust the structure and the consequent functioning of the forest ecosystem to resist harmful impacts of climate change. Adaptive management entails a process of observation, analysis, planning, action, monitoring, reflection and new action (Joyce et al 2009). Adequate monitoring is a crucial part of the adaptive management, and requires being capable of documenting changes and identifying when critical thresholds are reached in forest ecosystems to determine the effectiveness of adaptive options and strategies. To establish climate relevant monitoring mechanism, new indicators and designs will be required to be integrated to the existing systems. Moreover, forest managers are needed to recognize the complex interactions between human activities and climate change, and practice adaptive collaborative management involving different stakeholders (Colfer 2005, Diaw and Kusumanto 2005).

The principles of sustainable forest management have been noted to align well with the actions of adaptive collaborative forest management in maintaining the continuous flow of forest ecosystem services. Biodiversity has been recognized as an essential element of forest ecosystems to support their ecosystem services and maintain the adaptive capacity of forests and communities to climate change (Noss 2001). However, it is established that climate change has strong potential to adversely affect biodiversity. It is estimated that approximately 20-30% of species are at risk of extinction if global mean temperatures exceed 2°C to 3°C and about 40-70% of species will be lost if warming goes beyond 4°C (Fischlin et al 2007). Landscape-level based adaptive forest management employing reducing forest fragmentation and maintenance of corridors strategies has been argued to conserve biodiversity (Brockerhoff et al 2008). Landscape-level management resulting in increased landscape connectivity (Noss 2001, Vos et al 2008) enables natural migration of species to new sites with favourable climatic conditions.

Improved silvicultural practices in consideration of climate change have been suggested to be effective in tropical forests to deal with the issues of forest productivity (Peña-Claros et al 2008). At the same time, genetic studies exploring plantation of climate resistant alternate genotype or new species, and development and maintenance of seed banks have been advocated as useful anticipatory or proactive adaptation strategy. Sanitation thinning, increased amount of salvage logging and landscape planning may also be used as anticipatory adaptation to minimize spread of insects and diseases in changing climate. Conventional rotation length may be changed and followed by planting to enhance and assist the establishment of better adapted forest types.

Collaborative management of forest fire is likely to be increasingly important as climate changes. Management of fire hazards caused by human activities will necessitate active involvement of local stakeholders. Calling upon “a massive people’s movement with the involvement of women” the National Forest Policy of India stresses to maintain one-third area of the country under forest cover and to reduce pressure on forests with massive afforestation programme for fuelwood and fodder development, especially on all denuded, degraded, and unproductive lands (GoI 1988). The National Forest Policy of 1988 aims to combine the objectives of environmental stability and bio-diversity conservation with those of social justice (Sarin et al 1998).

Local Knowledge and Coping Strategies

Local forest-related knowledge, practices and associated social institutions that evolved over generations can play an important role for understanding forest dynamics in the face of changing climate conditions. Local knowledge systems are an important source of adaptive capacity for local forest-dependent communities in the given complex and uncertain impacts of climate change on forest ecosystems.

Many forest dependent communities are well recognized for their knowledge and experience on coping with climate variability. Based on their accumulated knowledge about forests and past experience of extreme weather events, these local communities have successfully recovered from extreme events and adapted to climatic variations. Communities depending on forests for subsistence have been noted to adopt adaptation options of planting drought resistant species providing fuelwood, and edible fruits and leaves to enhance food security and nutrition. Local coping strategies observed by communities to adapt to extreme events like droughts also include forest protection and traditional water conservation practices.

Traditional knowledge and local coping strategies can help to plan efficient and effective ways of enabling adaptation to climate change. Local knowledge about the uses of various forest species can be used for substitution of rare species with those that may become more abundant under changing climate. This knowledge can also be applied in forest rehabilitation and restoration in the face of climate change. However, the application of local forest-related knowledge to adaptive forest management requires active participation of local and forest dependent communities.

The relevance of local forest-related knowledge in strengthening adaptation of forests and communities to climate change should be recognized by forest managers. Actions should be taken to preserve and protect local knowledge. Efforts are required to elucidate underlying ecological principles that may enable wider application and further development of local knowledge and associated forest resource management practices to cope with adverse impacts of climate change (Roberts et al 2009).

Capacity Building, Education and Public Awareness

Capacity building, education and training of stakeholders including policy makers and practitioners both at local and national levels is vital to enable communities and forests to adapt to climate change. It will result in developing technical and institutional capacity to adapt to climate change impacts in forest departments as well at the forest dependent community level. Capacity building and training for stakeholders in forest sector would help the better assessments of vulnerability and effectiveness of adaptation options with associated costs.

In this context, it is important to recognize the role of universities, specialized institutes and centres of excellence and need for enhanced support with adequate funds for institutional capacity building for successful planning and implementing adaptation activities. Collaboration between educational centres and training institutes would help in disseminating knowledge, experience and lessons learned about adaptation options and measures.

It is also important to engage public in a dialogue on values and management under a changing climate scenario. There is a need to increase awareness and education within the forestry community about adaptation to climate change. A communication strategy involving mass media can work as an effective way of communicating with different stakeholders on climate change risks and adaptation needs, targeting actors ranging from those at the grassroots level to national and regional policymakers.

Research for Adaptive Forest Management

In order to understand better the impacts of climate change on forests, it is essential to develop a better understanding of the underlying change in climate. As important measures for adaptation in forest sector, the integration of climate change concerns into short to long-term planning and policy making process needs further research into future more reliable projections of climate change including extreme events. Most of the research efforts in forestry sector have focused primarily on the impacts of climate change on forests with a relatively low level of research into adaptation field. Research on forest adaptation to climate change is relatively recent.

Genetic studies and breeding research programmes aiming at species that would be better adapted to the projected future climate and withstand the increasing disturbances like fire hazards and pathogen attacks are needed to be initiated. Another important research gap lies in understanding the relationship between biodiversity and the resilience of ecosystem services at a scale relevant to human well-being (IPCC 2007c).

Non-timber forest products (NTFPs) are important source of livelihood security for forest dependent communities and often provide a ‘safety net’ during periods of economic stress due to crop failures that may become more common as a result of climate change. However, potential impacts of climate change on NTFPs and other ecosystem services provided by forests are not well researched. Consequently the contribution of forests to adaptive capacity of local communities is not well understood. More research work is needed to generate the information on forest related adaptation strategies relevant to livelihoods (Osman-Elasha et al 2009).

Adaptation Costs and Funding in Forestry Sector

Funding is vital in order to enable forest managers and communities to plan for and make choice from the portfolio of available adaptation options to cope with the current and projected climate change impacts. According to the Stern Review, the costs of strong and urgent action on climate change will be less than the costs thereby avoided of the impacts of climate change under business as usual (Stern 2006). According to World Bank (2006), the present annual costs of adaptation for developing countries are USD 9-41 billion while these costs vary from USD 4 to 37 billion as per Stern Review (2007) estimates. Another study estimates that by 2030 annual costs of adaptation for developing countries will be in the range of USD 86–109 billion (UNDP 2007). These annual costs will rise to USD 106.2 billion for wettest scenario and USD 94.7 billion for driest scenario by 2050 (World Bank 2010).

Natural ecosystems as well as communities need to adapt to climate change, and this involves finance. For agriculture, forestry, fisheries sectors, annual adaptation costs are estimated to be USD 7 billion by UNFCCC (2007) while World Bank study (2010) estimates these costs to be USD 7.6 billion for wettest scenario and USD 7.3 billion for driest scenario. Among communities, forest dependent poor, already the hardest hit by climate change, lack capacity as well as access to financial resources to adapt. Adequate flow of funds must be ensured to enable forest managers and forest dependent communities to enhance their efforts to adapt to climate change.

Several studies have emphasised the need for sustained financing for adaptation. Without sustained flow of funds, "adaptation runs the risk of not being effectively addressed and largely limited to 'reactive' funding" (UNFCCC 2008).This condition runs the risk of a costly short-term emergency relief and remains unsupportive of sustainable development. Sufficient and sustained funding is required to develop national adaptation strategies and implement action plans at local, regional and national levels.

Lack of funds has been considered a major barrier to implement effective anticipatory or proactive adaptation actions in the forest sector. Currently, whatever adaptations actions are being practiced in the forest sector they form a part of sustainable forest management practice as reactive or planned adaptation measures based on the awareness that conditions are changing and action is needed to maintain a desired state of forest resources. The literature on adaptation costs and benefits is limited and fragmented and does not take into account biodiversity or ecosystem services (Parry et al 2007, Stern 2007). Uncertainty around forest responses to future projected climate has failed to provide reasonable estimates of costs and benefits of adaptation to win the confidence of authorities and governments to allocate the much needed adaptation funds though adaptation is currently receiving considerable attention (UNFCCC 2007, Agrawala and Frankhauser 2008). Noting the uncertainties and difficulties involved in the estimation of the effect of climate change on ecosystems, there has been a shift towards more flexible adaptive management in this sector. (UNFCCC 2010).

Inter-Sectoral Coordination

It is important to note that actions in forest sector are influenced not only by forest policies but policy goals of other sectors also have an important bearing on decisions in forest sector which may or may not be in consonance with the objectives of forest policies. Policies and actions in other sectors may directly or indirectly affect forest sector and sometimes may impede its ability to adapt to climate change. For example, policies in the agricultural sector have the potential to lead to the clearing of forests and adversely affect the capacity of the forest sector to adapt to the climate change. At the same time, policies encouraging agro-forestry on farmers' land may result in reducing pressure on forests and increasing the adaptive capacity of communities to better adapt to changing climate. Thus, improving inter-sectoral coordination would be a first step towards an effective, integrated approach to landscape based forest management approach to adaptation.

In view of multiple and complex policy goals such as poverty alleviation, biodiversity conservation and climate change mitigation, it is critical for forest sector to develop flexible instruments and improve inter-sectoral coordination. Successful integration of adaptation to sustainable forest management will need mutually reinforcing positive interaction with policy development in other related sectors especially agriculture and energy sectors. A holistic coordination amongst all relevant sectors requires attention to ensure that actions in other sectors do not compete with forest land to meet their policy objectives.

6. Conclusions

The available scientific information in forest sector confirms that forest ecosystems and the services provided by them are already being impacted by climate change with an increase in the socio-economic vulnerability of forest dependent communities. The effect of non-climate factors such as clearing of forests for agriculture and infrastructure development, forest fire and pathogen attacks, and their interactions with climate change further complicate the understanding of the climate change impacts on goods and service of forests. To meet these challenges, adaptation in forest sector needs context sensitive flexible approaches aiming at strengthening of sustainable forest management at national level.

Future adaptation strategies need to focus on more systems-oriented and people centered approach emphasizing multiple interactive stresses. Integration of forest adaptation to national climate change framework poses opportunities to promote sustainable development, and reduce the risks and vulnerability of forest dependent people. As current funding is not sufficient to support adaptation needs, adequate resources need to be channeled to forest sector in order to promote such action. To enable workable and effective adaptation measures, integration of climate change in national level forest planning and budgeting in all levels of decision making is needed.

References

Agrawala S. and Fankhauser S. (eds.), 2008, *Economic Aspects of Adaptation to Climate Change. Costs, Benefits and Policy Instruments*, OECD, Paris.

Borgaonkar H.P., Sikder A.B. and Ram S., 2010, *High Altitude Forest Sensitivity to the Recent Warming: a Tree-Ring Analysis of Conifers from Western Himalaya, India*, Quaternary International, (in press) doi:10.1016/j.quaint.2010.01.016.

Bhatttacharya P. and Hayat F., 2004, *Sustainable NTFP Management for Rural Development: A Case from Madhya Pradesh, India*, International Forestry Review 6(2):161-168.

Brockerhoff E.G. et al, 2008, *Re-examination of Recent Loss of Indigenous Cover in New Zealand and the Relative Contributions of Different Land Uses*, New Zealand Journal of Ecology 32(1): 115–126.

Brooks B.W., Sodhi N.S. and Bradshaw C. J.A., 2008, *Synergies among Extinction Drivers under Global Change*, Trends in Ecology and Evolution 23(8):453-460.

Champion H.G. and Seth S.K., 1968, *A Revised Survey of the Forest Types of India*, Government of India, The Manager of Publications, Delhi

Chaturvedi R.K. et al, 2010, Impact of *Climate Change on Indian Forests: a Dynamic Vegetation Modeling Approach*, Mitig Adapt Strateg Glob Change, DOI 10.1007/s11027-010-9257-7, Available at: http://www.springerlink.com/content/87g2376642867270/.

Colfer C.J.P. (ed), 2005, *The Equitable Forest. Diversity, Community and Resource Management. Resources for the Future*, Washington, D.C.

Duraiappah A. et al (eds), 2005: *Ecosystems and Human Well-being: Biodiversity Synthes*is, Island Press, Washington.

Diaw M.C. and Kusumanto T., 2005, Scientists in Social Encounters, The Case for an Engaged Practice of Science, in Colfer C.J.P. (ed.), 2005, *The Equitable Forest. Diversity, Community and Resource Management, Resources for the Future*, Washington, D.C.

FAO, 2005, *Global Forest Resources Assessment 2005: Progress Towards Sustainable Forest Management*, FAO Forestry Paper 147, Food and Agriculture Organization of the United Nations, Rome.

FAO, 2010, *Global Forest Resources Assessment 2010: Main Report*, FAO Forestry Paper 163, Food and Agriculture Organization of the United Nations, Rome.

Fischlin A. et al, 2007, Ecosystems, their Properties, Goods, and Services, in Parry M.L. et al (eds.), 2007, *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

FSI, 1995, *The State of Forest Report 1995*, Forest Survey of India (FSI), Ministry of Environment and Forests, Dehradun.

FSI, 2005, *State of Forest Report 2005*, Forest Survey of India (FSI), Ministry of Environment and Forests, Dehradun, Dehradun.

FSI, 2011a, *Atlas: Forest Types* of India, Forest Survey of India (FSI), Ministry of Environment and Forests, Government of India, Dehradun.

FSI, 2011b, *India State of Forest Report 2011*, Forest Survey of India (FSI), Ministry of Environment and Forests, Government of India, Dehradun.

Gitay H., Suarez A., Watson R.T. and Dokken D.J. (eds.), 2002, *Climate change and biodiversity*, A Technical Paper of the IPCC (Intergovernmental Panel on Climate Change), Geneva, Switzerland.

GoI, n.d., *National Action Plan on Climate Change*, Government of India, Prime Minister's Council on Climate Change, Available at http://pmindia.nic.in/climate_change_english.pdf

GoI, 1988, *National Forest Policy*, Resolution no. 3-1/86-FP, dated 7 Dec. 1988, Ministry of Environment and Forests, Government of India, New Delhi.

GoI, 2009, *India's Forest and Tree cover: Contribution as a Carbon Sink, Ministry of Environment and Forests*, Government of India, www.envfor.nic.in.

Haripriya G. S., 2003, *Carbon Budget of the Indian Forest Ecosystem,* Clim Change 56:291–319.

Holling C.S., 1978, *Adaptive Environmental Assessment and Management*, John Wiley, Chichester.

Hooper D.U. et al, 2005, *Effects of Biodiversity on Ecosystem Functioning: a Consensus of Current Knowledge*, Ecol. Monogr., 75, 3-35.

ICFRE, 2013, *Forest Types of India Revisited*, Indian Council of Forestry Research and Education (ICFRE, Ministry of Environment and Forests, Government of India, Dehradun.

IPCC, 2007a, *Climate Change 2007: Synthesis Report*, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)], IPCC, Geneva, Switzerland.

IPCC, 2007b, Summary for Policymakers, in Solomon S. et al (eds), 2007, *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

IPCC, 2007c, Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry M.L. et al, eds, Cambridge University Press, UK, Cambridge.

ITTO, 2006, *Status of Tropical Forest Management 2005: Summary Report*, International Tropical timber Organization, Japan.

Joyce L.A. et al, 2009, Management for Adaptation, in Seppälä R., Buck A. and Katila P., 2009, *Adaptation of Forests and People to Climate Change – A Global Assessment Report*, IUFRO World Series Vol 22, International Union of Forest Research Organizations (IUFRO), Helsinki.

Julius S.H. and West J.M. (eds), 2008, *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources*, A Report by the US Climate Change Science Program and the Subcommittee on Global Change Research, US Environmental Protection Agency, Washington, DC. 873p.

Jump A.S. and Penuelas J., 2005, *Running to Stand Still: Adaptation and the Response of Plants to Rapid Climate Change*, Ecol. Lett., 8: 1010-1020.

Kaul M., Dadhwal V.K. and Mohren G.M.J., 2009, *Land Use Change and Net C Flux in Indian Forests,* Forest Ecology and Management 258:100–108.

Kelly P.M. and Adger W.N., 2000, *Theory and Practice in Assessing Vulnerability to Climate Change and Facilitating Adaptation*, Climatic Change 47: 325–352.

Lal M. and Singh R., 2000*, Carbon Sequestration Potential of Indian Forests*, Environmental Monitoring and Assessment 60:315–327.

Lee K.N., 1993, *Compass and Gyroscope: Integrating Science and Politics for the Environment*, Island Press, Washington, D.C.

Manhas R.K. et al, 2006, *Temporal Assessment of Growing Stock, Biomass and Carbon Stock of Indian Forests*, Clim Change 74:191–221.

Manoharan T.R., 2000, *Natural Resource Accounting: Economic Valuation of Intangible Benefits of Forests*, RIS Discussion Paper # 04/2000, Research and Information System for the Neo-aligned and other Developing Countries, New Delhi.

MoEF, n.d., *Asia Pacific Forestry Sector Outlook Study-II: Country Report*, Ministry of Environment and Forests (MoEF), Government of India.

MoEF, 2006, *Report of the National Forest Commission*, Ministry of Environment and Forests (MoEF), Government of India.

MoEF, 2009, *State of Environment Report: India 2009*, Ministry of Environment of Forests (MoEF), Government of India.

MoEF, 2010a, *Climate Change and India: A 4X4 Assessment – A Sectoral and Regional analysis for 2030s*, INCCA: Indian Network for Climate Change Assessment, Ministry of Environment of Forests (MoEF), Government of India, New Delhi.

MoEF, 2010b, *National Mission for a Green India* (Under the National Action Plan on Climate Change), Ministry of Environment and Forests, Government of India, Available at http://www.naeb.nic.in/documents/GIM-Report-PMCCC.pdf

MoEF, 2012, *India: Second National Communication to the United Nations Framework Convention on Climate Change*, Ministry of Environment of Forests (MoEF), Government of India, New Delhi.

Noss R.F., 2001, *Beyond Kyoto: Forest Management in a Time of Rapid Climate Change*, Conservation Biology 15: 578–590.

Ogden A.E. and Innes J., 2007, *Incorporating Climate Change Adaptation Considerations into Forest Management Planning in the Boreal Forest*, International Forestry Review Vol.9 (3).

Osman-Elasha B. et al, 2009, Future Socio-Economic Impacts and Vulnerabilities, in Seppälä R., Buck A. and Katila P., 2009, *Adaptation of Forests and People to Climate Change – A Global Assessment Report*, IUFRO World Series Vol 22, International Union of Forest Research Organizations (IUFRO), Helsinki.

Parry M.L., Canziani O.F., Palutikof J.P. and Co-authors, 2007, *Technical Summary, Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate

Change, Parry M.L., Canziani O.P., Palutikof J.P., van der Linden J.P. and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 23-78.

Peña-Claros M. et al, 2008, *Beyond Reduced-Impact Logging: Silvicultural Treatments to Increase Growth Rates of Tropical Trees*, Forest Ecology and Management 256:1458–1467.

Prasad, 2006, *Strategy for Sustainable Forest Management in India National Status Report for ITTO Mission to India*, Sept. 2006, Ministry of Environment of Forests, New Delhi.

Ravindranath N.H. et al, 2007, *Carbon Forestry Economic Mitigation Potential in India by Land Classification*, Mitig Adapt Strateg Glob Change 12(6):1027–1052.

Ravindranath N.H., Chaturvedi R.K., Murthy I.K., 2008, *Forest Conservation, Afforestation and Reforestation in India: Implications for Forest Carbon Stocks*, Curr Sci 95(2):216–222.

Ravindranath N.H,, Joshi N.V., Sukumar R. and Saxena A., 2006, *Impact of Climate Change on Forest in India*, Current Science, 90(3):354-361.

Ribot J.C., 2009, Vulnerability does not just come from the Sky: Toward Multi-scale Pro-poor Climate Policy in Robin M. and Andrew N. (eds.), *Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World*, The World Bank, Washington, DC.

Roberts G., Parrotta J. and Wreford A., 2009, Current Adaptation Measures and Policies, in Seppälä R., Buck A. and Katila P., 2009, *Adaptation of Forests and People to Climate Change – A Global Assessment Report*, IUFRO World Series Vol 22, International Union of Forest Research Organizations (IUFRO), Helsinki.

Sarin M. et al, 1998, *Who is Gaining? Who is Losing? Gender and Equity Concerns in Joint Forest Management*, SPWD, New Delhi.

Saxena N.C., 1999, *NTFP and the Poor in India*, Planning Commission, New Delhi.

Spittlehouse D.L. and Stewart R.B., 2003, *Adaptation to Climate Change in Forest Management*, BC Journal of Ecosystems and Management Vol 4 (1).

Stern N., 2006, *The Stern Review on the Economics of Climate Change*, HM Treasury, UK, Cambridge University Press, Available at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

Stern N., 2007, *The Economics of Climate Change: The Stern Review*, Cambridge University Press, Cambridge.

UNDP (United Nations Development Programme), 2007, *Human Development Report 2007/2008, Fighting Climate Change: Human Solidarity in a Divided World*, United Nations Development Programme, New York, Available at http://hdr.undp.org/en/media/HDR_20072008_EN_Complete.pdf

UNFCCC, 2007, *Investment and Financial Flows Relevant to the Development of an Effective and Appropriate International Response to Climate Change*, United Nations Framework Convention on Climate Change, Available at http://unfccc.int/resource/docs/publications/financial_flows.pdf

UNFCCC, 2008, *Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries*, United Nations Framework Convention on Climate Change.

UNFCCC, 2010, *Potential Costs and Benefits of Adaptation Options: A Review of Existing Literature*, Technical paper, FCCC/TP/2009/2/Rev.1, 11 May 2010, Available at http://unfccc.int/resource/docs/2009/tp/02r01.pdf.

Ved, D.K. and Goraya G.S., 2007, *Demand and Supply of Medicinal Plants in India*, NMPB, New Delhi and FRLHT, Bangalore, India, Available at http://www.nmpb.nic.in/WriteReadData/links/9517830850Contents.pdf.

Vedeld P., Angelsen A., Sjaastad E. and Berg G.K., 2004, *Counting on the Environment – Forest Incomes and the Rural Poor*, Environmental Economics Series, Paper No. 98. World Bank Environment Department, Washington, DC.

Vos C.C. et al, 2008, *Adapting Landscapes to Climate Change: Examples of Climate-Proof Ecosystem Networks and Priority Adaptation Zones*, Journal of Applied Ecology 45(6): 1722–1731.

World Bank, 2006. *Clean Energy and Development: Towards an Investment Framework*. World Bank, Washington D.C., Available at http://siteresources.worldbank.org/DEVCOMMINT/Documentation/20890696/DC2006-0002 (E)-CleanEnergy.pdf.

World Bank, 2010, *The Costs to Developing Countries of Adapting to Climate Change - New Methods and Estimates*, The Global Report of the Economics of Adaptation to Climate Change Study, Consultation Draft, Available at http://siteresources.worldbank.org/EXTCC/Resources/EACC-june2010.pdf.

SESSION 4 –IMPACTS OF CLIMATE CHANGE ON FOREST AND OTHER ECOSYSTEMS

The session was chaired by Dr. Renu Singh and the two papers were presented.

Discussion

1. **Impact of climate change on Bhutan Forest Ecosystems: Reviews and possible ways forward**

Dr. Purna Bdr. Chhetri explained about symptoms of climate change in Bhutan as reflected by flash floods, heavy precipitation, changes in physiology and phenology of the plants, die back diseases and also about the dominance of obnoxious invasive species in the altered environmental conditions.

Discussion: Mr. Wasantha Dissanayake from Sri Lanka enquired about whether dieback diseases are due to pathogens in natural forests. The presenter informed that the studies carried out by expertise from Australia proved that there is no involvement of any pathogen and it can be attributed to microclimate variability.

2. **Climate Change and possible impacts of invasive species in the Knuckles world heritage forest in Sri Lanka**

Mr. Wasantha Dissanayake in his presentation, informed that invasive species as a second largest threat to biodiversity (next to habitat loss) and are creating havoc in Sri Lanka. He listed major invasive species of Knuckles world Heritage Forest and explained how allelopathic effect of these invasive species detrimental to the native species.

Discussion: Dr. Druba Jyothi Das, from RFRI asked about any quantitative study and mapping of invasive species area done in Sri Lanka. The presenter informed that so far no work done on this aspect and in near future they are planning to take up this.

The chair persons in her concluding remarks pointed out the adaptive measures to be taken to control the invasive species, to take up more up research among SAARC countries to generate sufficient data so convince the policy makers. Further she emphasized the need to take up ecosystem restoration task in a warfooting in the context of rapid changing environment.

IMPACT OF CLIMATE CHANGE ON BHUTAN FOREST ECOSYSTEMS: REVIEWS AND POSSIBLE WAYS FORWARD

Purna B. Chhetri, PhD
Deputy Chief Research Officer,
RNR RDC Yusipang, DoFPS, MoAF
Thimphu, Bhutan
purna_b2000@yahoo.com

Abstract

The forests are the most valuable renewable natural resource and storehouse of terrestrial biological diversity and ecosystem integrity. The sustained ability of this storehouse to provide goods and services depends on how best conservation and management of these forest resources are put in place. It is well documented that genetic variation is crucial for species to evolve and adapt to changing environmental conditions. There are convincing evidences that conservation and maintenance of biodiversity is necessary for proper functioning and providing of ecosystem services for sustaining life-forms and human well being. These ecosystems services are being degraded due to human induced climate change, rapid land conversions from forested ecosystems to other land uses, habitat destruction, introduction of invasive species and melting of glaciers among others. Climate change affects all aspects of life, making weather phenomenon less predictable, changed seasonal characteristics and increases the likelihood and severity of extreme events such as floods and drought. The advances in science in recent decades showed that there are credible amount of knowledge generated regarding vulnerabilities of climate change at global, regional and national scales, however the integration of such volumes of knowledge into practice remain scanty and isolated. Bhutan being a mountainous and least developed country is highly exposed to adversities of climate change and its ramifications although it had been giving the top-most priorities for conservation over development e.g. Fir forest decline in 1980s, unusual rains (greater than normal) causing flooding and widespread properties damages (e.g. flooding in southern foothills in 1992, 2000) , glacier lakes outburst (GLOB) in 1994 causing unusual flooding in Punakha valley and loss of human lives, livestock, agricultural land and other properties. The country had seen frequent droughts, unusual storms, increased frequencies of hail-storms, decrease in snow fall days in higher elevations. The mainstreaming of climate change issues into national adaptation measures are being pursued in the country, however being a developing nation, addressing all the climate change adaptation measures posed greatest challenge. Contextualizing the climate change; Bhutan alone cannot withstand its adversities, a strategic approach is needed for detailed research on different ecosystem services and functions to estimate the potential impacts of climate change involving climatologists, hydrologists, ecosystem analysts, socio-economists and policy makers e.g. inter-comparison of key physical and biological processes in the region by establishing a comprehensive regional database, institutional linkages, regional policies covering biodiversity and ecosystem conservation, water management, energy and food security and most importantly the regional inter-ministerial coordination supported by the highest levels of government is most relevant to main streaming climate change issues in the Bhutan.

Key words: Bhutan, climate change, conservation, forest types, forest resources, ecosystems services and impacts

1. **Introduction**

This paper outlines some recent advances in climate science, ecosystem resilience and suggested adaptation strategies to counter the adversities of climate change at different scales. It briefly covers Bhutan's forest types, national programs governing the forest resources, forest vulnerabilities to climate change and its national framework for adaptation to climate change.

There are compelling evidences and there is a general agreement among the world's conservation bodies that maintenance of biodiversity is necessary for proper ecosystem functioning and the provisioning of services for sustaining living beings on the earth (Schulze & Mooney, 1994; IPCC, 2007; Sharma et al, 2010). These provisions and services of ecosystems are being degraded by human activities such as human induced climate change and rapid changes in land use. Changes in land use patterns, habitat destruction, overexploitation of resources, invasive species, globalization and climate change have considerable impact on the forest resources, which in turn have impact on livelihoods of people who are dependent on those resources for various goods and services (Sharma et al., 2010). Climate is a critical factor affecting forest ecosystems and their capacity to produce goods and services. The recent advances in research on human- induced ecosystem related change have shown that species' range shifts, (Thuiller et al, 2008; McKnenney et al, 2007; Theoharides and Dukes, 2007; Walther et al, 2005; Lavergne et al, 2006; Parmessan and Yohe, 2003, Phurba et al, 2011),woody-plants encroachment into grasslands, reducing biodiversity and altering ecosystem functions (Brandt et al, 2013) mediates range shift of insects (Parkash et al, 2013) loss of potential bird habitats (Bagchi et, 2013) changes in phenology of species (Fitter and Fitter 2002 ; Miller-Rushing and Primack, 2008 ; Gordo and Sanz, 2010 ; Lambert et al., 2010; Iler et al, 2013) and biodiversity loss and possibly extinctions (Rehm and Feeley, 2013; Parmesan, 2006; Pauli et al, 2006; Foden et al, 2007); wetland loss due to land use changes combined with climate changes (Ramshoo and Rashid, 2012, article in press) are already happening at global, regional and local scales and are expected to impact further (Joshi et al, 2012) with change in temperature and precipitation.

The evidences are growing of climate change and its ramification in the Himalayan region; e.g., the satellite derived NDVI with climatic factors over two and half decades (1982-2006) along the Koshi River basin in Nepal (Zhang et al, 2013) reported increased in average growing season by 0.0008 per annum and had shown fluctuating growing seasons within the study period; Mishra et al, (2013) reported winter and spring temperature increase (approximately 0.03 to 0.08 degree per annum) along the Kaligandaki River basin in Nepal and decreased trend in precipitation and significant negative trend in snow cover area, possibly link to climate change in higher mountains which will have consequences on different aspects of social- natural ecosystem in the region.

Temperature is normally believed to be one of the most significant environmental factors determining the upper altitudinal limit of forest ecosystem i.e., the timberline (Körner, 2012; Körner and Paulsen, 2004). With global warming, it is expected that montane forest species will shift their distributions upslope and colonize other forest types (Wangda and Oshawa, 2006). The elevated temperature impacts on forest carbon and gross primary productivity (Chen et al, 2013), Liu et (2012) reported non-monsoon period, the change in runoff was influenced by air temperature and subsurface water the reduction in runoff in Kurichu, with increased temperature there will be serious consequences to water availability for hydro-powers generation as the major rivers in Bhutan depend on snowmelt for discharge. The increase in temperature lowers productivity of forest growth under drought even in productive sites (Weemstra et al, 2013). The apprehension that such changes may lead to rapid and irreversible changes in the global ecosystem (Barnosky et al., 2012; Marcott et al., 2013) has heightened the need to understand how organisms respond to these processes. The climate change will not only affect the forest ecosystems and services provided by them; it has high potential to change agricultural systems, food production and distribution (Calzadilla et al, 2013). Changes in the monsoon may contribute to rainfall anomalies that result in catastrophic droughts or floods in largely agrarian Asia (Buckley et al, 2005). In the words of Weller et al (2013), the climate change can cause utter changes in biological world:

"..Direct and indirect effects on the Earth's biota occur at all biological levels and affect cellular and physiological processes, population sizes and distributions, the evolution of species, community-level interactions, and ecosystem processes. Responses can occur at both ecological and evolutionary timescales and may include phenotypic changes within the lifetime of long-lived organisms, evolutionary changes in populations that affect range limits, hybridization that affects the integrity of species, and interactions among species that affect abundance and precipitate species loss..."

The other consequences of climate change will be on human health (Kumaresan and Sathiakumar, 2010; Sharma, 2012; Bhattacharya et al, 2006) and equally it affects wildlife and their habitats (Dorji et al, 2011; Forrest et al 2012; Friggens et al, 2013), changes in water flow regimes especially in mountainous region due to glacial lake change (Gardelle et al, 2011) with altered water flow regimes in the Himalayas (Gurung, 2011, Liu et al, 2012) and atmospheric pollution by black carbon and ozone depletion is said to be increasing (Bonasoni et, 2012), which could have wider implication to ecosystems services. It is especially important for Himalayan ecosystems as long-term agricultural sustainability and food security is heavily dependent on the water and other ecosystem services it receives from the Himalayan ecosystems (Rasul, 2010), the poor countries will suffer the bulk of the damages from climate change (Mendelsohn et al, 2006).

The most important direct driver of biodiversity loss and change in ecosystem services is said to be habitat transformation, particularly from conversion of forests into other land uses. Deforestation and degradation of primary forests has the potential to cause catastrophic species extinctions (Groom et al., 2006). Natural habitat has been displaced by human disturbance (Turner II, 2002); and it is predicted, that the pressure on land use and habitat conversion will still increase in future (Tilman et al., 2001). Ecosystem services, such as provisioning services (supply of food, fodder, timber, fuelwood; regulating services (stabilizing ecosystem processes – water storage and purification), supporting services of soil formation and nutrient cycling and other socio-cultural aspects; recreational, spiritual, religious and non material benefits contribute to secure people's livelihoods have the potential and scope to protect those species on which our future well-being depends (UNEP, 2005; Perrings et al., 2011).

The climate change affects all aspects of life, making weather phenomenon less predictable, change seasonal characteristics, and increases the likelihood and severity of extreme events such as floods and drought (Sharma et al, 2009). Assessing the impacts and vulnerability to climate change, and subsequently working out adaptation needs, requires good quality information from multiple sectors such as climatologists, hydrologists, agriculturists, socio-economists amongst others (Fischer et al. 2002; Schroter et al. 2005).

Bhutan being in fragile eastern Himalayan region is already experiencing impacts of climate change, Fir forest decline in 1980s, unusual rains (greater than normal) causing flooding and widespread properties damages (e.g. flooding in southern foothills in 1992, 2000), glacier lakes outburst (GLOB) in 1994 causing unusual flooding in Punakha valley and loss of human lives, livestock, agricultural land and other properties. In 2013, on the other extreme, the country had seen frequent droughts, unusual storms, increased frequencies of hail-storms, decreasing in snow falling days in higher elevations. In 2013, Bhutan has seen unusual outbreak of pests army worms (Namgyel, T. 2013, www.kuenselonline.com) almost all over Bhutan, infestation by alien invasive species (giant African snail) in one region in eastern Bhutan (Norbu P., 2013). The invasive plant species are encroaching the native vegetation and have high potential of threatening native diversity and altering ecosystems (Theoharides and Dukes, 2007). The recent studies showed (NBC, 2009) *Mikania micrantha*, *Chomolaena odorata*, *Ageratina adenophora*, *Lantana camara*, *Opuntia vulgaris*, *Parthenium hysterophorus*, *Tithonia diversifolia*, *Robinia pseudoacacia*, *Cannabis sativa*, *Leucaena leucocephala*, *Eichhornia crassipes*, *Ageratum conyzoides, Pennisetum clandestinum* and *Trifolium repens* are the most problematic alien invasive species in Bhutan. Declining of ecosystem connectivity in the face of climate change remains a major source of vulnerability for both terrestrial and aquatic ecosystems. Shifting habitats is considered an indirect impact of climate change for wildlife such as takin, musk deer, red panda, and snow leopards (Lhendup et al, 2011).

2. Reviews on climate change impacts on ecosystems and possible implications to Bhutan

In the Himalayan region livelihoods of people depend on native plants biomass for medicine, food, grazing resources, wood for construction and fuelwood as well as cash from market sales. The recent advances have shown most useful plants of the region were most susceptible to climate change, which directly impacts local livelihoods sources such as medicines and livestock herding (Salicka et al, 2009). The climate change impacts various natural as well as socio-economic systems in the mountain regions such as water resources, ecosystems and biological diversity, natural hazards, health issues, and tourism (Beniston, 2003), large scale vegetation shift in response to altered temperature and precipitation profoundly impacting ecological climate-ecosystem feedback mechanism through alteration of carbon, water, and energy exchanges of the land surface (Adams et al, 2009) and shift extremes and rapid in ecotones (Allen and Breshears, 1998; Dulliner et al, 2004), change phenology of organism (Both et al, 2009). In the Himalayas, a considerable proportion of the annual precipitation falls as snow (Sharma et al, 2009) and the climate controls river flow and glacier mass balance and this varies considerably from west to east (Sharma et al, 2009; Bhutiyani et al 2008). The monsoon brings heavy precipitation mostly in southeast South-Asia and simultaneously summer accumulation and summer melt in the eastern Himalayas. With increasing temperatures, areas covered by permafrost and glaciers are decreasing in much of the region (Sarikaya et al, 2013; Gurung et al, 2011). The snow masses have acted as a natural form of storage, releasing moisture slowly into the ground or rivers, water is increasingly only available at the time of precipitation (Sharma et al, 2009). This affects river regimes, natural hazards, water supplies, people's livelihoods, and overall human welfare (Xu et al. 2007; Erickson et al. 2009). The Himalayan region, including the Tibetan Plateau, has shown consistent warming trends during the past 100 years (Yao et al. 2006).

The climate change affects each and everything in the world, it should be tackled and understood in multitude of ways; there are host of suggestion to adapt to climate change and in forestry the adaptation strategy to CC should include: reducing poverty, enhancing food security, water availability, combating land degradation and reducing loss of biological diversity (Sonwa et al, 2012) e.g. importance of provenance in future adaption under climate change scenarios (Taeger et al, 2013). The climate change impacts on crop productivity Kang et al, (2009) suggested to use stochastic projections model that could provide insight into model uncertainties and to develop risk management strategies, e.g. application of multi criteria decision model (MCDM) suggested by Bell et al, (2003); Huang et al, (2005); Qin et al, (2008); Jun et al, (2013) could be used both for acquiring knowledge of climate change impacts on multi-stakeholder environments as well as formulation of relevant adaptation policies. The proper carbon emission estimating system (Cherubini et al, 2013), the ecosystem based approach (EBA) could be counter-productive to the uncertainties associated with climate change and improve social–ecological resilience of climate change (Pramova et al, 2012; Mori et al, 2013), adaptive management (Buma and Wessman, 2013), Garcia et al, (2013) reported species distribution models and habitat suitability maps for formulating appropriate science-based adaptation policies, strategies and to enhance measures of resilience of threatened forestry tree species under climate change scenarios in tropical country like Philippines, Sovacool et al,(2012) suggested a functions-based approach to climate change resilience from a case study of on climate change adaptation of Bhutan, Bangladesh, Cambodia and Maldives. Thom et al, (2013) recommended two-stage approach (slow predisposing and fast inciting factors analysis) for bark beetle epidemic prediction in Austrian forests under climate change scenarios. Invasive ecology has the potential to predict changes in species distribution and their impacts on ecosystems such as invasive species spread and adaptability (Caplat et al, 2013).Multi-level and multi-stakeholder transboundary process and adaptation of conservation measures from a species approach to a landscape approach (Chhetri, et al, 2007) including transboundary collaboration linking conservation with sustainable use of resources by local communities were some of the suggestions. The pitfalls of abundance and sampling methods in species richness and comparisons could be avoided using accumulation and rarefaction curves based on either individuals or samples recommended by Gotelli and Colwell, (2001).

Udin et al, (2007) had reported that Bhutan's renewable energy resources such as water and forests have been proven to be indispensable for development and these sectors are potentially vulnerable to the adverse impacts of climate change and environmental degradation and suggested Clean Development Mechanism (CDM) outlined in Kyoto Protocol might offer alternative pathways to mitigate climate change impacts and also contributing to sustainable development of the country. The third pole environment (TPE) initiative as reported by Yao et al (2012) could offer interactions to reveal environmental change process and mechanism to cope with responses to global changes and offer opportunities to enhancement of human adaptation to the changing environments in the Himalayan region. Similarly the climate summit for living Himalayas initiated by Bhutan, Bangladesh, India and Nepal in 2011 for sustainable production of food, water, energy and biodiversity could offer regional level interactive sustainable production.

Although there are many advances in climate change issues both understanding the processes as well as suggestions to adaptations to such changes, however there are also disagreement on which methods could be best in tackling the complex issues like climate change at global, regional, national and local scales, e.g., with global increase in temperature, the melting of glacial was highly anticipated, impacting river discharge, hydro-energy and agricultural production and Glacial Lake Outburst Flood vulnerabilities were documented especially in the Himalayan region however there is no consistent methods to claimed such changes (e.g. Rupper et al, 2012; Mukhopadhyay, 2013) that call for adoption of reliable scientific methodology to conduct such research. A study by Jain (2012) trend analysis of rainfall and temperature of Indian subcontinent clearly highlighted the need of a network of baseline stations for climatic studies in the Indian sub-continent.

In Bhutanese context ecosystem based adaptations suggested by Pramova et al, (2012); Mori et al, (2013), adaptive management (Buma and Wessman, (2013) along with MCDM tools (Bell et al, (2003); Huang et al, (2005); Qin et al, (2008); Jun et al, (2013), clean development mechanism and third pole initiatives, the living Himalayas 2011 initiatives could offer better alternative pathways in adapting to climate changes and conservations of biodiversity; involving multi-level and multi-stakeholder transboundary process and adaptation of conservation measures from a species approach to a landscape approach (Chhetri, et al, 2007) including transboundary collaboration linking conservation with sustainable use of resources by local communities could be adapted in Bhutan.

3. Current state of forests in Bhutan

The important phytogeographic elements in the indigenous flora of Bhutan are shown in Figure 1 where significant number of genera and species may be shown to have connection with flora of other part of the world.

According to the latest estimates, forest area covers 27,052.91 km^2 corresponding to about 70.46 % of the land area. In the last decade, the direct contribution of forestry to national economy remained about 5 % (NSB, 2010). However forests have many indirect contributions which are not accounted for.

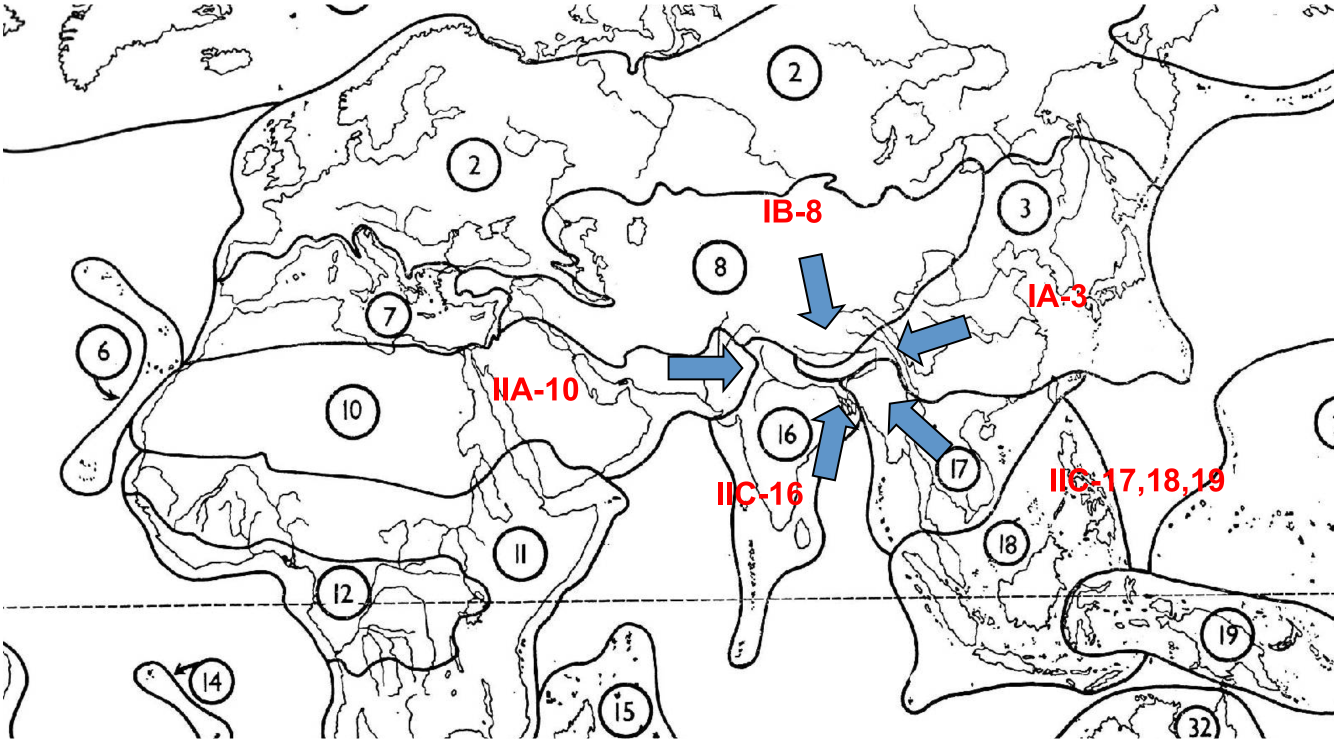


Figure 1: Map of the floristic region of the world (Takhtajan, 1969) in relation to Bhutan Himalaya in pattern of their distribution. II A. African subkingdom (10 Saharo-Sindian region), I A, Boreal subkingdom (3 Eastern Asia (Sino-Japanese) region, I B Tethyan (Ancient Mediterranean subkingdom (8 Irano-Turanian (western and Central Asiatic region, II C (Indo-Malesian (Indo-Malay) subkingdom (16 Indian region, 17 Indo-Chinese (Continental South-East Asia) region, 18 Malesian (Malayan) region, and 19 Papuan region (adapted from Oshawa, M. 2012).

The Forest provides livelihood to 69% of the population by way of supplying wood, fuel-wood, fodder, leaf-litter and non-wood forest products (DoFPS, 2011). The country being mountainous, keeping forest intact is vital to protect the fragile watersheds and farmlands. The government places a higher priority to the conservation function of forests over their economic functions. Knowing that the young and fragile Himalayan environments should be conserved for sustaining life, the Royal Government of Bhutan (RGOB) had launched several legislations aimed at regulating the sustainable management of the natural resources and environmental conservation. For instance, the Constitution of Bhutan has mandated that 60 % of the total geographical land should be under forest cover in perpetuity. In order to realise such over-arching goal, the country has declared 51.32% of the total geographical area into protected area system (PAS). These protected areas are not only rich reservoirs of biodiversity but have indirectly served as long-term stores of carbon, which may mitigate the adverse impacts of climate change. It encompasses a continuum of representational samples of all major ecosystems found in the country, ranging from the tropical/sub-tropical grasslands and forests in the southern foothills through temperate forests in the central mountains and valleys to alpine meadows in the northern mountains (NBC, 2009).

The Himalayan region is said to be on the crossroad of various geographical and endemic elements and situated on the ecotone between tropics and temperate forest types and Bhutan is centrally placed in the distribution of the rich Eurasian flora and is home to primitive angiosperms like *Decaisnea insignis* and vessel-less primitive angiosperm *Tetracentron sinense* (Oshawa, 2012). It has characteristic dry valley ecosystems along the major north-south valleys, which exhibit one of the richest concentrations of different ecosystems within a limited altitudinal or spatial range. Floristic elements concentrated in the dry valley ecosystems are the so-called Tethys elements which can be regarded as the palaeo-floristic elements once distributed along the coast of the Tethys sea (palaeo-Mediterranean sea) such as *Pinus roxburghii, Pinus excelsa, sclerophyllous Quercus semecarpifolia* trees (Oshawa, 2012).

Bhutan possesses a blend of many flora from seven known taxa from other parts of the world (Figure 2). The present floristic composition of Bhutan is made up of genera and species from SE Asia, Figure 2, IIC-17, 18, 19), some from African continent (figure 2, II A-10), Boreal taxa (Fig 2, IB-8, Sino-Japanese Taxas (I A-3), the decant (Indian taxas, IIC-16) .The elements from SE Asian region are more evident in Bhutan mostly in warm broadleaved and sub-tropical forests.

The detailed and systematic classification of the vegetation of Bhutan had been not been undertaken so far. The British botanists Grierson and Long (1983) roughly classified the Bhutanese vegetation into eleven types based on altitude and precipitation gradients. According to that classification, the sub-tropical, warm broad leaved and cool broadleaved types occur along high precipitation gradient with altitude ranging from 180-3000 m and precipitation above 3000 mm/year upto 4000 mm/year. The broadleaved scrub forest, evergreen oak, hemlock, fir and juniper-rhododendron and various mixture of conifer and broadleaved tree species are found in medium precipitation (1500-upto 3000 mm/year) and altitude ranging from 1000 upto 4300 masl. The most xeric forest types are chirpine and bluepine forests and are found in dry inner valleys. The chirpine forests are found from 900 upto 2000 masl in parts of west central and eastern inner dry valleys of Bhutan. The alpine meadows are the upper-most vegetation zone and are found above 4000 m. Oshawa (1987) had classified the Bhutanese vegetation considering altitude, precipitation, topography and dominant vegetation types and according to this study ten major dominant zones were identified (Figure 2).

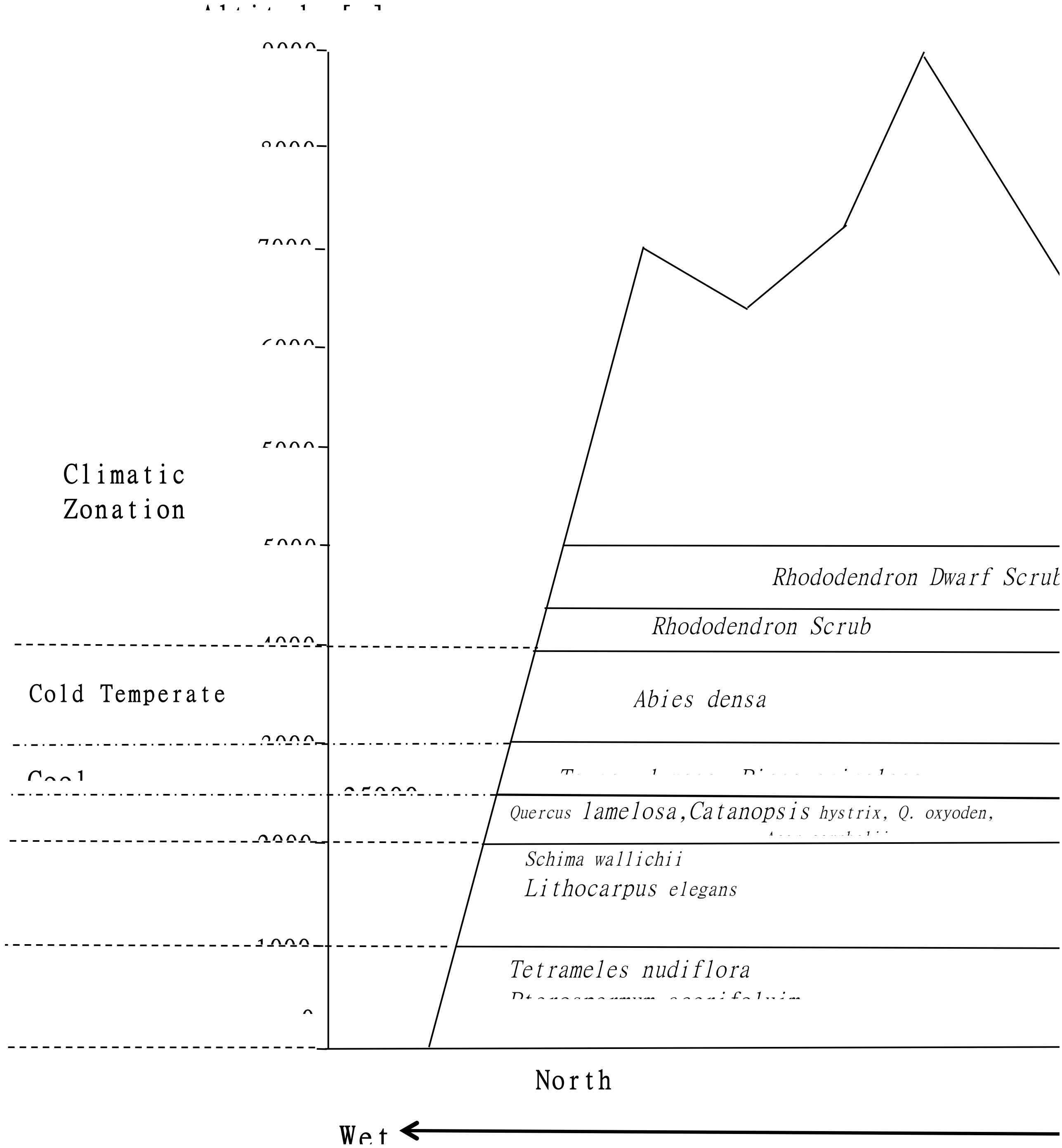


Figure 2: Scheme of vegetation distribution in Bhutan, according to precipitation and altitudinal gradient (after Oshawa, 1987).

4. National programs on forests and biodiversity conservations

Knowing its vital role for multiple functions, Bhutanese government placed high priority to the conserve the forests forgoing their economic benefits; In support of conservation of fragile environments, RGOB had enacted several legislations regarding the wise use of natural resources (eight Acts, nine policies and six rules and regulations). Further, the protection function of forest is increasingly important to protect watersheds which are indispensable to generate sustained hydro-electricity. The Bhutanese economy is largely based on revenue from hydro electricity (NBC, 2011).

The Ministry of Agriculture and Forests (MoAF) with its Department of Forests and Park Services (DoFPS) is the primary agency accountable for formulation of rules and regulations, policies and administration of forest resources including its ex-situ conservation. The Department of Forests (DoF) then, was established in 1952, since then it had been the main custodian of forest resources of the country. It is the main agency which frames strategies and policies for conservation and sustainable management of forest resources in consonance with national laws and priorities. Since its creation, DOFPS had gone strength to strength in conservation and sustainable management of forestry resources of the country. With its creation, the country could maintain more than 60 % forest cover upto today.

DOFPS implements its various forest resources related programs through its field division offices, national parks, wildlife sanctuaries, nature reserves and biological corridors located at strategic locations around the country. There are six functional divisions under DOFPS which contribute towards conservation and sustainable management of forest resources in the country. Out of six functional divisions, Watershed Management Division is entrusted to co-ordinate the climate change related programs in the country.

In order to support the sustainable management of forests resources, the need was felt to strengthen the forestry information base in all aspects and the Department of Forests created Forest Research Division in 1987 with a base at Taba, Thimphu. Since its inception, number of applied research works in sustainable forest management, forest ecology, non-wood forests products, human-wildlife conflicts and socio-economics of forest products were conducted. E.g. the group selection silvicultural system followed in temperate conifer forests was recommended from the research and likewise most of the development works within forestry sectors had their root in research. However with rapid change of socio-economic conditions and political climate, the forestry research should play proactive role in providing science based information to decision makers regarding various aspects of forests resources including climate change. In order to meet the emerging demand for various scientific information for various purposes the 11th five year plan (2013-2018) was aligned to achieve national goal of food security without compromising the conservation principles. Broadly the forest research will conduct research activities under three thematic areas (1) climate change and species conservation which includes species adaptation to climate change, wildlife and biodiversity conservation, (2) Water resource conservation and management which includes payment for environmental services, forest and carbon, soil water hydrology and (3) sustainable forest management and livelihood which includes all aspects of forests management including wood and non-wood forests products.

5. Vulnerability of Biodiversity and Ecosystem Services in an era of Climate Change in Bhutan.

Bhutan is a small Himalayan mountainous country with relatively small population and intact environment and forest conditions. Its geographical location combined with its physical relief enable different ecosystems to exist which host many ecosystems and are home to variety of life forms. Because of low human populations, these varieties of ecosystems and life-forms could evolve and thrive up to today. However, this trend is increasingly being under pressure due to increased developmental activities such as construction of hydropower, roads, other vital infrastructure for social- economic development and climate change in recent decades. Emerging from subsistence economy towards more integrated market economy, Bhutan is at the junction of conservation, development and climate change dilemma. All its past glory of conserving natural environments is faced with paradox. E.g. Hydropower development and road constructions are said to be the main drivers of land degradation **(**WMD, 2013**).**

The loss of biodiversity had been attributed to several factors such as changes in land use, over exploitation of natural resources, destruction of natural habitats, urbanization, human wildlife conflict, forest fires, hydropower development, industrial development, and invasive species among others. The climate change is said to compound the effects of stressors (CBD, 2009; MEA, 2005) and is likely to become the dominant direct driver of biodiversity loss in future. Human-induced climate change threatens biodiversity loss even further (Gitay et al, 2002, MEA, 2005).The global temperature is increasing and impact of such increased is changes in alpine treeline and glacial recession in higher altitude and latitude (Baker and Moseley, 2007) and rapidly warming climate and land use policy threatening both biodiversity and local livelihoods. The global warming is enhancing glacier retreats in parts of the Himalayas (Bolch et al, 2012).The Greater Himalayas hold the largest mass of ice outside Polar Regions and are the source of the 10 largest rivers in Asia and any changes will have cascading effects on water availability, biodiversity (endemic species, predator-prey relations), ecosystem boundary shifts (tree-line movements, high-elevation ecosystem changes), and global feedbacks of monsoonal shifts and loss of soil carbon (Xu et al, 2009). The sustainability of social-ecological systems depends on river flows being maintained within a range to which those systems are adapted to.

The climate change in mountain ecosystems has a high potential to cause severe decline or even loss of ecosystem and are prone to severe consequences of climate change considering low ecological and economics resilience. In fact, its location in the Himalayas makes it more vulnerable to the impacts of climate change because warming trends are higher and the impacts are magnified by the extreme changes in altitude over small distances (Shrestha & Eriksson, 2009). These raise concerns for the persistence of our biodiversity and the livelihood of 69 percent of our rural population who depend directly on agriculture and natural resources.

Furthermore, with climate change the disturbance regimes such as increased forest fire incidences, windy/stormy weather, increased incidences of forest pest and diseases aggravates the resilience of Bhutanese forests. Developing and adopting an adaptation strategy to increase the resilience of ecosystems against such climate related adversaries/calamities needs systemic knowledge, however there are no systematic studies in the country on climate change impacts on species as well as species response to such changes thus far.

The average rate of glacial retreat in Bhutan from 1963 to 1993 was estimated at about 2 m/year vertically and about 7 m/year horizontally, about 8.1 percent area shrinkage in 66 selected glaciers in 30 years (Tse-ring et al, 2003). Reports pointed that in coming decades, many Himalayan glaciers will retreat with smaller glaciers disappearing altogether (Eriksson et al, 2009; Gurung et al, 2011). With such disappearance of glaciers, the growth and life cycle of alpine vegetation may be disrupted owning to lack of snow melt water (Singh, undated). Such situation could lead to change in species composition, structure and functioning of alpine meadows leading to the habitat alteration and disappearance of ecologically sensitive and economically important species such as *Ophiocordyceps sinensis* and other important medicinal plants such as *Picorrhiza spp*, *Fritillaria* and *Rhodiola,* among others. Further, such situation will severely disrupt the live of communities living in those areas (NBC, 2011).

Although no studies had been conducted on response of climate change to shifting of tree line the forest types might experience disarray/shift from one type of forests to another. For example Bluepine (*Pinus wallichiana*) encroachment into spruce/maple/birch forests was observed in some pockets in the country. The strong correlation between the upper limit of evergreen broadleaved species and the winter temperature was reported The distribution of evergreen broad-leaved species along the altitudinal slope of dry valley mid-hills was limited by coldest month's mean temperature of minus one degree Celsius which coinciding at 2900 masl (Wangda & Ohsawa, 2006). There was increased trend of winter temperature over a decade (Figure 2) (RNR RDC Yusipang unpublished data, 2010). The increased in temperature varied between locations, on averaged the increased was 0.09^0C/year, such increased trend of temperature, which might have increased the upper limit of evergreen broadleaved species from 2900 m to higher altitudes in future which might lead to the disruption of conifer forest ecosystems (Wangda and Oshawa, 2006).

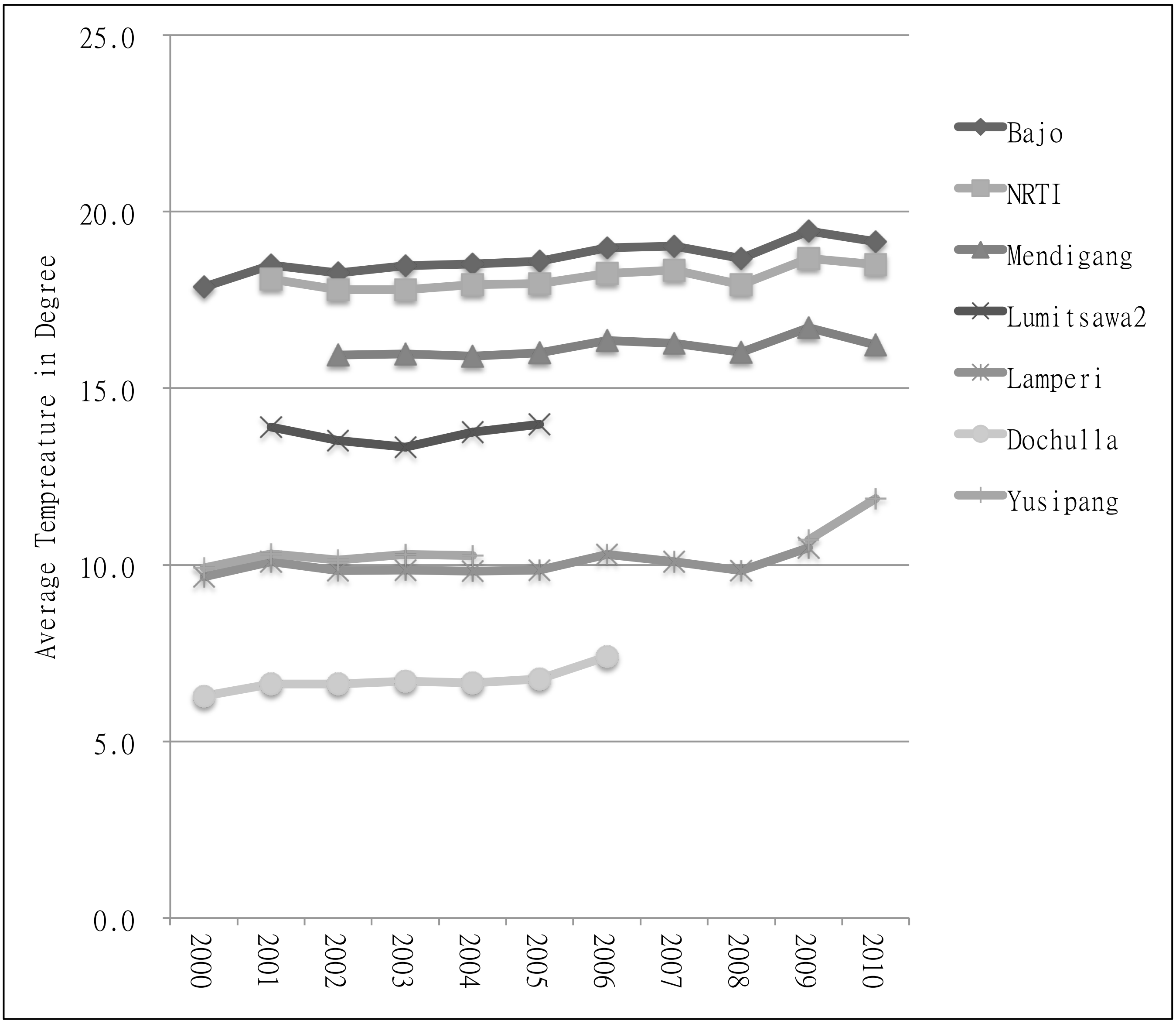


Figure 3: Average temperature (2000-2010) in mid-Himalayas east facing slope from valley bottom Bajo (1200 m) to mountain pass Dochula 3120 m exception Yusipang (2700 m) lies in western facing slope in upper limit of dry valley.

Similarly, the upper limit of conifer species forest types *Abies densa, Tsuga-Picea and Juniperus-Rhododendron types* may shift higher or may become extinct in the process. In the cold temperate forest ecosystem, *Abies densa* forests on the mountain tops declined in the 1980s due to moisture stress (Donaubauer, 1986 and 1994, Gratzer et al, 1997). With rising temperature, leading to increased incidences of moisture stresses, the vulnerability of this forest type is high. Concerns are similar for other forest types which are vulnerable to change in temperature and human disturbances which could lead to habitat loss for some important relict plant species like *Taxus, Magnolia, Tetracentron* and endangered bird species such as hornbills. The projection of climate change scenarios on forest types in India (Gopalakrishnan et al, 2011) using models showed 45 % of the forest to undergo change and the vulnerabilities to such climatic change was mostly concentrated in the upper Himalayan stretches, parts of Central India, northern Western Ghats and the Eastern Ghats indicating that Bhutan forests will certainly be impacted with climate change. Therefore Integration of climate change aspects in biodiversity management is the fundamental requirements for long term biodiversity conservation (Sharma et al,2010) and species specific conservation measures (e.g., Bisht, 2011) for critical species. A major forest types and processes involved that may have impact on different forest types of Bhutan are presented (Table 1). The possible impact from climate change will be range of species shifts, invasion by alien species, degradation of forest ecosystems by forest fires and outbreak of pest and diseases. The drought may wipeout sensitive species, the glacial melting disrupt life cycles of important medicinal plant and fungi species in higher elevations. There are high possibilities of alpine meadows turning into brush lands as evident from several reported cases in the region (Lhendup et al, 2011; Vijayprakash and Ansari 2009 cited by Lhendup et al, 2011; Dubey et al. 2003).

Table 1: The Forest types, climatic zonation, mechanism of potential climate change and drivers of change on the Bhutanese ecosystems (After Grierson and Long 1983 and Champion Seth, 1968)

Grierson and Long (1983)	Champion and Seth (1968)	Altitude (m)	Impact mechanism	Drivers of change
Sub-tropical region	East Sub-Himalayan wet mixed Forest	200-1000 (1200)	Ecological range shift of species ,invasion by alien species on native vegetations	Climate change (droughts, floods, increased temperature) , socio-economics (land use changes, transport, developmental activities (hydropower, roads) and fragile geology
Warm-broadleaved zone (	Bengal Sub tropical Forests hill forest	1000-2000 (2300)	Ecological range shift of species ,invasion by alien species on native vegetations, possible extinctions due to displacement and degradation of habitats	Climate change (droughts, floods, increased temperature) , socio-economics (land use changes, grazing, transport, developmental activities hydropower, roads) Inherit (fragile geology
Chirpine zone	Himalayan subtropical pine forests	900-1800 (2000)	Ecological range shift of species ,invasion by alien species on native vegetations, possible extinctions	Climate change (droughts, floods, increased temperature, pest and diseases) , socio-economics (land use changes, grazing, transport, forest fire, developmental

			due to displacement and degradation of habitats	activities hydropower, roads) Inherit (fragile geology
Cool broadleaved	Eastern Himalayan wet temperate forests	2000-2900		
Evergreen oak	Eastern Himalayan wet temperate forests	1800-2600	Ecological range shift of species ,invasion by alien species on native vegetations, possible extinctions due to displacement and degradation of habitats	Climate change (droughts, floods, increased temperature, pest and diseases) , socio-economics (land use changes, grazing, transport, logging and collections of nwfps, forest fire, developmental activities, hydropower, roads) Inherit (fragile geology)
Bluepine zone	Lower Bluepine forests	2100-3100	Ecological range shift of species ,invasion by alien species on native vegetations, possible extinctions due to displacement and degradation of habitats	climate change (droughts, floods, increased temperature, pest and diseases) , socio-economics (land use changes, grazing, transport, logging and collections of nwfps, forest fire, developmental activities, hydropower, roads) Inherit (fragile geology)
Spruce zone	Eastern mixed coniferous forest	2500-3200	Ecological range shift of species ,invasion by alien species on native vegetations, possible extinctions due to displacement and degradation of habitats	Climate change (droughts, floods, increased temperature, pest and diseases) , socio-economics (land use changes, grazing, transport, logging and collections of nwfps, forest fire, developmental activities, hydropower, roads) Inherit (fragile geology)
Hemlock zone	Eastern oak-hemlock forests	2800-3200	Range shift of species, possible extinctions due to displacement and degradation of habitats.	Tourism , grazing , illegal collections , over harvesting , climate change (retreat of glaciers)
Fir zone	Eastern oak-fir forest	3100-3800	Ecological range shift of species ,invasion by alien species on native vegetations, possible extinctions due to displacement and degradation of habitats	Tourism , grazing , illegal collections , over harvesting , climate change (retreat of glaciers)

Juniper rhododendron scrub zone	Moist alpine scrub	3700-4200	Ecological range shift of species ,invasion by alien species on native vegetations, possible extinctions due to displacement and degradation of habitats	Tourism , grazing , illegal collections , over harvesting , climate change (retreat of glaciers)
Dry alpine scrub	Dry alpine scrub	4000-4700	Ecological range shift of species ,invasion by alien species on native vegetations, possible extinctions due to displacement and degradation of habitats	Tourism , grazing , illegal collections , over harvesting , climate change (retreat of glaciers)

6. Bhutan's framework on climate change

Bhutan is party to the United Nations Convention on Biological Diversity (UNCBD), United Nations Framework Convention on Climate Change (UNFCC), United Nations Convention to Combat Desertification (UNCCD), and United Nations Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES). Most recently, Bhutan committed to remain carbon neutral during the United Nations Climate Change Conference, COP 15 at Copenhagen in 2011.

Bhutan is committed to a strong national conservation mandate not only for its national well-being but also to add to global well-being in line with its development philosophy of Gross National Happiness. The climate change issues are seriously perused by Royal Government of Bhutan. Thus Bhutan's Gross National Happiness Commission (GNHC) the body responsible for developing and planning overall development plans for the country had adapted a framework called **"Mainstream Environment, Climate Change and Poverty (ECP)"** in the 11th five year plan (2013-2018). In order to make ECP mainstreaming more pragmatic GNHC had included a separate provision requiring all central and local agencies to formulate ECP-integrated development plans and programs. Further the agencies' outcomes from ECP related activities will be monitored and evaluated through national monitoring and evaluation systems (National Key Results Areas (NKRAs) and Sector Key Result Areas (SKRAs) (GNHC, 2012). The climate change and strategized climate change adaptations mechanism were put in placed such as National Adaptation Program of Action and National Action Plan Biodiversity Persistence and Climate Change (NBC, 2011).

However this commitment is not without challenges when considering the fact that 69% of the Bhutanese population still live on subsistence agriculture and their high dependence on natural resources. Inadequate information coupled with poor information sharing mechanism, inadequacy in the knowledge of forests and associated interactions are the main constraints to develop sound and improved management practices for forest resources in the country.

The review showed clearly that there is a considerable knowledge of the natural resources in the Eastern Himalayas and their vulnerability to climate change; however in Bhutan, many of those advances in science need to be developed especially on systematic monitoring and documentation and to link the status of biodiversity with similar conditions of the region. Despite various projections of climate change vulnerabilities; little attention was paid to generate science base information on adaptations to climate change adversaries on regional scale. Apparently there is also shortfall of human, institutional set ups and linking of policy imperatives to tackle climate change issues at the regional scale. The review clearly highlights the need for comprehensive plan of actions on adaptations to climate change at the regional scale as climate change impacts are interdependence and inter connected.

Contextualizing the climate change; Bhutan alone cannot withstand its adversaries, a strategic approach is needed for detailed research on different ecosystem services and functions to estimate the potential impacts of climate change involving climatologists, hydrologists, ecosystem analysts, socio-economists and policy makers e.g. inter-comparison of key physical and biological processes in the region by the establishing a comprehensive regional mountain database, institutional linkages, regional policies covering biodiversity and ecosystem conservations, water management, energy and food security.

7. Conclusion

There are convincing evidences that conservation that maintenance of biodiversity is necessary for proper functioning and provisioning of services for sustaining life-forms and human well beings. These provisioning from ecosystems are being degraded due to human induced climate change, rapid land conversions from forested ecosystems to other land uses, habitat destruction, and introduction of invasive species, melting of glaciers among others. The climate change affects all aspects of life, making weather phenomenon less predictable, changed seasonal characteristics, and increases the likelihood and severity of extreme events such as floods and drought. The advances in science in recent decades showed that there are credible amount of knowledge generated regarding vulnerabilities of climate change global, regional and national scales, however the integration of such volumes of knowledge into practices remain scanty and isolated. Bhutan being mountainous and least developed country is highly exposed to adversaries of climate change and its ramifications although it had been giving the top-most priorities for conservation over development e.g. Fir forest decline in 1980s, unusual rains (greater than normal) causing flooding and widespread properties damages (e.g. flooding in southern foothills in 1992, 2000) , glacier lakes outburst (GLOB) in 1994 causing unusual flooding in Punakha valley and loss of human lives, livestock, agricultural land and other properties. The country had seen frequent droughts, unusual storms, increased frequencies of hail-storms, decreasing in snow falling days in higher elevations. The mainstreaming of climate change issues into national adaptation measures are being pursued in the country, however being developing nation and putting all the climate change adaptation measures posed greatest challenge. In the context of climate change; Bhutan alone cannot withstand the adversaries of changes, a strategic approach is needed for detailed research on different ecosystem services and functions to estimate the potential impacts of climate change involving climatologists, hydrologists, ecosystem analysts, socio-economists and policy makers e.g. inter-comparison of key physical and biological processes in the region by the establishing a comprehensive regional database, institutional linkages, regional policies covering the basic fundamentals of human wellbeing such as biodiversity and ecosystem conservations, water management, energy and food security. And most importantly the regional inter-ministerial coordination supported by the highest levels of government is most relevant (Saito, 2013) to main streaming climate change issues in the Bhutan.

References

Adams, H.D., Guardiola-Claramonte, M., Barron-Gafford, G.A., Villegas, J.C., Breshears, D.D., Zou, C.B., Troch, P.A., and Huxman, T.E., (2009). Temperature sensitivity of drought-induced tree mortality portends increased regional die-off under global-change-type drought. PNAS (106), 17: pp. 7063-7066.

Allen, G.D., and Breshears, D.D. (1998). Drought-induced shift of a forest–woodland ecotone: Rapid landscape response to climate variation. Proc. Natl. Acad. Sci. (95), pp 14839-14842.

Arora, M. , Goel, N.K., and Singh, P. (2005). Evaluation of temperature trends over India. Hydrological Sciences Journal. (50), 1: pp. 81-93.

Baker, B.B. and Moseley, R.K. (2007). Advancing treeline and retreating glaciers: Implications in conservation in Yunnan, P.R. China. Artic, Antarctic and Alpine Research. (39), 2. pp. 200-209.

Bagchi, R., Crosby, M., Huntley, B., Hole, D.G., Butchart, S.H.M., Collingham, Y., Kalra, M., Rajkumar, J., Rahmani, A., Pandey, M., Gurung, H., Trai, L.T., Van Quang, N., Willis, S.G. (2013). Evaluating the effectiveness of conservation site networks under climate change: Accounting for uncertainty. Global Change Biology (19), 4 , Pages 1236-1248.

Bell, M.L., Hobbs,B. F. and Ellis,H. (2003). The use of multi-criteria decision-making methods in the integrated assessment of climate change: implications for IA practitioners. Socio-Economic Planning Sciences (37) pp. 289–316.

Beniston, M. (2003). Climatic Change in Mountain Regions: A Review of Possible Impacts. Climate Variability and Change in High Elevation Regions: Past, Present & Future. Advances in Global Change Research (15) 2003, pp 5-31.

Bhattacharya, S. , Sharma, C., Dhiman, R.C., and Mitra, A.P. (2006). Climate change and malaria in India (Review): (90), 3. pp 369-375.

Bhutiyani, M.R. , Kale, V.S., and Pawar, N.J. (2010).Climate change and the precipitation variations in the northwestern Himalaya: International Journal of Climatology (30), 4, Pages 535-548.

Billionnet, A. (2013). Mathematical optimization ideas for biodiversity conservation: Invited Review. European J.of Operational Research,(231) pp.514-534.

Bisht, H., Prakash, V., and Nautiyal, R. (2011). Conservation strategies for the threatened quercus semecarpifolia sm. a himalayan timberline oak. International Journal of Conservation Science. (2) 4 pp 275-284.

Buma, A. and Wessman,C.A. Forest resilience, climate change, and opportunities for adaptation: A specific case of a general problem. For. Ecol. And Mgt. (306) pp.216-225.

Bonasoni, P., Cristofanelli, P. , Marinoni, A., Vuillermoz, E.,and Adhikary, B. (2012). Atmospheric pollution in the Hindu Kush-Himalaya region. Mountain Research and Development. (32), 4. pp. 480-486.

Bolch,T. Kulkarni, A.,Kääb,A.,Huggel1,C., Paul1,F.,Cogley,J.G.,Frey1,H.,5, J. S. Karge,J.S., Fujita,H., Scheel1,M., S. Bajracharya,S. and Stoffel, M. (2012). Review: The State and Fate of Himalayan Glaciers. Science (336),6079, pp. 310-314.

Both, C., Asch van, R.G., Burg van den, A.B., and Visser, M.E. (2009). Climate change and unequal phenological changes across four trophic levels: constraints or adaptations? Journal of Animal Ecology: 78 , pages 73-83.

Brandt, J.S., Haynes, M.A., Kuemmerle, T., Waller, D.M., and Radeloff, V.C. (2013). Regime shift on the roof of the world: Alpine meadows converting to shrublands in the southern Himalayas. Biological Conservation (158) 2013, Pages 116-127.

Buckley, B.M., B. I. Cook, B.I., A. Bhattacharyya,A., Dukpa,D., and Chaudhary, V. (2005). Global surface temperature signals in pine ring-width chronologies from southern monsoon Asia. Geophysical Research Letters. (32), L 20704.

Caplat,P.,Cheptou, P.O., Diez , J.,Guisan, A., Larson, B. M. H. , Macdougall, A. S., Peltzer, D. A., Richardson,D. M.,Shea ,K ., van Kleunen , M., Zhang,R., and Buckley, Y. M., (2013). Movement, impacts and management of plant distributions in response to climate change: insights from invasions. Oikos (122) pp.1265–1274.

Champion, H.G., and Seth, S.K., (1968) reprint in 2005. General Silviculture for India. Natraj Publishers , Dehra Dun, India.

Chen, B.,Araizn, M.A. , Khomik, M., Trofymow, J.A.,Grant, R.F. , Kurz, R.A., . Yeluripati , J. and Wang, J.Z. (2013).Evaluating the impacts of climate variability and disturbance regimes on the historic carbon budget of a forest landscape. Agri. And For. Met. (180), pp.265-280.

Cherubini,F., Bright, R.M., and Strømman, A.H. (2013).Global climate impacts of forest bioenergy: what, when and how to measure? 2013 Environ. Res. Lett. 8 014049.

Chhetri, N., Sharma E, Shakya, B., and Bajracharya, B. (2007). Developing Forested Conservation Corridors in the Kangchenjunga Landscape, Eastern Himalaya. Mountain Research and Development (27) 3 pages 211–214.

Coblentz, B.E 1990. Exotic organisms: a dilemma for conservation biology. Conserv. Biol., 4 (1990), pp. 261–265.

DOFPS. (2011). National Forest Policy of Bhutan. RGOB, MoAF, Thimphu Bhutan.

DoFPS (2011). Forestry facts, figures & trends. DoFS, MoAF.

Donaubauer, E. (1986): Technical Advisory Services for Forest Development Bhutan Forest Pathology, FAO (Rome).

Donaubauer, E. (1994): On the Decline of Fir (Abies densa Griff.) in Bhutan. Institute of Forest Protection, Forest Research Station, Vienna (Austria).

Dorji S, Vernes K, Rajaratnam R (2011) Habitat Correlates of the Red Panda in the Temperate Forests of Bhutan. PLoS ONE 6(10): e26483. doi:10.1371/journal.pone.0026483.

Dubey, B., R. R. Yadav, J. Singh, and R. Chaturvedi. “Upward shift of Himalayan pine in western Himalaya, India.” Current Science 85, no. 8 (2003): 1135-1136.

Dukpa, D. 2012 , Distribution of invasive alien plant species along the altitudinal gradient of Bhutan. B.Sc dissertation , Dolphin Institute of Bio-medical and Natural Sciences, H.N.B.Garhwal Central University , Srinagar, Uttarakhand, India.

Dullinger, S., Dirnbock, T. and Grabherr, G. Modelling climate change-driven treeline shifts: relative effects of temperature increase, dispersal and invisibility. Journal of Ecology, 92 241-252.

Eriksson, M; Jianchu, X., Shrestha, A.B.; Vaidya, R.A.; Nepal,S., and Sandström K., (2009). The changing Himalayas: Impact of climate change on water resources and livelihoods in the Greater Himalayas. Kathmandu: ICIMOD.

Fischer, G., Shah, M., and van Velthuizen, H., (2002) .Climate change and agricultural vulnerability, special report to the UN World Summit on Sustainable Development, Johannesburg 2002. Laxenburg (Austria): Int’l Inst. for Applied Systems Analysis.

Fitter,A.H., and Fitter, R.S.R. 2002 .Rapid changes in flowering time in British plants . Science 296: 1689-1691.

Forrest, J.L., Wikramanayake, E., Shrestha, R., Areendran, G., Gyeltshen, K., Maheshwari, A., Mazumdar, S., Naidoo, R., Thapa, G.J., Thapa, K. (2012). Conservation and climate change: Assessing the vulnerability of snow leopard habitat to treeline shift in the Himalaya. Biological Conservation.(150), 1: Pages 129-135.

Friggens, M.M., Finch, D.M., Bagne, K.E., Coe, S.J., and Hawksworth, D.L. (2013). Vulnerability of species to climate change in the Southwest: Terrestrial species of the middle Rio Grande. General Technical Report RMRS-GTR, USDA Forest Service: 306 GTR, pages i-191.

Garcia, K., Lasco, R., Ines, A. Lyon, B., and Pulhin, F. (2013). Predicting geographic distribution and habitat suitability due to climate change of selected threatened forest tree species in the Philippines. Applied Geography 44 (2013) pp.12-22.

Gardelle, J., Arnaud, Y. and Berthier, E.(2011). Contrasted evolution of glacial lakes along the Hindu Kush Himalaya mountain range between 1990 and 2009. Global and planetary change 75 (2011) pp. 47-55).

GISP, 2004. Tropical Asia invaded: the growing danger of invasive alien species. The Global Invasive species programme. 64 pp.

Gitay, H., Suarez A., Watson, R.T., Dokken, D.J., (eds.), (2002). Intergovernmental Panel on Climate Change, Technical paper V.

Gopalakrishnan, R., Jayaraman, M., Bala, G., and Ravindranath, N.H.(2011). Climate change and Indian forests. Current Science (101) 3 pp. 348-355.

Gordo, O. and Sanz, J.J,2010. Impact of climate change on plant phenology in Mediterranean ecosystems. *Global Change Biology* 16 : 1082 – 1106 .

Gotelli , N.J. and Colwell, R. (2001) Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Reviews: Ecology Letters, (4) : pp.379-391.

Grabherr, G., Gottfried, M., and Pauli, H. (2010). Climate change impacts in Alpine Environments. Geography Compass: (4/8) pp.1133-1153.

Gratzer, G., Rai, P.B., and Glatzel, G. (1997). Ecology of the Abies densa forests in IFMP Ura, DoF, MoA Bhutan.

Groom, M.J., Meffe, G.K. & Carroll, C.R. (2006) Principles of Conservation Biology, Third Edition edn. Sinauer Associates, Sunderland.

GNHC (2012). Framework to Mainstream Environment, Climate Change and Poverty (ECP) concerns into the Eleventh Five Year Plan (2013-2018). Gross National Happiness Commission, Royal Govt. of Bhutan, Thimphu.

Gurung, D.R. , Kulkarni, A.V., Giriraj, A., Aung, K.S., and Shrestha, B.(2011). Monitoring of seasonal snow cover in Bhutan using remote sensing technique. Current Science. (101), 10: pp 1364-1370.

Huang,Y.F., Huang, G.H.,Maqsood, I. and Chakma, A.(2005). Development of an expert system for tackling the public's perception to climate-change impacts on petroleum industry. Expert Systems with Applications (29) pp. 817–829.

Iler, A.M, HØye,T.T. Inouye, D. W., and Schmidt, N.M.(2013). Long-term trends mask variation in the direction and magnitude of short-term phonological shifts. American Journal of Botany 100(7): 1398–1406.

Iler, A.M, HØye,T.T. Inouye, D. W., and Schmidt, N.M. (2013). Nonlinear flowering responses to climate: are species approaching their limits of phenological change? Phil.Trans. R.Soc.B. 368: 20120489.

IPCC, (2007). Climate Change 2007: Synthesis Report.

Jain, S.K., and Kumar, V. (2012). Trend analysis of rainfall and temperature data for India (Review): (102),1: pp 37-49.

Jain, S.K.a, Kumar, V., and Saharia, M. (2013). Analysis of rainfall and temperature trends in northeast India (33), 4: Pages 968-978.

Joshi, P.K. , Rawat, A., Narula, S., and Sinha, V. (2012). Assessing impact of climate change on forest cover type shifts in Western Himalayan Eco-region. Journal of Forestry Research (23) 1, pp. 75-80.

Jun, K., Chung, E. and Kim, Y. (2013). A fuzzy multi-criteria approach to flood risk vulnerability in South Korea by considering climate change impacts. Expert Systems with Applications. (40) pp.1003-1013.

Kang,Y., Khan, S., and Ma, X. (2009). Climate change impacts on crop yield, crop water productivity and food security – A review. Progress in Natural Science (19) pp.1665–1674.

Kumaresan, J. and Sathiakumar, N.(2010). Climate change and its potential impact on health: a call for integrated action Bull World Health Organ 2010;88:163 doi:10.2471/BLT.10.076034.

Körner, C., 2012. Alpine Treelines. Springer, Basel, Switzerland.

Kumar, V., and Jain, S.K. (2010). Trends in seasonal and annual rainfall and rainy days in Kashmir Valley in the last century. Quaternary International (212), 1Pages 64-69.

Körner, C., Paulsen, J., 2004. A world-wide study of high altitude treeline temperatures. J. Biogeogr. 31: 713–732.

Lambert A. M.,Miller-Rushing,A. J.,and Inouye. D.W. 2010 . Changes in snowmelt date and summer precipitation affect the flowering phenology of *Erythronium grandiflorum* (glacier lily; Liliaceae). American Journal of Botany 97: 1431 – 1437.

Lhendup,P.,Wikramanayake, E., Freeman, S.,Sindorf, N., Gyeltshen, K., and Forrest, J. (2011). Climate Change Vulnerability assessment of Wangchuck Centennial Park. WWF, Bhutan.

Liu, J., Wang, Z., Gong, T., and Uygen, T., (2012). Comparative analysis of hydroclimatic changes in glacier-fed rivers in the Tibet- and Bhutan-Himalayas. Quaternary International 282 (2012) pp. 104-112.

Long,D.G.,Grierson, A.J.C (1983). Flora of Bhutan including a record of plants from Sikkim Vol. I Part I. RBG. Edinburgh.

Maanson, G.P., Resler, L.M., Bader, M.Y., Holtmeier, F.K., Butler, D.R., Daniels, L.D. and Fagre, D.B.,(2011). Mountain Treelines: a Roadmap for Research Orientation Arctic, Antarctic, and Alpine Research, (43) 2, pp. 167–177.

Marcott, S.A.,Shakun, J.D.,Clark, P. U.,and Mix,A.C.(2013) . A reconstruction of regional and global temperature for the past 11,300 years. Science 339: 1198-1201.

McKenney, D.W., Pedler, J.H., Lawrence, K., Campbell, ,K., and Hutchinson, M.F.(2007). Potential Impacts of Climate Change on the Distribution of North American Trees, BioScience, (57), 11, pp. 939-948.

Miller-Rushing, A.J., and Primack, R.B. (2008).Global warming and flowering time in Thoreau's Concord: A community perspective Ecology 89: 332-341.

Mendelsohn, R., Dinar, A., and Williams, L. (2006) distributional impact of climate change on rich and poor countries. Environment and Development Economics Issue 2. pages 159-178.

Millenium Ecosystem Assessment (MEA) (2005) Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington D.C.

Mishra,B. Babel, M.S. and tripathi, N.K.(2013). Analysis of climatic variability and snow cover in the Kaligandaki River Basin, Himalaya, Nepal. Theoretical and Applied Climatology. (2013) pp.1-14.

Mooney,H.A and Hobbs R.J. (Eds.), (2000). Invasive Species in a Changing World, Island Press, Washington, DC.

Mori, A.S, Species, T.A., Sudmeier-Rieux, K., and Andrad, A. (2013). Reframing ecosystem management in the era of climate change: Issues and knowledge from forests. Bio.Conservation . (165), pages 115-127.

Mukhopadhyay, B. (2013).Signature and hydrologic consequences of climate change within the upper-mid Brahmaputra Basin. Hydrological Processes (27) 15, pp. 2126-2143.

NBC (2009). Biodiversity Action Plan (2009). MOAF, Thimphu Bhutan.

Norbu, P. (2013). Not the nice kind of GALS (www.kuenselonline.com, May 25, 2013).

Oshawa, M. (2012) . Sustainable Utilization of Resources and Climate Impacts on Forests of Bhutan. Seminar presentation at CoRRB, Ministry of Agriculture and Forest, Thimphu Bhutan.

Oshawa, M.(Ed.) (1987). Life Zone Ecology of the Bhutan Himalaya. Laboratory of Ecology, Chiba University, Japan.

Pramova,E., Locatelli, B., Djoudi, H., *and* Somorin, O.A.(2012). Forests and trees for social adaptation to climate change variability and change. Wiley Interdisciplinary Reviews: Climate Change. 3(6) p. 581-596.

Perrings, C., Duraiappah, A., Larigauderie, A. & Mooney, H. (2011) The Biodiversity and Ecosystem Services Science-Policy Interface. Science, 331, 1139-1140.

Qin, X.S., Huang, G.H., Chakma, A., Nie, X.H., and Lin, Q.G. (2008).A MCDM-based expert system for climate-change impact assessment and adaptation planning – A case study for the Georgia Basin, Canada. Expert Systems with Applications 34 , pages. 2164–2179.

Rasul, G. 2010. The role of the Himalayan Mountain Systems in Food Security and Agricultural sustainability in South Asia. International Journal of Rural Management. (6) 1. pp 95-116.

Rehm, E.V., and Feeley, K.J. (2013).Forest patches and the upward migration of timberline in the southern Peruvian Andes. For.Ecol and Mgt. (305). pp 204-211.

Romshoo, S.A. , Rashid, I. (2012,) . Assessing the impacts of changing land cover and climate on Hokersar wetland in Indian Himalayas (Articles not published yet, but available online Article in press About articles in press (opens in a new window) Article in Press. Arabian Journal of Geosciences 2012, Pages 1-18.

RGOB (2011) Statistical Yearbook, National Bureau of Statistics, Thimphu Bhutan.

Rupper, S., Tshering , K., Schaefer, J.M., Burgerner, L.K. and Koening, L.S. (2012). Sensitivity and response of Bhutanese glaciers to atmospheric warming. Geophysical Research Letters. (39) L 19503: doi:10.1029/2012GL053010, 2012.

Saito, N. (2013). Mainstreaming climate change adaptation in least developed countries in South and Southeast Asia. Mitigation and Adaptation Strategies for Global Change (18), 6 Pages 825-849.

Salicka, J,Fang, Z., and By, A. (2009)Eastern Himalayan alpine plant ecology, Tibetan ethnobotany, and climate change . Global Environmental Change (19)2,pp. 147–155.

Sala, O.E., Meyerson, L.A. & Parmesan, C. (2009) Biodiversity change and human health: From ecosystem services to spread of disease. Island Press, Washington.

Sarikaya, M.A., Bishop, M.P., Shroder, J.F., Ali, G. (2013). Remote-sensing assessment of glacier fluctuations in the Hindu Raj, Pakistan. International J.of Remote Sensing. (34)11, pp.3968-3985.

Savocool, B.K., D'Agostino, A.L.,Meenawat, H., and Rawlani, A. (2012). Expert views of climate change adaptation in least developed Asia. J. of Envi. Mgt. (97) 78-88.

Savocool, B.K., D'Agostino, A.L.,Meenawat, H., and Rawlani, A (2012).Improving climate change adaptation in least developed Asia. Envi.Sci and Policy (21) pp 112-125.

Schulze, E.D. & Mooney, H.A. (1994) Biodiversity and ecosystem functioning. Springer, New York.

Schroter, D., Cramer, W., Leemans, R.,Prentice, I.C., Arau´jo, M.B., Arnell, N.W., Bondeau, A., Bugmann, H., Carter, T.R.,Garcia, C.A., de la Vega-Leinert, A.C., Erhard, M., Ewert, F.,Glendining, M., House, J.I., Kankaanpa, S., Klein, R.J.T.,Lavorel, S., Lindner,M., Metzger,M.J., Meyer, J., Mitchell ,T.D.,Reginster, I., Rounsevell, M., Sabate,´ S., Sitch, S., Smith, B.,Smith, J., Smith, P., Sykes, M.T., Thonicke, K., Thuiller, W., Tuck,G., Zaehle, S., and Zierl, B. (2005). Ecosystem service supply and human vulnerability to global change in Europe. Science. 310 pp.1333-1337.

Sharma, R. (2012). Impacts on human health of climate and land use change in the Hindu Kush-Himalayan region. Mountain Research and Development (32) 4, pp.1-18.

Sharma, E. , Chettri, N., and Oli, K.P. (2010). Mountain biodiversity conservation and management: A paradigm shift in policies and practices in the Hindu Kush-Himalayas. Ecological Research. (25), 5. Pages 909-923.

Sharma, E., Chettri, N., Tse-ring, K., Shrestha, A.B., Fang Jing., Mool, P., and Eriksson, M., (2009). Climate change impacts and vulnerability in the Eastern Himalayas. Kathmandu: ICIMOD.

Shrestha, A.B and Erikson, M. (2009). Climate Change in the Himalayas. Information Sheet No. 3/09. ICIMOD, Kathmandu, Nepal.

Sonwa, D.J,Somorin,O.A., Jum, C., Bele,M.Y., and Nkem,J.N.(2012). Vulnerability, forest-related sectors and climate change adaptation: The case of Cameroon. Forest Policy and Economics, 23. Pages 1-9.

Taeger, S., Zang, C., Liesebach, M., Schneck, V. and Menzel, A. (2013). Impact of climate and drought events on the growth of Scots pine (Pinus sylvestris L.) provenances. Forest Ecology and Management (307) pages. 30-42.

Tenzin, N. (2013). Invasion of army warm (www.kuenselonline.com, 23 May 2013)

Thom, D., Seidl, R., Steyrer, G., Krehan, H., and Formayer, H.,(2013). Slow and fast drivers of the natural disturbance regime in Central European forest ecosystems. For.Ecol and Mgt. (307) pp.293-302.

Theoharides, K.A., and Dukes, J. S. (2007). Plant invasion across space and time: factors affecting non-indigenous species success during four stages of invasion. Tansley review, New Phytologist: 176: pp.256-273.

Thuillera,W., Alberta,C., Araujob,M.B.,Berry, P.M., Cabeza, M.,Guisane,A., Hicklerf,T., Midgley,G. F., Paterson, J.,Schurrh,F.M.,Sykesf,M.T., and Zimmermann, N.K. (2008). Predicting global change impacts on plant species' distributions: Future challenges Perspectives in Plant Ecology, Evolution and Systematics: 9, 2008 pp.137–152.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W., Simberloff, D. & Swackhamer, D. (2001) Forecasting agriculturally driven global environmental change. Science, 292, 281-284.

Tobgay, S. (2009). Status of Forest Regeneration in Dieback Affected Abies densa (Eastern Himalayan Fir) Stands of Chamgang-Helela region (Thimphu), Western Bhutan. M.Sc. thesis, BOKU, Vienna, Austria.

Tse-ring, K., (2003). Constructing future climate scenario of Bhutan in Project report on climate change vulnerability and adaptation study for rice production in Bhutan for Project: Climate Change studies in Bhutan, Activity No. www 094505-But.2. Thimphu: Ministry of Agriculture

Tshering, C., (2012). Composition and Distribution Pattern of Herbaceous Plants Including Invasive Alien Plants along the Altitudinal Gradient of the Wangchu-Dochula-Punatsangchu series. B.Sc. dissertation, College of Natural Resources, University of Bhutan, Lobeysa Bhutan.

Turner II, B. (2002). Toward integrated land-change science: Advances in 1.5 decades of sustained international research on land-use and land-cover changes. Challenges of a changing earth: proceedings of the global change open science conference,

Amsterdam, The Netherlands, 10 - 13 July 2001 (eds) W. Steffen, J. Jäger, D. Carson and C. Bradshaw), pp. 21-26. Springer, Berlin.
UNEP (2005) Ecosystem management programme – a new approach to sustainability. United Nations Environment Programme, Nairobi.
Undin , S.N., Taplin, R., and Yu, X. (2007). Energy, environment and development in Bhutan. Renewable and Sustainable Energy Reviews. (11) pp. 2083–2103.
Walther, G. (2010): Review : Community and ecosystem responses to recent climate change. Phil. Trans. R. Soc. B. 365, 2019–2024.
Weemstra, M., Eilmann, B., Sass-Klaassen, U.G.W., and Sterck.F.J. (2013).Summer drought limits tree growth across 10 temperate species on a productive site. Forest Ecology and Management (306) pages.142-149.
Weller,S.G., Sunding,K., and Saka, A.K. (2013). Botany and Changing World: Introduction to the special issue on global biological change. American Journal of Botany 100(7): 1229–1233.
Wilcove, D.S., McLellan, C.H., Dobson, A.P., 1986. Habitat Fragmentation in the Temperate zone. In: Soule, M.E. (Ed.), Conservation Biology: The Science of Scarcity and Diversity. Sinauer Associates, Sunderland, MA.
Xu, J., Grumbine, R.E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y., and Wilkes, A. (2009). The melting Himalayas: Cascading effects of climate change on water, biodiversity, and livelihoods. Conservation Biology. (23) 3, pp.520-530.
Yao,T.,Thompson,T.G.,Mosbrugger,V.,Zhang,F.,Ma,Y.,Luo,T.,Xu,B.,Yang,X.,Joswiak,D.R., Wang,W.,Joswiak, M.E., Devkota,L.P., Shrestha,T., Jilani, R., Fayziev,R.(2012). Third Pole Environment (TPE). Envi. Development (3).pp 52-64.
Yates, E.D., Levia Jr.D. C., and Williams, C. L. (2004). Recruitment of three non-native invasive plants into a fragmented forest in southern Illinois. For Ecol and mgt. (190) 2–3. P 119–130.
Zhang, Y., Gao, J., Liu, L., Wang, Z., Ding, M., and Yang, X. (2013). NDVI-based vegetation changes and their responses to climate change from 1982 to 2011: A case study in the Koshi River Basin in the middle Himalayas. Global Planetary Change: 108 pp. 139-148.

CLIMATE CHANGE AND POSSIBLE IMPACTS OF INVASIVE FLORA IN THE KNUCKLES WORLD HERITAGE FOREST IN SRI LANKA

M.G.W.M.W.T.B. Dissanayake,
Deputy Conservator of Forests,
Central-Uva Region, Nuwaraeliya, Sri Lanka
rdcfne@yahoo.com
and
N.D.R. Weerawardane,
Chief Research Officer,
Forest Research Centre, Kumbalpola, Boyagane, Sri Lanka.

Abstract

Knuckles forest region has been inscribed as a Natural World Heritage Site under the UNESCO World Heritage Program in 2010, taking into account its' unique importance to the entire world including the rich biological diversity. Number of threats affecting the biodiversity of the area has been recorded. Apart from the adverse anthropogenic activities, biotic processes such as forest dieback and spreading of non-native invasive species are also likely to play an important role. Study carried out in the area revealed that at least fifteen non-native invasive species are colonizing in the disturbed areas; especially associated with forest edges of the different forest ecosystems. They include different species of trees, shrubs, and herbs, as well as grass species. With the predicted climate change scenarios, the impacts of invasive species are likely to be more severe. In order to address this problem, scientifically sound systematic actions for controlling them in the entire forest area are urgently required.

Key words: Climate change, Impacts, Invasive species, Forests, Biodiversity, Sri Lanka, Knuckles World Heritage Forest,

1. Introduction

Sri Lanka is endowed with a unique biodiversity including a variety of natural ecosystems and habitats. Forest types range from dry monsoon forests in the dry lowlands, closed canopy rainforests in the wet zone and tropical montane forests in the central highlands. The Island's high biodiversity and diverse ecosystems provides a wide range of ecosystem services such as providing fresh water, ameliorating the climate, containing soil erosion and maintaining soil fertility, ensuring the flow of surface water, buffering the impacts of extreme weather events like cyclones and floods, etc.

Climate change impacts may disrupt the fragile ecosystems of the country and this in turn could affect the ecosystem services. Subsequently the overall impact could severely affect the country's food security, livelihoods, nutrition, public health and overall economic development. Conserving the island's rich biodiversity and maintaining the ecosystems are among the most practical climate change adaptation strategies that Sri Lanka can pursue. (National Climate Change Adaptation Strategy of Sri Lanka, 2011 – 2016)

Alien invasive species represent one of the primary threats to biodiversity, especially in geographically and evolutionary isolated ecosystems. Since Sri Lanka is an island, the country is especially vulnerable to invasive species. The risk of invasion is increasing due to increased global trade, transport, tourism as well as climate change. As reported in many countries, invasive species may threaten the survival of threatened and endangered species in the native forests, in addition to their other undesirable effects to the ecosystems. Both invasive flora and fauna have been identified in Sri Lanka and several national seminars and workshops on invasive species have been conducted and large amount of information has been collected. However, the effects of climate change on invasive species and their combined effects on ecosystems are not yet well understood.

2 Climate Change

Climate Change is defined as statistically significant variation in either mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcing or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2001).

Since the industrial revolution, change of climate has been occurring at an accelerated rate as a result of human activities such as fossil fuel burnings, change of land use practices (in particular deforestation), emission of industrial gases etc. The global warming of the earth-atmosphere system is brought about by enhanced greenhouse effect. Greenhouse effect makes the surface of the earth some 33°C warmer than it would otherwise be (i.e. with a mean surface temperature of 14°C instead of –19°C) and allows life forms to exist The gases that are responsible for this enhanced greenhouse effect in the natural atmosphere are Water vapor (H_2O), Carbon Dioxide (CO_2), Nitrous Oxide (N_2O), Methane (CH_4), Ozone (O_3), Hydrofluorocarbons (HFCs), Sulphur Hexafluoride (SF_6) and Perfluorocarbons (PFCs). Atmospheric concentration of CO_2 has rapidly been increased from 280 ppm during the pre-industrial era to 365 ppm at present, due to enhanced anthropogenic activities to make human lives more comfortable (Basnayake, 2011).

2.1 Climate Change in Sri Lanka

Sri Lanka is negligible contributor to global warming. However, the country is highly vulnerable to the impacts of climate change, which include:

- **Increase in the frequency and intensity of disasters such a droughts, floods and landslides;**
- **Variability and unpredictability of rainfall patterns;**
- **Increase in temperature; and**
- **Sea level rise, among others.**

2.1.1 Rainfall Change

Annual average of rainfall over Sri Lanka has been decreased by an amount of 144 millimetres, about seven percent, during 1961 to 1990 period compared to 1931 to 1960 period (Chandrapala 1997) with the standard deviation increasing from 234 to 263 millimetres. Northeast monsoon rainfall over Sri Lanka has been decreased from 1931–1960 to 1961-1990 periods, with an increased variability. Southwest monsoon rainfall has not shown any significant change during these two periods; however variability has been decreased during 1961-1990 compared to 1931-1960. High variability of annual rainfall is reported at Baticaloa, Kurunegala, and Rathnapura meteorological stations in the recent past compared to other meteorological stations. No significant trends of annual rainfall have been noticed during the last century. High variability of rainfall patterns could probably be due to global climate change with the increase of greenhouse gases in the atmosphere (Basnayake, 2011).

2.1.2 Temperature Change

Annual mean air temperature anomalies have shown significant increasing trends during the recent few decades in Sri Lanka (Basnayake et al 2002). The rate of increase of mean air temperature for the 1961-1990 period is in the order of 0.016°C per year (Chandrapala, 1996). Annual mean maximum air temperatures have shown increasing trends in almost all stations with the maximum rate of increase about 0.021°C per year at Puttalam. Night time annual mean minimum air temperatures have also shown increasing trends with higher gradients. The maximum rate of increase of night time annual mean minimum air temperature is reported about 0.02°C per year at Nuwara-Eliya (Basnayake, 2011).

It has been evident that increase in average annual surface temperatures across the country during recent time is largely due to the increase in night time minimum temperature than that of the day time maximum temperature. This trend is similar to the global trend of rising temperature during the last century. Enhanced greenhouse effect could partly be responsible for this warming in addition to the local heat island effects caused by the rapid urbanization that has been taken place during the recent past (Basnayake, 2011).

2.2 Future Scenarios of Rainfall

Extreme events (floods, droughts, etc.) would be more intense and more frequent with the climate change [IPCC, 2001], due mainly to variability of rainfall. In addition, wet areas get wetter and wetter and dry areas get drier and drier with the climate change. According to Basnayake (2011), in Sri Lankan context, the southwest monsoon rainfall, which usually confines to the western and southwestern parts of the island, is projected to increase during the next two decades. Similarly, the northeast monsoon rainfall is also projected to increase particularly over the eastern and northern areas of Sri Lanka.

2.3 Future Scenarios of Temperature

The global mean temperature is projected to be risen in the range of 1.4° – 5.8°C by the year 2100 under the different emission scenarios [IPCC, 2001]. It is revealed that the mean temperature during the northeast monsoon and southwest monsoon seasons is projected to increase about 2.9°C and 2.5°C respectively, over the baseline, by the year 2100 (Basnayake, 2011).

2.4 Projected Climate Change Scenarios

According to Basnayake (2011), the southwest monsoon and northeast monsoon rainfall in Sri Lanka is projected to increase in the future. The aerial extent, where the highest rainfalls are confined, is also projected to increase with the increase of rainfall. Rainfall change is higher during the southwest monsoon season than the northeast monsoon season. Much higher increments are noticed on the windward side of the central hills in each monsoon and less increment is noticed on the leeward side. Therefore, there is a strong possibility of having water scarcity problems in the regions where the rainfall is less especially on the leeward side of the central hills and adjoining areas in each monsoon due to the population growth and increasing demand for water in the future. This situation may be aggravated as the mean temperatures are also projected to be increased with the increase of greenhouse gases of the atmosphere.

2.5 Possible impacts of Climate Change on Invasive Species

Forests are particularly vulnerable to climate change as they are composed of slow growing woody species with limited ability to move or respond to changing conditions. As a consequence, climate change is likely to reduce the ability of trees to survive and to increase the occurrence of forest dieback. Moreover, disturbed forests are more vulnerable to pests, invasive species and fire. Fire can have a significant impact on forest floor, destroying soil seed bank and impeding the forest regeneration. This facilitates the colonization of invasive and non-invasive weed species which in turn further prevents forest regeneration. Forest fire release stored carbon in the forests and also disturbed soils can release more carbon into the atmosphere.

3 Knuckles World Heritage Forest

3.1 Introduction

The Knuckles forest region covering an area of about 210 sq. km is situated at latitude 7° 5' N and longitude 81° E. It falls within Kandy and Matale Districts of the central province of Sri Lanka. The Knuckles massif is separated from the main central highlands of the island by a deeply incised valley of the Mahaweli River commonly referred to as the Dumbara Valley in the south and East, and by the Matale Valley in the west.

The general landscape of the area is extremely rugged, with several peaks rising above 1500m. Gombaniya is the highest peak which reaches up to 1906m. In addition, there are some spectacular peaks in the Knuckles massif, such as Knuckles (1863m) Dotalugala (1758m), Kirigalpotta (1648m), Kalupahana (1629m), Dumbanagala (1615m), Kirimetiyakanda (1519m), and Lakegala (1319m) (Cooray,1998). Originally the local people called this region the "DumbaraKanduwetiya" meaning the misty mountains.

The location of the Knuckles massif as a barrier to both the monsoonal winds has resulted in a wide range of rainfall differences in different parts of the region. The highland areas of the forest range is extremely wet throughout the year, with an average rainfall of about 5000 mm, while the lower eastern slopes are much drier, with less than 2500mm. the area is also exposed to strong winds during monsoon periods. As a result, Knuckles area exhibits a unique characteristic that it represents most of the major climatic zones of Sri Lanka in a relatively very small area (IUCN, 1994).

3.1 Vegetation types

The wide range of climatic and landscape features in the Knuckles region has resulted in a variety of natural vegetation types. Among them there are three main forest formations:

a) Montane evergreen forests
b) Sub montane forests (Mid-elevational evergreen forests)
c) Moist Monsoon forests (Moist mixed evergreen forests)

Extensive strips of Riverine forests are also located in areas flanking rivers and streams.

In addition to these natural vegetation types, man-influenced semi-natural vegetation types present in the area include patches of wet patana grasslands and extensive dry patana grasslands interspersed with Savannas. Man-influenced secondary vegetation types are located mainly in the forest edge areas, and these include scrublands/scrublands, home gardens and agricultural land. In addition, patches of plantation forests consisting of Pines and Eucalyptus are also located in different parts of Knuckles. (Ekanayake S.P. and C. N.B. Bambaradeniya, 2003)

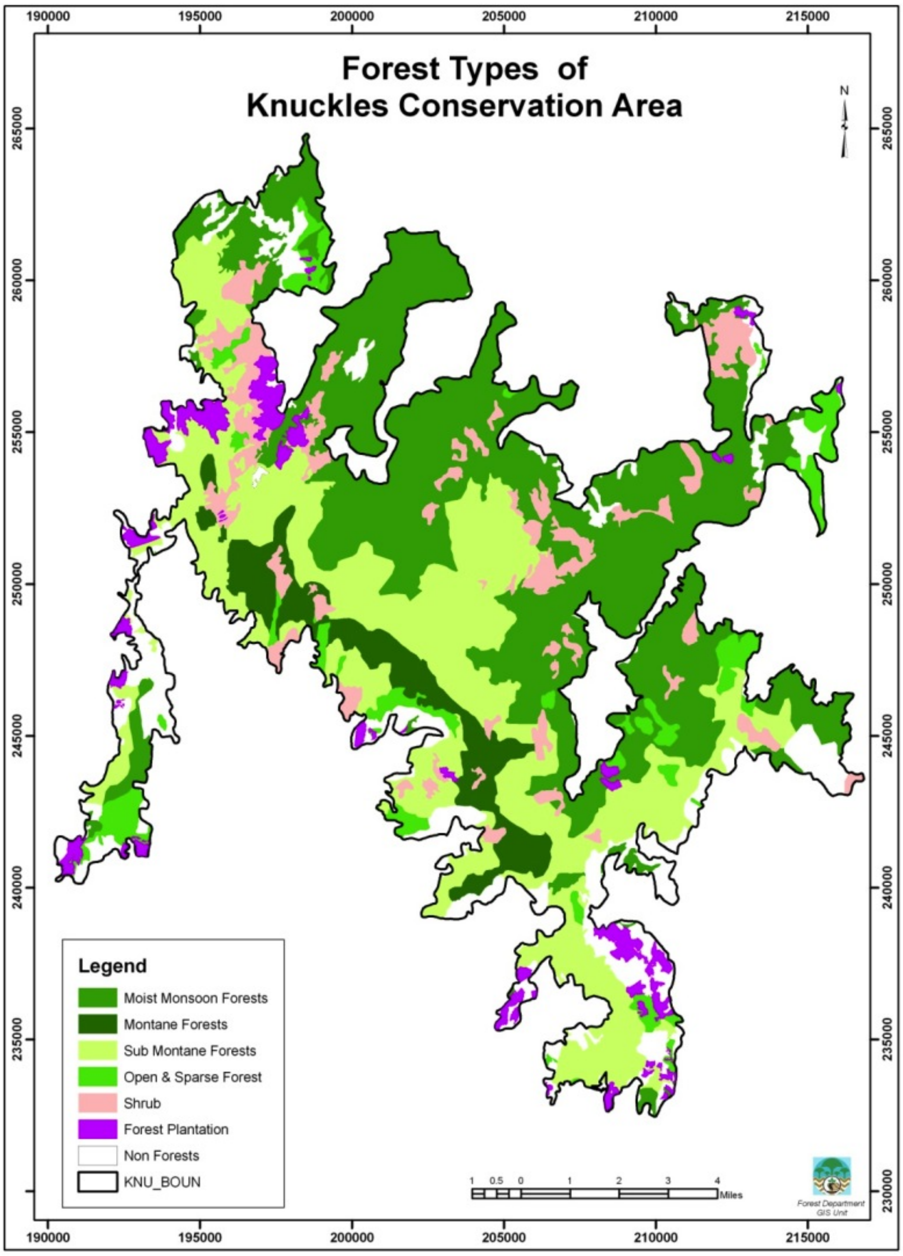


Fig. 1 Forest types of Knuckles World Heritage Forest

3.2 Biodiversity

All these vegetation types harbor a rich composition of animals and plants, some of which are unique to Sri Lanka.

The high level of biological diversity and endemism prevailing in the Knuckles, and the presence of unique habitats in this area were highlighted in the National Conservation Review report of 1997.

Table 1 – Faunal Diversity of the Knuckles forest region

	Family	Genus	Species	Endemic	Endemic to Knuckles	Nationally threatened
Birds	26	42	128	17	-	20
Amphibians	3	4	20	12	1	12
Butterflies	4	11	60	5	-	8
Mollusks	6	10	17	12	-	0
Mammals	12	17	31	4	-	9
Reptiles	4	10	53	23	1	24
Fish	4	9	15	8	3	7
Total	**55**	**94**	**324**	**81**	**5**	**80**

Source: Designing an optimum protected areas system for Sri Lanka Natural Forests (1997)

The 247 species of vertebrates recorded from the Knuckles forest region represents approximately 38% of the inland native vertebrate animals in Sri Lanka. Among them, 26% are endemic to Sri Lanka, while 28% are nationally threatened. Among the endemic vertebrates, five species, consisting of three freshwater fish, one amphibian and one lizard are restricted only to the Knuckles Forest Range.

Table 2 – Flowering plants Diversity of the Knuckles forest region

Families	Genera	Species	Rare	Endemic	Nationally threatened
141	595	1033	12	160	11

Source: Designing an optimum protected areas system for Sri Lanka Natural Forests (1997)

Of the 1033 flowering plants recorded in the Knuckles, 288 are woody plant species. Of which 85 are endemic and 11 species are nationally threatened. Among the endemic plants, the herb *Brachys telmalankana* is restricted only to the Knuckles forest region, occurring in the patana grassland area.

Number of threats affecting on the biological diversity of the Knuckles World Heritage Forest have been identified. Of which, cultivation of cardamom inside the high elevation natural forest areas appears to be the most threatening factor. In addition, forest and grassland fires and unauthorized development activities carried out in the private lands also contributes to a significant level. Other detrimental abiotic factors on biodiversity include illicit felling, extraction of non timber forest products, encroachments and poaching. In addition, biotic processes such as spreading of non native invasive species and forest die back also has negative impacts on biodiversity

3.3 Economic and Social Aspects

The Knuckles forest region is one of the most important and critical watersheds of Sri Lanka. It contributes to nearly 08 percent of the watersheds of Victoria and Randenigala reservoirs of the river Mahaweli. Furthermore, it represents nearly 80 percent of upper watersheds of the proposed Moragahakanda and Kalu Ganga reservoirs.

There are 86 villages located in the immediate neighborhood of the Knuckles World Heritage Forest. About 16000 families (approximately 60,000 people) are living in these villages. Socio economic survey conducted in 2009 shows that more than 40 percent of the villagers are below the poverty level. The study further revealed that nearly 48 percent of the population depends mainly on subsistence agriculture and more than 18 percent earn their daily income by working as labours in agricultural sector.

3.4 Legal status

The biological and hydrological value of the Knuckles forest region was recognized more than a century ago, when the area above 1500m was declared as a climatic reserve in 1873 (IUCN, 1994). In April 2000, it was declared as the country's first ever conservation forest, under the section 3 "A" of the Forest Ordinance, administered by the Forest Department. In the year 2010, it was inscribed as a Natural World Heritage Site along with two other important forests in the central highlands of Sri Lanka under the UNESCO World Heritage Program.

4 Forest invasive species

Forest clearing and associated opening of the canopy and fire occurrence usually facilitates the entrance of invasive species into the forest. Lack of early response to control these species may cause them spreading into a larger area. With regard to most invasive species, eradication is now impossible and only the option of proper management to keep them under control is possible. However, in most cases due to lack of awareness on the impact of these species on forest ecosystems, as well as lack of funds to control these species usually leave this problem unattended. Although alien invasive species play a prominent role in this phenomenon, certain native invasive species are also becoming problematic in some circumstances.

A list of forest Invasive plant species in Sri Lanka has been prepared and updated regularly. Some important forest invasive species recorded in the country are, *Acacia nilotica, Alstonia macrophylla, Leucaena leucocephala, Myroxylon balsamum, Prosopis juliflora, Swietenia macrophylla, Ageratum (Eupatorium) riparia, Annona glabra, Ardisia species, Austroeupatorium innulifolium, Bambusa bambos, Cestrum aurantiacum, Clusiarosea, Dillenia suffruticosa, Lantana camera, Miconia calvescens, Ochlandra stridula, Opuntia dillenii, Psidium littorale, Ulex europeus, Clidemia hirta, Dicranopteris linearis, Mimosa invisa, Acacia caesia, Anamirta cocculus, Micania micrantha, Imperata cylindrica, Panicum maximum and Pennisetum polystachyon.* Some of these species are invasive only in a particular forest ecosystem and have a limited distribution while others are widespread across a number of forest ecosystems.

Most forest invasive species currently spreading in the country have been introduced by Botanic gardens a long time back (Wijesundara, 2009). These species had not been identified as invasive species at that time. Therefore, due attention to confine these species to botanic gardens has not been paid and as a result they have been planted at various places and have started spreading into a larger area within the country. Their invasive behaviour in later stages after introduction may be due to various human activities and favourable climatic conditions.

Importation of plant materials and their associated contaminants can have a direct effect on introducing invasive pests and diseases. Although no such incidences have been reported in the forestry sector in the country, it can be considered as an important potential pathway of introducing invasive species. Deliberate introduction of species for forestry and agriculture has become an important source of introduction of invasive species.

Invasion pathways into the forest ecosystems have been identified as follows;

- Human activities such as forest disturbance by way of felling trees, burning etc.
- Natural spread by producing large number of seeds and strong vegetative propagation methods by wind, animals and water

Forest disturbance and burning have largely paved the way for spread of these species into the forests. Natural spread is also taking place and lack of attention to control these species may eventually become a severe threat to forest ecosystems. These are on-going processes and further spread of invasive species particularly in the disturbed forests will be inevitable in the future. Therefore, immediate action to control some of the important invasive species will be required.

5 Invasive species and their impacts in the Knuckles forest range

Knuckles forest region has been affected by invasive species as in the case of other forests reserves in the country. Various forest ecosystems found in this forest range have different tree composition and shade levels in addition to different altitudinal range and rainfall patterns, which facilitates introduction and spread of a variety of invasive species. Generally, none of the undisturbed natural forests with a dense canopy is affected by invasive species. Similarly, dense natural forests in the knuckles are not found to be affected but their boundary is occupied by invasive species in some places. Open forests formed due to various anthropogenic activities are mostly susceptible to invasive species. Open grasslands covered mainly by mana grass (*Cymbopogan confertiflorus*) are subjected to invasion by various invasive species. These grasslands are annually burnt during the dry season and fire tolerant invasive species are found to be growing in these areas.

Several surveys have been conducted in the Knuckles World Heritage Forests to identify invasive species and a list has been prepared by the Research Division of the Forest Department as ‘widely distributed and important invasive species’ (Table 3).

Ausroeupatorium inulifolium is widely distributed in degraded grasslands and along the roads. It is apparently invading mana grasslands. *Ageratum riparia* has spread intensively along roads. *Clidemia hirta* is an important invasive species, which has spread to a larger area in the country, particularly along forest edges and roads. *Clusiarosea* is another important invasive species in open lands. Though it has a limited distribution so far, it has spread into considerably larger areas in the south-western slopes of the Knuckles region and likely to cause a severe threat to open forest areas in future. *Cymbopogan confertiflorus* is a grass species, which has invaded into open areas extensively. It is fire tolerant and is well capable of occupying degraded lands. *Chromalaena odorata* is found in degraded open lands.

Dicranopteris linearis is a fern that invades open lands particularly after fire occurrences. *Lantana camera* is a common invasive species found in degraded forest areas. It spreads through seeds, which are edible for birds. *Mikania micrantha* is a vine, which spreads in open and abandoned lands and can cause a threat to the developing seedlings and saplings in forests. *Mimosa pigra*is one of the worst invasive species, which is introduced to new areas due to human activities and once established it, spreads due to negligence or lack of control activities. *Panicum maximum* is a widespread invasive species in the country and attracts fire in forest ecosystems in addition to suppression of tree seedling growth. *Rubus* species are native species and have been observed to spread suppressing other vegetation and can be considered as a potential invasive species in the Knuckles forest. *Sphagneticola triloba* is a runner, which has been introduced by tea estates and now freely spreading along roads. *Tithonia diversifolia* is found in abandoned areas and pause a moderate threat to other species.

Table 3: Major Invasive species recorded in the Knuckles World Heritage Forest

Invasive species	**Family**	**Life form**	**Affected Forest Type**	**Affected habitat**
Austroeupatorium inulifolium	Asteracea	shrub	Sub Montane	open areas
Ageratum riparia (Mist flower)	Asteracea	herb	Montane, Sub Montane, Moist Monsoon	Forest edges, roadsides
Chromalaenaodorata	Asteraceae	shrub	Montane, Sub Montane Moist Monsoon	open areas
Clidemiahirta (Koster's curse)	Melastomataceae	herb	Sub Montane	forest edges, open areas
Clusiarosea	Clusiacea	shrub	Sub Montane	open areas
Cymbopogan confertiflorus (Mana)	Poaceae	grass	Montane, Sub Montane, Moist Monsoon	open areas
Dicranopteris linearis	Gleicheniaceae	herb	Sub Montane, Moist Monsoon	open areas
Lantana camera	Verbanaceae	shrub	Sub Montane, Moist Monsoon	scrublands, grasslands
Mikania micrantha	Asteracea	vine	Montane	open areas
Mimosa pigra	Fabaceae	shrub	Moist Monsoon	open areas
Panicum maximum (Gini grass)	Poaceae	grass	Sub Montane, Moist Monsoon	open areas
Rubus sop*	Rosaceous	vine	Sub Montane, Moist Monsoon	scrublands
Sphagneticola triloba	Asteracea	runner	Sub Montane	open areas, roadsides
Tithonia diversifolia (Wild sunflower)	Asteracea	shrub	Sub Montane, Moist Monsoon	Scrublands
Alstonia macrophylla	Apocynaceae	Tree	Sub Montane, Moist Monsoon	Open areas.

*potential invasive species

These invasive species have spread in knuckles forest to varying degrees and particularly found in open areas where no forest canopy exists. Therefore, the current threat is mainly for open areas but with the disturbance of natural forest they may spread into the interior of the forest. Estimated distribution and impact rate of different species are given in the Table 4.

Table 4: Invasive species and their distribution, density and impact on the Knuckles World Heritage Forest ecosystems

Invasive species	**Distribution in the Knuckles Range**	**Density**	**Severity of impact on forest ecosystems**
Austroeupatorium inulifolium	medium	high	high
Ageratum riparia	medium	high	low
Chromalaena odorata	medium	high	medium
Clidemia hirta	low	medium	low
Clusia rosea	low	medium	low
Cymbopogan confertiflorus	low	high	high
Dicranopteris linearis	medium	high	high
Lantana camera	medium	high	medium
Mikania micrantha	low	medium	medium
Mimosa pigra	low	low	low
Panicum maximum	high	high	high
Rubus spp.	medium	medium	medium
Sphagneticola triloba	low	medium	high
Tithonia diversifolia	low	medium	low
Alstonia macrophylla	low	low	low

6 Constraints and issues with regard to invasive species

Projected water scarcity and increase of mean temperatures due to climate change scenarios could seriously affect the agricultural, water resources and land use sectors. The communities living close to the forest ecosystems will therefore encounter serious difficulties in continuing their subsistence farming livelihood strategies. As a result, forest ecosystems will also be increasingly vulnerable to various biotic as well as abiotic detrimental factors. Forest fires are likely to be increased causing extensive damage to the natural ecosystems making them more susceptible to alien invasive species.

Constraints for the control of invasive species have been identified in the past (Weerawardane, 2005; Marambe, 2009). One important requirement to work with these species is the collection of information on behaviour, reproduction and spread of invasive species. How these aspects are affected by climate change is also important since some growing threats of invasive species are evident nowadays. Another requirement is the impact assessment of these species on the other species and ecosystems. Such information is being generated currently by large number of researchers working on these species. However, since researchers work in their own interest, concerted efforts on nationally important species are somewhat lacking.

A big issue with regard to control of invasive species is the lack of early action on controlling them associated with inadequate mobilization of funds for this purpose. Forest invasive species were not clearly identified in the past and was not considered as an important issue. Things are getting improved gradually with the acquaintance of knowledge on the impact of invasive species on the ecosystems. With the growing awareness and attention on protection of biodiversity in the forest ecosystems, the threat caused by the invasive species has been realized. However, the real action to control these species is still inadequate.

7 Conclusions and Recommendations

With the predicted climate change scenarios for Sri Lanka, it can be expected that Knuckles World Heritage Forest, as well as other forests in the country will have negative impacts. One of the important such impacts will be the invasion of both exotic and native invasive species particularly in the disturbed forest ecosystems. Knuckles forest consists of large patches of such disturbed areas and observation shows spread of a number of invasive species causing a severe threat to different forest ecosystems in the area. Climate change impacts may have a direct effect on the forest degradation in the area, in terms of spread of invasive species, fire occurrences, and forest dieback incidences, though a direct relationship of those two factors are not yet proven scientifically.

In order to cope with this situation, scientifically sound systematic actions for controlling invasive species in the entire forest area are urgently required. They may include, early identification of new invasive species, control of existing invasive species, reduction of fire occurrences, reduction of forest fragmentation, maintenance and restoration of biodiversity, educating the stakeholders, as well as strengthening related research.

References

Bandarathillake, H.M. 1988. Some hydrological Aspects of the Knuckles Region. Paper presented at the workshop on preparation of the management plan for the conservation of the Knuckles Forest.

Basnayake, B.R.S.B. 2011.Climate Change in Sri Lanka. Department of Meteorology publication, Sri Lanka.

Cooray, P.G. 1998. The Knuckles Massif – A Portfolio. Forest Information Service, Forest Department, Sri Lanka

Ekanayake S.P & C.N.B. Bambaradeniya. 2003. A Guide to the Biodiversity of Knuckles Forest Region. IUCN – The World Conservation Union, Sri Lanka Country Office, Colombo, Sri Lanka

Forest Department, Sri Lanka. 2011. Management Plan for the Knuckles Conservation Area.

Marambe, B. 2009.Research priorities on invasive alien species in Sri Lanka. Proceedings of National Symposium on invasive alien species held on 11 November, 2008, Sri Lanka Association for the Advancement of Science (ed. Ranwala, S.M.W.), 7-12.

Ministry of Environment, Sri Lanka, 2010. National Climate Change Adaptation Strategy for Sri Lanka, 2011 to 2016.

Ministry of Lands and Land Development, Sri Lanka. 1988. Knuckles Conservation Project. Project Proposal.

Ministry of Lands and Land Development, Sri Lanka. 1992. Knuckles Conservation Project. Project Proposal

Weerawardane, N.D.R. 2005.Status of forest invasive species in Sri Lanka. Proceedings of the Asia Pacific Forest Invasive Species conference.17-22 August 2003, Kunming, China.FAO RAP Publication 2005/18, 114-120.

Wijesundara, S. 2009. Major invasive plant species in different climatic zones of Sri Lanka. Proceedings of National Symposium on invasive alien species held on 11 November, 2008, Sri Lanka Association for the Advancement of Science (ed. Ranwala, S.M.W), 15-21.

World Conservation Union & Forest Department, Sri Lanka. 1995. Management Plan for the Conservation of the Knuckles Forest, Phase II.

World Conservation Union & Forest Department, Sri Lanka. 2001. Eco-Tourism Development Plan for the Knuckles Conservation Area.

VIEWS OF CLIMATE CHANGE IN SUNDARBAN MANGROVE FORESTS OF BANGLADESH

Mozammel Hoque Shah Chowdhury
Divisional Forest Officer
Pulpwood Plantation Division, Bandarban
Bangladesh Forest Department
E-mail: mozammelhsc@yahoo.com

Introduction

Climate change directly and indirectly affects the growth and productivity of forests. Directly due to changes in atmospheric carbon dioxide and climate and indirectly through complex interactions in forest ecosystems. Climate also affects the frequency and severity of many forest disturbances. In conjunction with the projected impacts of climate change, forests face impact from land development, suppression of natural periodic forest fires and air pollution. Although it is difficult to separate the effects of these different factors, the combined impact is already leading to changes in our forests. As these changes are likely to continue in the decades ahead, some of the valuable goods and services provided by forests may be compromised. Bangladesh is widely recognized to be one of the most climate-vulnerable countries in the world. It experiences frequent natural disasters, which cause loss of life damage to infrastructure and economic assets and adversely impacts the lives and livelihoods, especially of poor people. The eastern region being covered by hilly areas is more stable and it has one of the longest beaches in the world. In the western coastal area of Bangladesh lies a large mangrove forest. Although that area is almost flat, damage due to storm surges in this area is still much less than it is in other areas that have less mangrove coverage. Thus one of the most immediate and useful adaptation strategies should be to protect the mangrove forest from denudation and implement a massive afforestation program all along the coastal belt. In fact, Bangladesh has a couple of ongoing projects aiming at that. Afforestation will also help stabilize the land, create more accretion leading to more land, and also raise the level of topography that will reduce inundation by sea level rise.

Climate Change could lead to submergence of low-lying coastal areas and saline water intrusion up coastal rivers and into ground water aquifers, reducing fresh water availability; damage to the Sundarbans mangrove forest, a World Heritage Site with rich biodiversity and drainage congestion inside coastal polders.

Bangladesh is the deltaic country in the world with low lying coastal zones. The coast line of Bangladesh is about 710 km. long and coastal zone covers about 23% of the country and it is critically vulnerable due to sea level rise and salinity intrusion. In this situation, only the forest can play an important role to mitigate the natural disaster, biodiversity and soil conservation. Plants as well as flora are the first green standing life of the living planet. Carbon can be assimilated by the plants and in that sense at least 25% forest land area of a certain region are to be required for normal phenomena and settle down for better livelihood. Bangladesh is the most densely populated country. Disaster is one of the general phenomena in our country. Global warming, climate change, forest degradation and human induced caused are highly responsible for the increasing of natural disasters. Forest and plants play an important role to conserve the ecosystem that reduces disasters and other calamites. Forests are home to 300 million people around the world. Forest store more than 1 trillion ton of carbon- twice the amount found in the atmosphere. Over 40% of the world's oxygen is produce from rain forests. Forest are home of 80% terrestrial biodiversity. It provides habitats to about two-thirds of all species on earth. Forest provides fire wood, furniture, different household utensils, educational instruments, body building of different vehicles etc. Actually forest and plants are required in every step of our life, from birth to death. Every year 130,000 km^2 of the world's forest are lost due to deforestation. Deforestation accounts for 12-20 % of the global green house gas emission, which contribute to global warming. Deforestation of closed tropical rainforest could account for biodiversity loss of as many as 100 species a day (Paul, 2011). Due to degradation of the forest and cutting of the trees, we are facing greater risk of different natural disasters and calamities.

Effect of forest degradation and global warming

Bangladesh is already evidencing the adverse impacts of global warming and climate change due to forest degradation and climate change. The following impacts have been observed: Summers are becoming hotter, monsoon irregular, untimely rainfall, heavy rainfall over short period causing water logging and landslides, very little rainfall in dry period, increased river flow and inundation during monsoon, increased frequency, intensity and recurrence of floods, crop damage due to flash floods with salt water and monsoon floods, crop failure due to drought, prolonged cold spell, salinity intrusion along the coast leading to scarcity of potable water and redundancy of prevailing crop practices, coastal erosion, river bank erosion, deaths due to extreme heat and extreme cold, increasing mortality, morbidity, prevalence and outbreak of dengue, malaria, cholera and diarrhea, etc. Climate change impacts are already adding significant stress to our physical and environmental resources, our human ability, economic and social activities.

The impacts of global warming and climate change are worldwide. For Bangladesh, they are most critical as large part of the population is chronically exposed and vulnerable to a range of catastrophe, disaster natural hazards. Already the human suffering and cost to development is massive to the country and its people who are victims of human induced global warming by the developed countries. Global warming and climate change have become a serious threat to the survival of biological organisms and the well being of people around the world. Global warming and climate change are the principal scenarios of long term effect of the natural disaster. Climatic hazards, including extremes like floods, cyclones, tornado, tsunami, ayla, lyla, storm surge, water logging, tidal bore etc are not new to Bangladesh and the country has a scarred history claiming many lives and resulting in losses of assets in the Sundarbans and the coastal region of Bangladesh. Revival of forest and forestry can also reduce the disasters.

Green house effect

Global warming and climate change have become a serious threat to the survival of biological organisms and the well being of people around the world (Lee, 2000). People rely more on biomass than on hydroelectric dams and nuclear fuel plants as their main sources of energy for cooking and heating in the world combined. Estimates suggest that the number of people relying on wood fuel will increase to 3 million by 2000 (Lee, 2000). He also opined that among these perhaps 100 million users face fuel shortages as supplies of wood fuels dwindle by 2000, deficit amount of global fuel wood production is estimated at one billion cubic meter, 500 cubic meter million in Asia, 300 cubic million in Africa, 140 cubic million in Latin America and 60 cubic million in other countries. To meet the deficit, about 25 to 105 million ha of fuel wood plantation are required in developing region (Helal Siddiqui, 2009).

The world forests are habitats for biodiversity of life and yet they are increasingly suffering from human induced stress, such as - industrial pollution, large scale clearing, land use changes for agricultural and urban development for increasing population density. The most likely cause of warmer atmosphere is increased concentrations of green house gases in the atmosphere. Depending largely on limited non-renewable energy, such as - fossil fuels around the world adds significantly to the buildup of green house gases. The main green house gases are CO_2, CH_4, N_2O and CFC of which CO_2 is undoubtedly the biggest contributor to global warming.

Cyclones and Storms

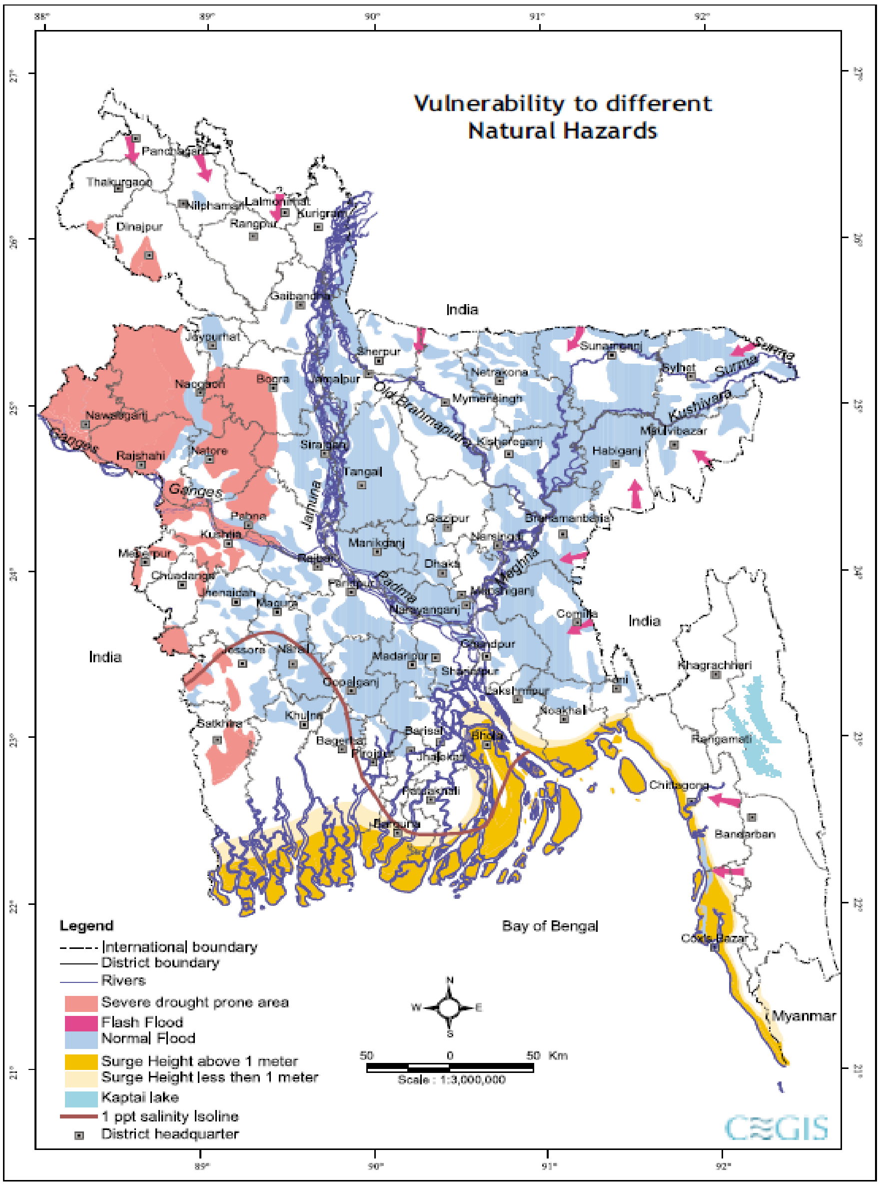
Severe cyclones generally occur in October and November. Cyclones are accompanied by tidal surge and autumnal storm. The storms and tidal surge can cause severe damage to forest, agricultural crops, fishery and human settlements. During the last 125 years, more than 42 cyclones have crossed the coast of Bangladesh, of which 11 tracked through the Sundarbans. The most severe recent ones were Nov.1970, May 1985, Nov.1988 and April 1991. The cyclones wind rotation is anti-clock wise and the most of the Sundarbans can expect moderate damage compared to most severe damage in lower Meghna estuary.

Table-1: Chronology of extreme cyclonic storms and tidal surge in Bangladesh

Year	Month & date of occurrence	Maximum wind speed km/hr.	Storm surge (ft)
1981	10 December	120	08
1983	14-15 October	93	-
1983	5-9 November	136	05
1985	24-25 May	Ctg:153,Sandip: 140,Cox'sB:100	15
1986	8-9 May	Ctg:110,Khunla: 90	2-3
1988	24-30 November	160	14.5
1991	25-29April	225	12-22
1991	31 May-2 June	Ctg:110,Cox'sB: 88,Patuakhali:75	06
1992	17-19 May	Ctg:90,Cox's B:75	-
1992	17-21 November	50	-
1994	29 April-3 May	210	-
1995	7-10 November	-	-
1996	7-8 May	56	-
1996	26-29 October	75	-
1997	16-19 May	220	10

1997	25-27 September	150	6-10
1998	16-20 May	120	6-8
1998	19-22 November	90	4-6
2007	15 November	226-240, Entire coastal districts	

Map 1. Areas affected by different types of climate-related disaster



Source: CEGIS, Dhaka.

CO_2 absorption

Lee (2000) stated that to produce 1.0g of biomass, forest absorbed 1.630g of CO_2 and released 1.185g of O_2 as of 1990. The total biomass, its annual growth and CO_2 carbon absorption on in the forest were as follows: 516.8 million tons of CO_2 and 140.9 million tons of carbon by total biomass and 37.2 million tons of CO_2 and 10.1 million tons of carbon by annual growth shown in Table-2.

Table-2: Total biomass, its growth and CO_2 /carbon absorption in the forest

Status	Biomass 10^3 tons.	Absorption	
		CO_2 10^3 tons.	Carbon 10^3
Present	317061	516809	140948
Annual	22818	37193	10144

Source: Lee (2000)

Consequences

Global warming or climate change in general and its consequences are among the pressing issues in future. About 20-30 million people live in the coastal areas within 1(one) meter elevation from the high tide level and these people are in the frontline of the consequences. Over the last 4 decades since 1973, about 0.17 million hectares (20.4%) new land has been salt affected. The consequences of north arctic zones ice melting and adverse effect of human induced pollution as well as air pollution which are polluted from the industries through suspended particulate matters, oxides of sulfur (Sox), oxides of nitrogen (NOx), carbon monoxide (Co), hydrocarbons, carbon dioxide (CO_2). Fossil fuel emission, CFC gas and other radioactive substances are increasing temperature and creating sea level rise. The green house gases are carbon dioxide 39%, methane 18%, CFCs 14%, nitrous oxides (NOx) 6% and others 13%. In the last few decades, average temperature of the world increased at least 0.70°C and caused sea level rise. These can adversely affect human health, biodiversity, vegetation, building, materials and our livelihood. Sea level rising, thermal changing, ice melting, acid rain, depletion of ozone layer and adding others radioactive substances to the air are also the direct and indirect human induced effect of environment. "Sea level rise is the greatest threat and challenge for sustainable adaptation within South and Southeast Asia. A 45 cm rise in global sea levels would lead to the destruction of 75 percent of the Sundarbans mangroves," the report warned. The report, "Case Studies on Climate Change and World Heritage", features 26 examples - including Sundarbans (in India and Bangladesh). Along with global sea level rise, there is a continuous natural subsidence in the Sundarbans, causing a rise of about 2.2 mm per year. The resulting net rise rate is 3.1 mm per year at Sea, the biggest delta of Sundarbans, the report added. The consequences in terms of flooding of low-lying deltas, retreat of shorelines, salinitisation and acidification of soils and changes in the water table raise serious concerns for the well being of the local population.

General description of the Sundarbans

The Sundarbans is the World largest single tract mangrove forest having a unique ecosystem with various resources and rich biodiversity. The forest occupies the south-west corner of Bangladesh between longitudes 89°00'E and 89°55'E and latitudes 21°30'N and 22°30'N. The forest covers an area of 6017 km^2, of which 4143 km^2 are landmass and remaining 1874 km^2 are under water bodies in form of rivers, canals and creeks (Chaffey *et al.*1985, Karim 1995, Helal Siddiqui 2002). The forest is tidally inundated twice a day. The biodiversity of the

Sundarbans is very rich in its flora and faunal species. It supports 334 plant species. Among the floral species sundri (*Heritiera fomes*), gewa (*Excoecaria agallocha*), goran (*Ceriops decandra*) and golpata (*Nypa fruticans*) are the most important species in the Sundarbans. Sundri (*Heritiera fomes*) and gewa (*Excoecaria agallocha*) are the major species all over the Sundarbans. In 52.7% of the total forest area of the Sundarbans, sundri is the predominant species and in another 14.8% of the forest area sundri is co-dominant and sundri alone constitutes 63.8% (Chaffey *et al*. 1985, Karim 1995). The vegetative status and abundance of trees and saplings (regeneration) differ from zone to zone and site to site of the Sundarbans (Chaffey *et al*.1985, Siddiqi, 2001; Helal Siddiqui, 2002). More than 95% of the Sundarbans lands (411234 hectares) is vegetated with profuse natural stands of two timber species; sundri (*H. fomes*) and gewa (*E. agallocha)* occur in almost pure stands by themselves or in association with each other and with some lesser abundant species such as keora (*Sonneratia apetala*), passur (*Zylocarpus mekongensis*), baen (*Avicennia officinalis*), kankra (*Bruguiera gymnorrhiza*), dhundul (*Zylocarpus granatum*) and goran (*Ceriops decandra*) (Canonizado and Hossain 1998).

In recent years, sundri trees have been affected by a disease syndrome called top dying and a substantive depletion of the growing stock of the species has been observed (Karim 1995). This disorder causes death from top to downwards.

Damage caused by the Sidr (Cyclone and Storms) in Sundarbans

The Sundarbans sustained the main blow of the sidr, saving human lives by slowing down the natural disaster. Damage administered on the wildlife of the forest that provides livelihood to more than 2 million people. Finding the devastating scenarios of the coastal forest areas it was initially reported that 25% of the Sundarbans forest has been damaged by sidr and 8-10% of the forest has been damaged completely, which will not regrow and 15% has been partially damaged.

Fig-1: Devastated scenario of sidr in Sundarbans

Fig-2: Sidr hit in Sundarbans

Fig-3: Devastated scenario of sidr in Sundarbans

Fig-4: Sidr effect in Sundarbans

The Sundarbans mangrove forest no doubt bore the main brunt of the sidr, acting as a shelter belt to save human lives and wild animals. The different kinds of wild animals including deer, wild boar, monkey, lizards, otter, python, snakes, royal bengal tiger, fowls, crocodiles, beautiful native and visitor birds might have lost their lives during sidr.

The Keora forest type regions were affected seriously. Sundri trees also uprooted at Bogi and near the river bank. Passur, Baen and Keora trees were also broken in scattered patches within the Sundarbans. Golpata also disrupted near the river bank. Goran and gewa forest were merely damaged. The entire coastal and southern part of Bangladesh was devastated and lives were ruptured. Sundarbans always plays a great shelter belt for its ecosystems.

Table-3: Devastating scenarios of different planted mesophytic species at Sundarbans

Name of species	Year of Plantation	Area	Percentage(%) of devastating
Babla, Minjiri, Raintree and koroi	1986	3.00	60
Koroi, minjiri, Raintree and Golap	1987	2.00	60
Jarul, Koroi, Raintree and Babla	1988	2.00	60
Jarul, Koroi, Raintree and Babla	1989	2.00	35
Jarul, Koroi and Raintree	1993	2.00	35
Jarul, Koroi, and Raintree	1994	2.50	40
Jarul, Koroi and Raintree	1995	2.50	40

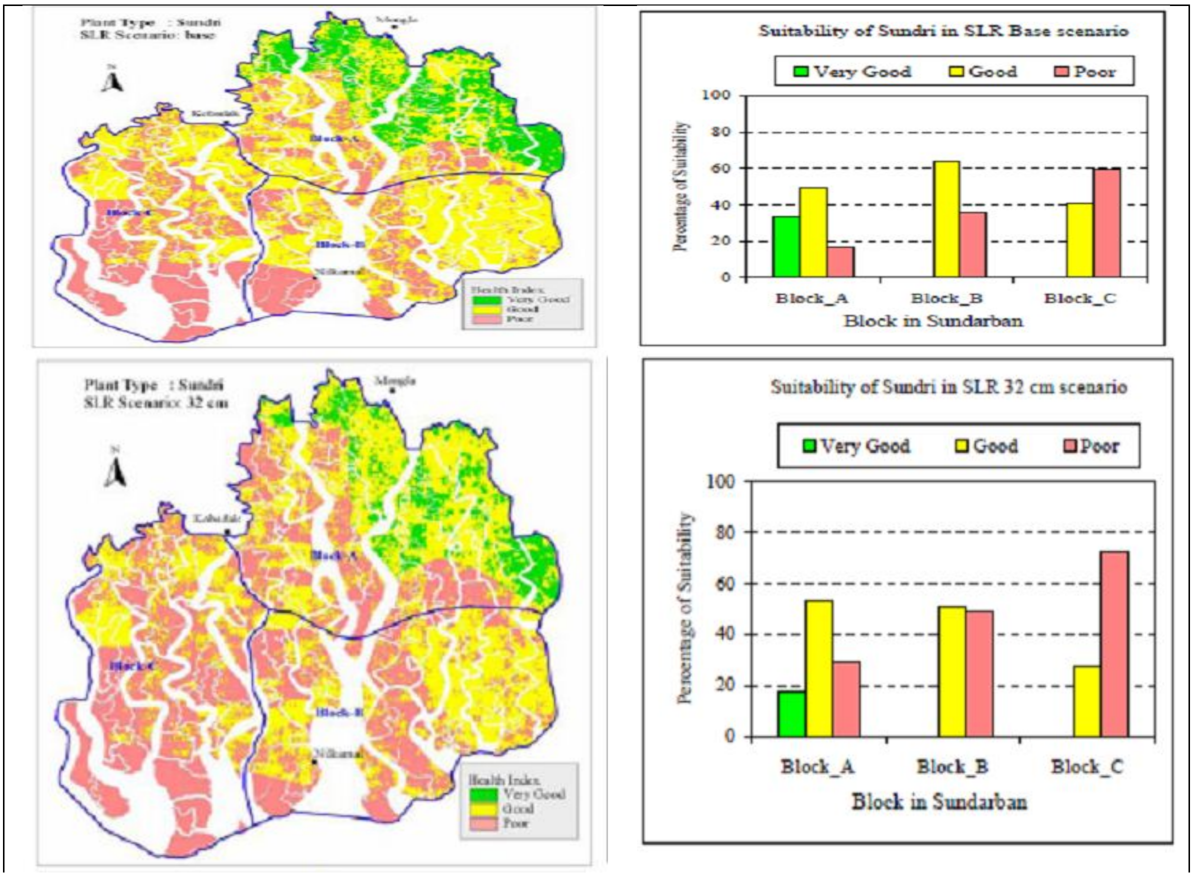
Top Dying of Sundri (*Heritiera fomes*)

In recent years, sundri trees have been affected by a disease syndrome called top dying and a substantive depletion of the growing stock of the species has been observed (Karim 1995). This disorder causes death from top to downwards. Height and dbh. of sundri trees in the fresh water zone is highest then followed by moderate zone and lowest in strong saline zone.

The top highest of sundri is 17m, 16m and 9m and average height is 10.11m, 8.88m, 4m respectively.

Fig-5: Top dying affected Sundri trees

Water salinity differs from place to place and time to time. Salinity varies from 0 to 28 ppt. in the different locations in the Sundarbans of Bangladesh.



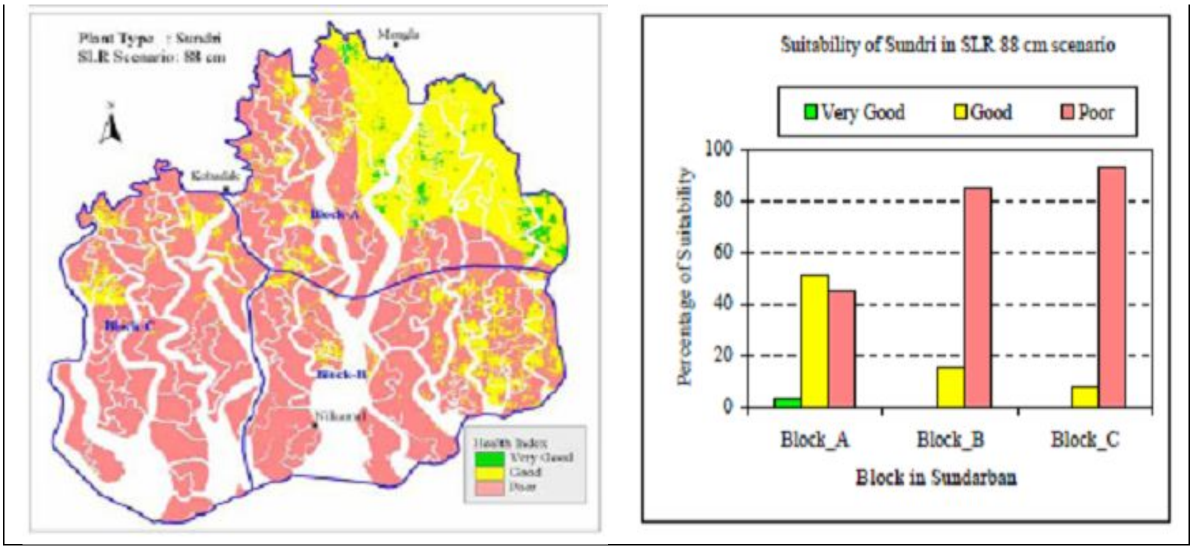


Fig-6: Plant Type-Sundari-health Index under different SLR scenarios (Source: CEGIS, 2006)

Heart rot disease of passur (*Zylocarpus mekongensis*)

Passur is a valuable and highly useful tree species in the Sundarbans. It has great commercial value. It is found mainly in the saline areas on the north-western part of the Sundarbans in association with amur, kakra, keora and baen. It is a moderate size deciduous tree species attaining a height of 10 to 20 m.

The natural vegetation of this species has declined in a large scale in the Sundarbans due to disorder. This disorder causes dries of the upper branches of the tree and gradually death from top to downwards. The trunk and big branches of the tree are affected causing wood decay inside the middle portion of the stem and gradually causing a hole locally known as *'Dhor'*. This disorder is called heart rot disease of passur. The affected wood changes reddish to dark gray in colour and finally damages the timber. The causes of this disease have not been identified till date. An initial primary survey report shows that about 50% aged passur trees are infested by heart rot disease in the affected areas of the Sundarbans. It is caused by fungal pathogen and other ecological factors are balso associated with this problem.

Table-4: Percentage (%) of heart rot affected Passur trees at different locations in the Sundarbans

Name of location	Percentage (%)of heart rot affected tree
Kalabogi	64 %
Bania Khali	60 %
Bojboja	62 %
Kasiabad	54 %
Chunkuri-ChallaBogi	48 %
Sarankhola-Supati	17 %

Fig-7: Affected passur trees   Fig-8: Heart rot affected big tree

Table-5: Water salinity of different locations in the Sundarbans

Location	Water salinity (ppt.)			
	June /96	December /96	March /97	September /97
Sarankhola	02	04	06	00
Supati	01	04	07	00
Charaputia	06	05	09	01
Karamjal	05	06	10	00
Kalabogi	19	20	23	10
Bozbosa	22	24	23	06
Burigoalini	26	27	28	09
Kalagachia	23	24	24	10
Munshiganj	24	26	22	12

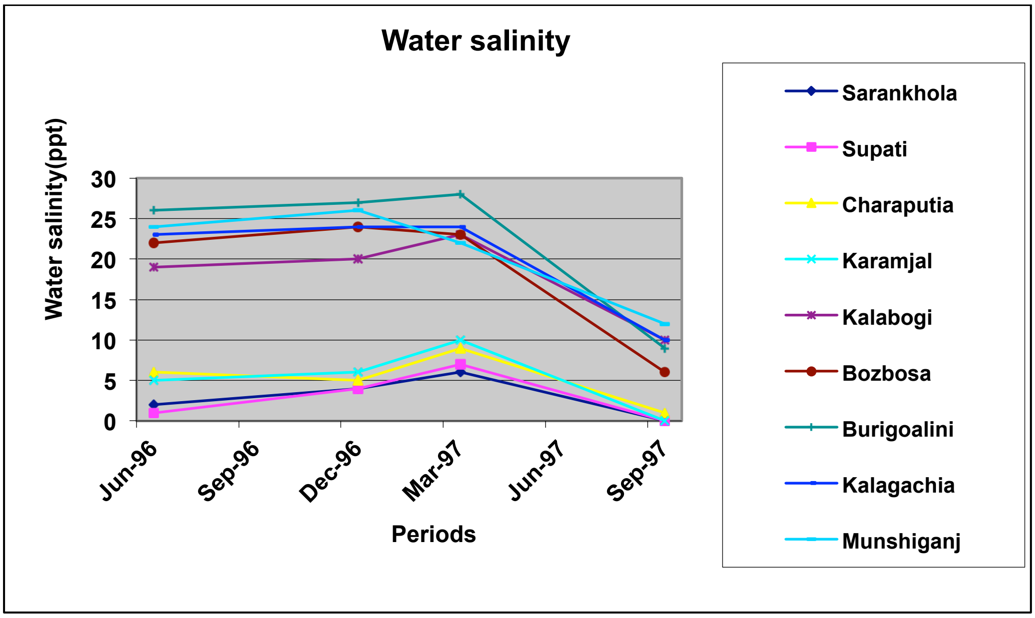


Fig-9: Level of water salinity of different locations in the Sundarbans

The Intergovernmental Panel on Climate Change (IPCC) are forecasting that the already extreme weather, with its frequent severe storm surges, droughts and floods will get worse and as the water rise, eventually submerging the entire Sundarbans. A 2007 report by UNESCO, "Case Studies on Climate Change and World Heritage" has stated that an anthropogenic 45-cm rise in sea level (likely by the end of the twenty-first century). According to the Intergovernmental Panel on Climate Change (IPCC), combined with other forms of anthropogenic stress on the Sundarbans, could lead to the destruction of 75% of the Sundarbans mangroves. As per IPCC average precipitation in Bangladesh is projected to increase in June –August period by up to12.5 % in the 2020s and 20% in the 2050s.

Table-6: Climate change scenarios for Bangladesh

Year	Temperature Change (◦ C) Mean			Precipitation Change (%) Mean			Sea level Rise (cm)
	Annual	Dec-Feb	June-Aug	Annual	Dec-Feb	June-Aug	Prediction
2030	1.0	1.1	0.8	5	-2	6	14
2050	1.4	1.6	1.1	6	-5	8	32
2100	2.4	2.7	1.9	10	-10	12	88

Over the last decade however, the sea has steadily eaten into the Sundarbans and the entire Bengal basin region is now threatened by an ecological disaster. The Intergovernmental Panel on Climate Change (IPCC) are forecasting that the already extreme weather, with its frequent severe storm surges, droughts and floods will get worse and as the waters rise, eventually submerging the entire Sundarbans. In Shyamnagar upazila (or sub-district, the lowest level of administrative government), the inhabitants, the majority of them farmers, have noticed changes in the weather over the last decade, which have begun to severely affect them. The consequences of rising sea levels and extreme temperatures are becoming increasingly real and immediate in their everyday lives.

Climate Vulnerability of some regions in Bangladesh
The climate change sensitivity of a few vulnerable regions in Bangladesh and the impacts of these limits are presented in Table-7 below (Rahman 2009).

Table-7: Sensitivity of Bangladesh to climate change

Change in Climatic Elements and Sea-Level Rise	Vulnerable Region	Primary Change	Impacts Primary	Impacts Secondary
0.5-2°C (10- to 45-cm sea-level rise)	Bangladesh Sundarbans	- Inundation of about 15% (~750 km2) - Increase in salinity	- Loss of plant species -Loss of wildlife	- Economic loss - Exacerbated insecurity and loss of employment
~2°C (-5 to 10% rainfall; 45-cm sea-level rise)	Bangladesh lowlands	- About 23-29% increase in extent of inundation	- Change in flood depth category - Change in monsoon rice cropping pattern	- Risk to life and property - Increased health problems - Reduction in rice yield

In South Asia, key sectors like food and fiber, biodiversity, water resources, coastal ecosystems and settlements have been ranked to highly vulnerable while human health as moderately vulnerable to climate change. Climatic changes in Bangladesh would likely exacerbate present environmental conditions that give rise to land degradation, shortfalls in food production, rural poverty and urban unrest. About 15,000 Himalayan glaciers form a unique reservoir, which supports perennial rivers such as the Indus, Ganges and Brahmaputra, which in turn, are the lifeline of millions of people in Bangladesh. The Forest is being managed primarily for the production of timber, pulpwood, thatching materials and honey. Citing from the Metrological Department, Helal Siddiqui (2009) stated that maximum annual temperature varies from 30°-34.1°C and minimum 17.4° – 22°C, average annual maximum rainfall 2040 mm. and minimum 1080mm. and average annual minimum and maximum humidity 79%-82% respectively last (1987-1996) ten years.

Role of the forest

Forests are home to 300 million people around the world. Over 1.6 billion people's lively hood depends on forest and 30% of forest are used for production of wood and non-wood products. Annual value of wood removed from forests is estimated to be more than $100 billion. Trade in forest products were estimated at $327 billion in 2004. Tropical forests provide a vast array of medicinal plants used in healing and healthcare, worth an estimated $108 billion per year. Forest store more than 1 trillion ton of carbon- twice the amount found in the atmosphere. Over 40% of the world oxygen is produced from rain forests. Forest are home of 80% terrestrial biodiversity. It provides habitats to about two-thirds of all species on earth. The forest can provide and contribute as follows in brief.

- Controlling natural disaster
- Biodiversity conservation
- Food supply and food security
- Shelter and shelter belt
- Environmental equilibrium
- Nesting and niche formation
- Formation of breeding grounds for biodiversity
- Soil erosion conservation
- Lively hood development
- Poverty alleviation
- Income generation

Impacts of Climate Change on Biodiversity and Forests

Climate is an important determinant of the geographical distribution, species composition and productivity of forests and changes in the climatic regimes can modify the pattern and productivity irreversibly, affecting anthropogenic livelihoods, forest based industries, soil and water resources. Impact of climate change on biodiversity and forest will be very complex. According to the IPCC, at least one third of the forests will be adversely affected by climate change, reducing carbon sinks, soil fertility and precipitation and conversely increasing the incidence of pests, forest fires and natural disasters. The Intergovernmental Panel on Climate Change (IPCC) projected that the state of tropical forest ecosystems is likely to worsen from climate change. Bangladesh being in the tropical region, different physical effects of climate change including increased temperature and precipitation, increased salinity and extreme weather events such as floods, cyclones and droughts will have profound negative impacts on its forests. Because of the increased rainfall in monsoon, water runoff rate on the forest floor has increased from the previous one. As a result, rapid soil erosion causes nutrient leaching and destroys micro organism and reduces overall site quality for better forest growth in the previously dense hill forests of Chittagong, Chittagong Hill Tracts (CHT), Sylhet and Cox's Bazar. Most of the forests are also likely to be affected from the absence of ecological memory that is the network of species for interaction between each other and environment and building the capacity for reorganization within or outside the forest patch after different perturbations.

Few Speculation/possibilities

1. The permanently inundated vegetation will gradually die.
2. During the process, more detritus will be released from the rotting vegetation and that in turn will temporarily boost up the aquatic population, especially the fish. Higher inundation one of the resultant affects of sea level rise is likely to be higher levels of inundations. Such situations will definitely change the species composition.

3. The species that do not thrive under higher inundation will die off from the areas that start receiving higher inundations.
4. The fauna will be affected by loss of habitat and elimination of many of water holes that are supplying drinking water to the wildlife at present.
5. The tiger population in turn is very likely to decline and seriously suffer from short of prey possibly turning to humans as prey.

Higher Salinity is a very important factor for mangrove ecosystems. With the impact of climate change, the whole of Sundarbans is very likely to experience higher salinity. Salinity is a very important factor for the mangroves in determining the species. The existing fresh water zone (technically low salinity zone of Northern parts of Sundarbans) is likely to get obliterated. Biodiversity human induced land use, land use change and forestry (LULUCF) activities worldwide currently account for 20 - 25% of annual global GHG emissions or roughly 1.0 - 1.5 billion tons of carbon.

Conclusion

Climate change and global warming is a vital issue for the world. It can control the overall environmental situation of the World. This is important for nature protection and the conservation of biodiversity due to the degradation of forest. This requires appropriate nursery techniques initiation that ensures highest survival of seedlings with minimum cost. If a plantation is successful and productive it may represent an economic and improve the entire ecosystems. Climate change, sea level rising, human induced activities, fossil fuel emission, industrial pollution, soil and water pollution etc. can be reduced for ecological balance by artificial planting, natural forest conservation and management plan development. People have discovered the forest partly as one of the last areas of silence. The best option to maintain sustainable productivity of the forest is to rehabilitate the degraded and poorly regenerated forest and to increase decreasing tendency of the acute endangered species through appropriate silvicultural intervention. The professional research personnel, policy maker, planners and environmentalist should take initiatives to conserve the forest ecosystems to prevent, mitigate and revival of its biodiversity. The appropriate plantation projects and studies have been taken in consideration on conservation of ecosystem, wild lives, protection of soil erosion, controlling of the desertification, reducing carbon emission, employment, poverty alleviation and improvement of socio-economic condition for sustainable development and to mitigate the challenges. Thus it will be automatically revive the forest and reduce the disaster and other natural calamities from Bangladesh.

References

Azam, M.A. 2007.Importance of Bangladesh Coastal Forest Particular Reference to land Zoning, Soronika, National Tree Plantation Movement and Tree Fair.43-50 pp.

Canonizado, J.A. and Hossain, M.A. 1998. Integrated forest Management Plan for the Sundarbans reserved Forest. Mandala Agricultural Development Corporation and Forest Department, Ministry of Environment and Forest, Dhaka.

Chaffey, D. R., F. R. Miller and J.H.Sandom.A.1985, Forest Inventory of the Sundarbans Bangladesh. Main report ODA, London, 196pp.

Climate Change Cell, 2007. Climate change and Bangladesh. Department of Environment, Government of the People’s Republic of Bangladesh.

FAO 1997. State of the World Forests. 200p.

Helal Siddiqui, A. S. M. 2000.Top Dying of Sundri (*Heritiera fomes*) Trees in the Sundarbans of Bangladesh. Mangrove Silviculture Division, Bangladesh Forest Research Institute, Khulna. Unpublished Bulletin. 23pp.

Helal Siddiqui, A. S. M. 2002. Silvicultural aspect of Baen (*Avicennia* spp.) the pioneer tree species in the Sundarbans. Indian Journal of Non Timber Forest Products. Vol.9 (3/4:156-162).

Helal Siddiqui, A. S. M. 2009. The Disease and Disorder of the Mangrove Species in the Sundarbans. Abstract, Section II, Twenty First Bangladesh Science Conference.

Helal Siddiqui, A. S. M. 2009b. Sundarbaner mullaban passur gash chashabad obortaman obostha. *Present condition and uses of passur, in* Krishi Katha, 66(4):112-113.

Helal Siddiqui, A. S.M. and Khair, A. 2012. Regeneration Status and Identification of Heart Rot Disease of Passur (*Xylocarpus mekongensis*) Tree in the Sundarbans of Bangladesh. Indian Journal of Forestry, Vol. 35(4):435-442.

Helal Siddiqui, A.S.M. and Khair, A. 2013. Infestation status of Heart Rot disease of Passur (*Xylocarpus mekongensis),* Tree in the Sundarbans. Indian Forester, Dehra Dun, (UP.), Vol. 138(2):

Karim, A. 1988. Environmental factors and distribution of mangroves in Sundarbans with special references to *heritiera-fomes* Ph.D. thesis university of Calcutta. 222pp.

Karim, A.1995. Report on Mangrove Silviculture, Integrated Resource Development of the Sundarbans. FAO/ UNDP/ project, BGD/84/056, Khulna. 148pp.

Lee, D. K.2000. Plantation For Fuelwood Production.XXI , IUFRO World Conference, The Role of Research, Sub Plenary Session, Vol.1., 7-12 August/2000, Kuala Lumpur, Malaysia, 356-365pp.

MoEF, 2008.Bangladesh Climate Change Strategy and Action Plan 2008. Ministry of Environment and Forests. Government of the People's Republic of Bangladesh, Dhaka, Bangladesh, Xvi + 68 pp.

Paul. N.K. 2011. International Year of Forests. Sharanika, National Tree Plantation Movement and Tree Fair 2011, Forest Department, Dhaka, Bangladesh, 92-94 pp.

Rahman. M.A.2009. Climate change and its impact on Bangladesh in general and that of the sundarbans in particular. *In Badabon,* Sundarban Academy Journal-03/09. (Sapon Guha *et al.* eds. 290p) 25-41pp., Khulna.

Ruediger Detsch and Ulrich Ammer, 2000. Multifunctional Rehabilitation of Forest in Central Europe, Vol-I. 320-327 pp.

Siddiqi , N.A. 2001. Mangrove Forestry of Bangladesh. Institute of Forestry and Environmental Sciences, University of Chittagong, Chittagong. Bangladesh. 102-103, 104-115, 138-141, 154-157, 178-181 pp.

UNESCO, 2007. Case Studies on Climate Change and World Heritage, 82 pp http://whc.unesco.org/documents/publi_climatechange.pdf

UNESCO, 2007. Case Studies on Climate Change and World Heritage, 82 pp http://whc.unesco.org/documents/publi_climatechange.pdf

SESSION 5 –IMPACTS WITH SPECIAL FOCUS ON DEPENDENT HUMAN COMMUNITIES

The session was chaired by Mr. Wasantha Dissanayake and one paper was presented.

Discussion

Impacts of anthropogenic and climatic factors on forest degradation and goods and services in Northeast India

Dr. N.S. Bisht described about land cover changes in Northeast India due to practice of shifting cultivation, change in cropping pattern, shrinkage of natural bamboo area, severe crises in water availability, disease manifestation like mortality of Pine and Parkia in Manipur state, reduction in the diversity of fungi etc and also about the invasive species and their effect on native plants. Further, he also mentioned about the adaptive measures taken up by the people of this region to combat the environmental changes and to suit to altered life form.

IMPACTS OF ANTHROPOGENIC AND CLIMATIC FACTORS ON FOREST DEGRADATIONAND GOODS AND SERVICES IN NORTHEAST INDIA

N. S. Bisht

Director, Rain Forest Research Institute, Jorhat, Assam, India

1. Introduction

The Northeast India is the eastern-most region of the country comprising of the contiguous seven sister states viz., Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura and the Himalayan state of Sikkim. The Siliguri Corridor in West Bengal, with an average width of 21 km to 40 km, connects the Northeastern region with the mainland. The region shares more than 4,500 km of international border with China (South Tibet) in the north, Myanmar in the east, Bangladesh in the southwest, and Bhutan to the northwest (Fig. 1).

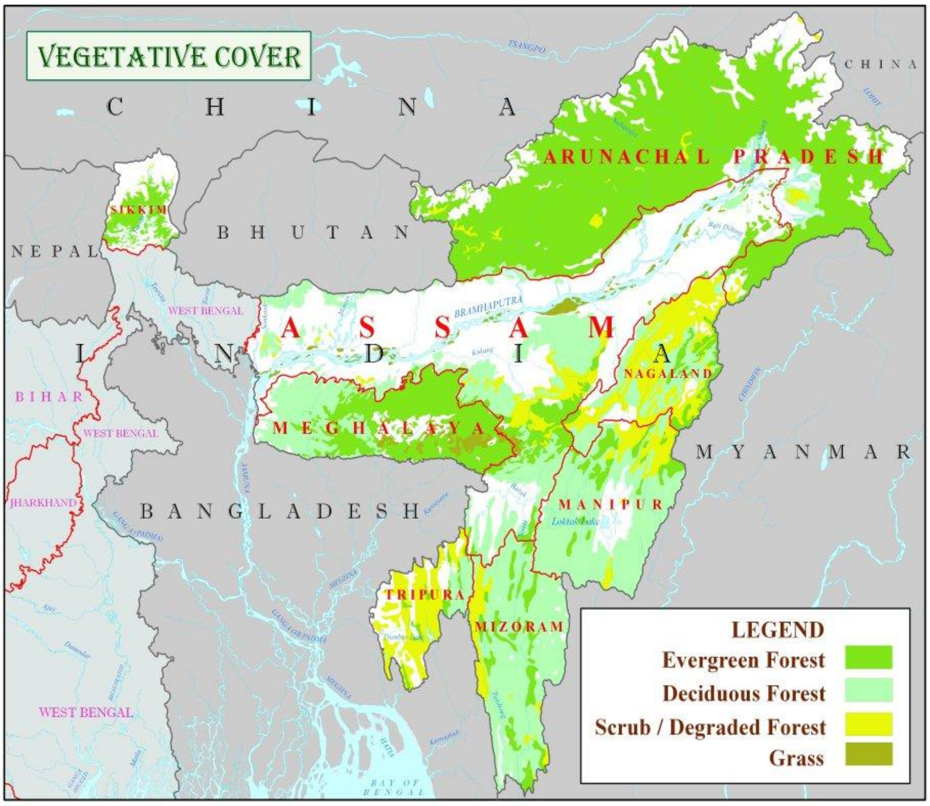


Fig. 1: Vegetation cover map of Northeastern states of India

Physiographically, the Northeastern region can be categorized into the Eastern Himalayas, Northeast Hills (Patkai-Naga Hills and Lushai Hills) and the Brahmaputra and the Barak Valley Plains. The climate is predominantly humid sub-tropical with hot, humid summers, severe monsoons and mild winters. Rainfall is very high in all northeastern states and average rainfall varies from 1200mm in Manipur to 11,000mm in Meghalaya. Geographically, apart from the Brahmaputra, Barak and Imphal valleys and some flat lands in between the hills of Meghalaya and Tripura, the remaining two-thirds of the area is hilly terrain interspersed with valleys and plains. Altitude varies from almost sea-level in Assam to over 7,000 meters above MSL in Arunachal Pradesh and Sikkim. The state wise details of land use pattern in various northeastern states are mentioned in Table 1.

Table 1: Land use pattern in Northeastern states of India (Area in 000' Hectare)

Landuse categories/States	A.P[1]	Assam	Manipur	Meghalaya	Mizoram	Nagaland	Sikkim	Tripura
Total geographical Area	8,374	7,844	2,233	2,243	2,108	1,658	710	1,049
Reporting area for land Utilization	5,659	7,850	1,965	2,227	2,109	1,621	723	1,049
Forests	5,154	1,853	1,693	948	1,594	863	319	606
Area not available for cultivation	64	2,626	27	226	133	98	250	134
Permanent pastures and other grazing lands	19	160	1	0	5	0	4	0
Land under miscellaneous tree crops and groves	37	196	6	160	46	121	5	27
Culturable wasteland	65	77	1	393	5	60	2	1
Fallow lands other than current fallows	70	59	0	157	171	90	30	1
Current fallows	40	126	0	59	60	73	5	1
Net area sown	211	2,753	236	284	95	316	107	280

[1]= Arunachal Pradesh (Source: ISFR, 2011)

The northeastern states cover an area of around 26.2 million hectare, which constitute 7.97%of the total area of the country. Area wise, Arunachal Pradesh is the largest state, followed by Assam, Meghalaya, Manipur, Mizoram, Nagaland, Tripura and Sikkim, respectively having 83,743sq.km.,50,137sq.km., 22,327 sq.km., 22,429 sq.km., 16,579 sq.km., 10,486 sq.km. and 7,096 sq.km. area. The total population of the northeast region is approximately 40 million, which constitutes approximately 3.3%population of the country. Assam with a population of 31.17 million is the most populated state, followed by Tripura, Meghalaya, Manipur, Nagaland, Arunachal Pradesh, Mizoram and Sikkim with a population of 3.67, 2.96, 2.72, 1.98, 1.38, 1.09 and 0.61 million, respectively. The population density is highest in Assam with 397 persons per sq. km., followed by Tripura, Meghalaya, Manipur, Nagaland, Sikkim, Mizoram and Arunachal Pradesh, respectively having 350, 132, 122, 119, 86, 52 and 17 persons in per sq. km area. The region is characterized by large area under forest cover, low population density, large percentage of indigenous communities and large rural population i.e. almost 70% to 80% of their total population is staying in rural areas except Mizoram where the ratio of rural and urban population is 48.49% and 51.51%, respectively.

The main forest types of the region are tropical semi evergreen forest, tropical moist deciduous forest, tropical moist semi evergreen forest, sub tropical broad leaved hill forest and sub tropical pine forest, while Arunachal Pradesh and Sikkim also have temperate and alpine forest. The maximum numbers of forest types are found in Arunachal Pradesh and

Assam due to their large geographical areas, while Tripura has only two forest types viz., Tropical moist deciduous forests and Tropical semi-evergreen forests (Table 2).

Table 2: State wise details of forest types of Northeastern states of India (Area in %)

Forest types	A.P.	Assam	Manipur	Meghalaya	Mizoram	Nagaland	Sikkim	Tripura
Tropical Wet Evergreen Forests	1.48	12.04				0.49		
Tropical semi-Evergreen Forest	68.75	51.71	24.82	1.93	71.94	16.34		11.06
Tropical Moist Deciduous Forests	5.35	25.64	3.05	61.62	27.40	47.43	5.15	88.94
Subtropical Broadleaved Hill Forest	3.35		52.94	17.71	0.04	15.63	25.15	
Subtropical Pine Forests	0.84	0.45	8.47	8.29	0.62	7.49		
Himalayan Moist Temperate Forest	7.43						6.45	
Himalayan Dry Temperate Forest	1.51							
Alpine Forest including moist and Dry Alpine Scrub	11.24						36.49	
Tropical Dry Deciduous Forests		0.09						
Montane wet temperate Forests			10.46					
Tropical wet Semi evergreen Forest				10.45		12.69	24.78	
Total area (%)	100	100	100	100	100	100	100	100

(Source: ISFR, 2011)

1.1 Biodiversity richness

The entire northeast region is very rich in biodiversity due to its specific location at the confluence of Indo-Malayan, Indo-Chinese, and Indian biogeographical realms. Due to its high endemism in higher plants, vertebrates and avian diversity 'Eastern Himalayas' was declared as a biodiversity 'hotspot' (Myers *et al.*2000). The Conservation International upscaled the 'Eastern Himalaya Hotspot' to the 'Indo-Burma Hotspot', which now includes all the eight states of Northeast India, along with the neighboring countries of Bhutan, Southern China and Myanmar. The lowland and montane moist to wet tropical evergreen forests of the region are considered to be the northernmost limit of true tropical rain forests of the world (Proctor *et al*., 1998).The Indian Council of Agricultural Research (ICAR) has identified this region as a centre of rice germplasm, while the National Bureau of Plant Genetic Resources (NBPGR) has highlighted the region as being rich in wild relatives of crop plants. The region is also considered as the centre of origin of citrus fruits. IUCN in 1995 identified Namdapha in Arunachal Pradesh as a centre of plant diversity. The important milestones of the region are mentioned below:

- 51 forest types belonging to six major types of Champion and Seth classification (1956) are found in the region,
- Out of approximately 1,500 endangered floral species, 800 are reported from Northeast India (Red Data Book, Botanical Survey of India).
- The International Council for Bird Preservation, UK identified the Assam plains and the Eastern Himalaya as an Endemic Bird Area (EBA). The EBA has an area of 220,000 sq. km. following the Himalayan range in the countries of Bangladesh, Bhutan, China, Nepal, Myanmar and the Indian states of Sikkim, northern West Bengal, Arunachal Pradesh, southern Assam, Nagaland, Manipur, Meghalaya and Mizoram. Because of a southward occurrence of this mountain range in comparison to other Himalayan ranges, this region has a distinctly different climate with warmer mean temperatures and fewer days with frost and has much higher rainfall.
- Out of 450 tribal communities of the country, 135 are found in this region.

- WWF has identified the entire eastern Himalayas as a priority Global 200 Ecoregion (Olson and Dinerstein1998.).
- 825 out of 1,145 species of orchids, 80 out of 90 species of Rhododendron, 80 out of 140 species of bamboos, and 25 out of 56 species of canes are found in this region.
- Some of the unique plants of the region are mentioned in Table 3.

Table 3: Unique plants of Northeast India

Trees	**Medicinal plants**	**Orchids**	**Cane and bamboos**	**Miscellaneous**
Amentotaxus assamicus Aquillaria malaccensis Albizzia arunachalensis Cephalotaxus mannii, Illicium griffithii Garcinia cowa	*Homalomena aromatic Panes sikkimensis Piper mullesua Clerodendron colebrookianum*	*Vanda coerulia Reinantheraim schootiana*	*Daemonoropsjen kinsiana Plectocomia assamica Phyllostachys bamboosoides Schizostachyum arunachalensis*	*Clethera monostachya Napenthes khasiana*

2. Forest degradation in NE states

The north-eastern states are very rich in forest and tree cover. It ranges from a minimum of 37.27% in Assam to a maximum of 91.58% in Mizoram, which is highest in the country (ISFR, 2011). The tropical rain forests are one of the finest ecosystems of the world, which have very unique floral and faunal diversity, where one can find hundred or so species of different trees growing in a small area competing for light and space (Deb and Sundriyal, 2011). However, with the passage of time, these forests are facing tremendous anthropogenic pressure from increasing population and unplanned development activities. The most dangerous factor is the construction of roads, which are being made without following essential environmental safeguards. Since major portion of northeastern states is hilly and fragile, construction of roads leads to huge amount of debris, which is simply thrown in the down hillside thus choking streams and rivers creating future potential landslide and flood hazard zones. The other important causes of forest degradation are:

- Population explosion,
- shifting cultivation and other land use changes i.e. conversion for agriculture, horticulture and forestry plantations,
- Infrastructure development: roads and buildings, etc.
- Increase in the value of land
- Community ownership? (Lalnunmawia and Lalzarliana, 2013)

2.1 Impacts of forest degradation

Some of the visible impacts of forest degradation as observed in the northeastern states are mentioned below:

2.1.1 Shift from Dense forest category towards Open category forests

It has been observed that in the northeastern states, there is a gradual shift from very dense and moderately dense forest categories towards open forest category mainly due to anthropogenic factors. For example, incidence of shifting cultivation is very high in the states of Mizoram, Nagaland, Manipur, Meghalaya and Tripura, and the percentage of open forest category area to the total forest area in these states is 61.48%, 45.72%, 42.79%, 31.51% and 30.33%, respectively (Table 4), which is comparatively higher than the average distribution of very dense, moderately dense and open forest areas in other states of the country (ISFR, 2011).

Table 4: Status of different categories of forests in NE states of India (%)

States	Forest & tree cover	Very dense forests	Moderately dense	Open forest	Scrub	Non forest
Arunachal Pradesh	81.16	24.92	37.64	17.94	0.14	19.36
Assam	37.27	1.84	14.54	18.90	0.23	64.49
Manipur	77.40	3.27	27.55	45.72	-	23.46
Meghalaya	79.60	1.93	43.58	31.51	2.16	20.42
Mizoram	91.58	0.64	28.87	61.18	0.01	9.30
Nagaland	82.27	7.80	29.74	42.79	0.02	19.65
Sikkim	47.69	7.05	30.45	9.84	5.12	47.54
Tripura	77.79	1.04	44.67	30.33	0.69	23.27

(Source: ISFR, 2011)

2.1.2Shrinkage of natural bamboo areas

Bamboo is a wonderful, multipurpose and the most valuable species for the rural people of this region. Many species of bamboos are found in abundance in all north-eastern states. The most common species includes *Arundinaria maling*, *Bambusa tulda, Dendrocalamus hamiltonii, D. longispathus, Melocalamus compactiflorus, Melocanna baccifera,* etc (Bisht and Naithani, 2011).People in remote areas are highly dependent on bamboos for construction and maintenance of their houses and for various day to day agriculture and household uses.

It has been observed that the natural bamboo area in these states is decreasing gradually mainly due to following reasons:

- Change in land use i.e. conversion of natural bamboo areas to agriculture, horticulture and forestry plantations or permanent construction areas,
- Poor regeneration and establishment of bamboos after flowering,
- Shortening of jhum cycle; abandoned jhum areas being occupied by weeds,
- Forest fires,
- Over exploitation of fresh shoots of bamboos for food, and
- Sporadic flowering of bamboos: most of the time seed setting is not there. All culms die after flowering and re-establishment of such clumps is poor due to weeds, fire and other biotic factors.

Two such examples are discussed below:

i. Gregarious flowering of *Melocanna baccifera* started in the northeastern states in 2003, after that culms died and the area started regenerating from seeds, which were produced in large quantities. However, in many areas where regeneration and establishment was poor due to biotic (Climatic ?) factors, and seeds were damaged by rats, burning of areas for jhum cultivation and other disturbances, the space created by the dead culms has been occupied by weeds such as Mikania, grasses and wild bananas depending on aspect, slope and other microclimatic factors. Thus the area under muli bamboo (*Melocanna baccifera)* has reduced considerably.

ii. Another striking example of loss of large natural bamboo area is from Jasawantgarh to Jung area in Arunachal Pradesh, where gregarious flowering of *Arundinaria maling* was reported during 2006 (Naithani et al., 2007). All culms died after flowering. Seed setting was good; however, most of the seeds got washed away due to untimely heavy rains (Climate impacts) thus affecting regeneration and establishment of the species. The upcoming regeneration was damaged by the grazing by yaks. This species, which was occupying over 100 sq. km. area before flowering, is struggling for survival in few pockets and ninety percent of its original area is now completely barren.

2.1.3Increase in disease incidents in forest plantations

Following specific instances have been reported in this region:

2.1.3.1Khasi pine: *Pinus kesiya* (Khasi pine), a fast growing three-needle pine, has been planted in large areas in Meghalaya, Manipur and Arunachal Pradesh. Heavy mortality of Khasi pine trees has been reported at Ukhrul, Serui, and Phanguriin Manipur and Shillong in Meghalaya. Many trees have been found to be heavily infested with borers and fungi, resulting in top dying of the trees. Fruiting bodies of *Fomitopsis pinicola,* a root rot fungus, were found associated with the diseased trees, while no fruiting bodies were observed on healthy trees. *Fomitopsis pinicola* alone is the key driver of increased pine mortality is not proved yet and detailed study on these insects and fungi, and their interaction with the host and microclimate is required to reach at some logical conclusion. Increase in temperature may also be a factor as life cycles of most of the insects are affected by temperature changes.

2.1.2.2*Gmelinaarborea*: Gamari is an important fast growing commercial tree species of the northeast region. It is widely used for furniture and livelihood of large numbers of local craftsmen is dependent on regular supply of this species. One can find many shops on the highways selling beautiful show pieces of rhino, hornbill and other birds and animals to the tourists.

Gamari has been widely planted in the entire northeastern region. These plantations are affected by many insects and pests such as *Calopepla leayana, a* defoliator that causes immense damage to trees. Jamaluddin*et al.* (1992) studied damage from a combined pest and fungus attack causing defoliation, drying of young shoots, canker and callus formation in twigs and stems, and mortality in two provenance trials in India. It has been observed that incidents of diseases are high in those stands where gamari has been planted as monoculture. In Mizoram, pure plantations of gamari have been extensively damaged by *Loranthus* and the intensity of damage is so severe that the state govt. has decided to replace all such areas with mixed species.

2.1.2.3*Parkia roxburghii:* *Parkia roxburghii* or tree bean is a multipurpose tree species, which is widely planted in the home gardens in all northeastern states. It is known as Aoelgap (Garo), *Bire-Phang* (Kachari), *Unkamn pinching* (Naga), *Yongchak* (Manipuri) and *Zongto*in Mizoram. Flowers, tender pods and seeds are edible and are a good source of protein, fat, carbohydrates, vitamins and minerals compared to other legumes. It is also used as insecticides, pesticides, antibacterial, face wash and shampoo, etc.

Large scale mortality of tree beans has been observed in all northeastern states. The actual cause of disease is still not clear and reports assign it due to *Verticillium* wilt, radiation from mobile towers and climate change (temperature). Few people assign it due to decline in flying fox population, which plays a major role in pollination and seed dispersal of this species. Recently, the RFRI, Jorhat has taken up a research project for making a detailed study of this disease in these states and hopefully the position may become clear after a year or two.

2.1.2.4 Distribution of wood decaying fungi and mushrooms

It has been observed that although large numbers of felled/fallen/burnt/half burnt stumps and trees are available along the road sides and jhum cultivation areas, and in spite of good temperature and moisture conditions, the number of wood decay fungi and mushrooms growing on these logs/stumps is very less (Bisht, 2011).

A simple reason may be that many of such trees or logs are immediately covered by grasses, mikania or other weeds from all sides thus obstructing the entry /landing of spores or inoculums of these fungi. Another reason of the low availability of wood decay fungi and mushrooms may be that due to burning and re-burning in jhum cultivation areas, surface of these logs/stumps becomes very hard, water repellant and the cellulose contents of the surface area gets burnt, thus not supporting the spores of these fungi to settle and establish.

2.2 Shifting cultivation: impacts, vulnerability and adaptations

Shifting cultivation is a prevalent agriculture practice in most of the northeastern states of India. It is a labour intensive farming system, which provides assured source of food security to the sustenance level farmers of this region. It fulfills all needs of the farmers and minimizes his dependency on external inputs. It represents an effective form of landuse by way of optimum utilization of space where as many as 60 varieties of crops are raised at a time in the same plot. It has contributed greatly towards conservation of agrobiodiversity particularly the germplasm of native crop varieties. The important crops grown in shifting cultivation areas include paddy, maize, mustard, yam (*Dioscoria*), lady's finger, brinjal, chillies, beans, cucumber, cassava (*Manihot esculenta*), millet (*Pennisetum glaucum*), watermelon, sweet potato (*Ipomoea batata*).

However, there are disadvantages too, i.e.it accelerates soil erosion, loss of nutrients, useful fauna and microbes from the soil. Burning of slash lowers soil acidity, organic matter and total nitrogen but enhances phosphorus and cations. Silva *et al*. (2011) estimated that in India, green house gas emission from shifting cultivation are approximately 97,80,539 (CO_2), 6,07,524(CO), 39,700 (CH_4), 13,594 (NOx) and 1,203 (N_2O) annually by clearing of around 15,16,408 hectare area. The state wise details of the area under shifting cultivation in northeast region and percentage of geographical areas affected are mentioned in Table 5.

Table 5: Shifting cultivation areas vis-a-vis% of geographical area covered in NE states

Items	Arunachal	Assam	Manipur	Meghalaya	Mizoram	Nagaland	Tripura
Shifting cultivation area (in lakh ha)	2.10	1.39	3.60	2.65	1.89	1.91	1.12
% of G.A.	2.50	1.77	16.12	11.81	8.96	11.52	10.68

(Source: Anonymous,2009)

2.2.1 Vulnerability of shifting cultivation areas

There are many instances, which indicate that shifting cultivation areas, specially abandoned areas, are highly vulnerable to climate change than natural forests. Some of the observations made in this regards are discussed below:

2.2.1.1 Increased incidents of forest fire: The abandoned shifting cultivation areas are highly vulnerable to forest fire, and studies have indicated that the incidents of forest fire are maximum in the northeastern region of the country. The total numbers of reported forest fire cases in 2005 were 8,431, which increased to over 300% to 26,118 reported cases in 2009. The worst affected states of the region were Mizoram, Assam, Manipur, Nagaland, Arunachal Pradesh and Tripura having fire incidents varying from a maximum of 3,400incidents in Mizoram to a minimum of 725 cases in Tripura (Fig. 2). Amongst the worst affected 10 districts of the country in 2009, six were from NE region. Aizawl was the most affected district of the country with over 1,500 cases, followed by Lunglei (Mizoram), North Cachar Hills and Karbi Anglong in Assam, Lawngtlei (Mizoram) and Churachandpur in Manipur (Fig. 3). The impact of forest fire is so high that during fire season many a times it has happened that flights did not land at Lengpui airport, Aizawl and went back to Kolkata because of poor visibility due to heavy smoke from jhum fires.

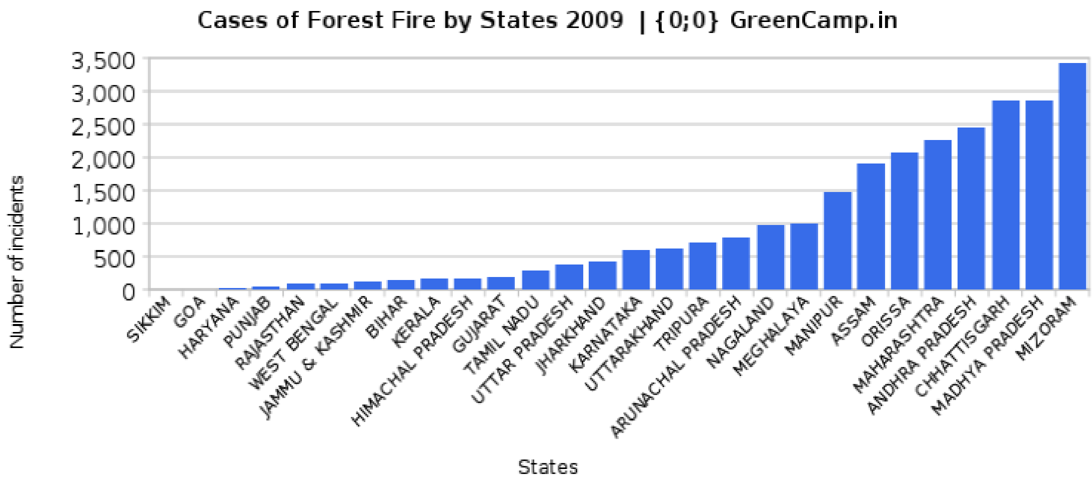


Fig. 2: Cases of forest fire in different states of India in 2009

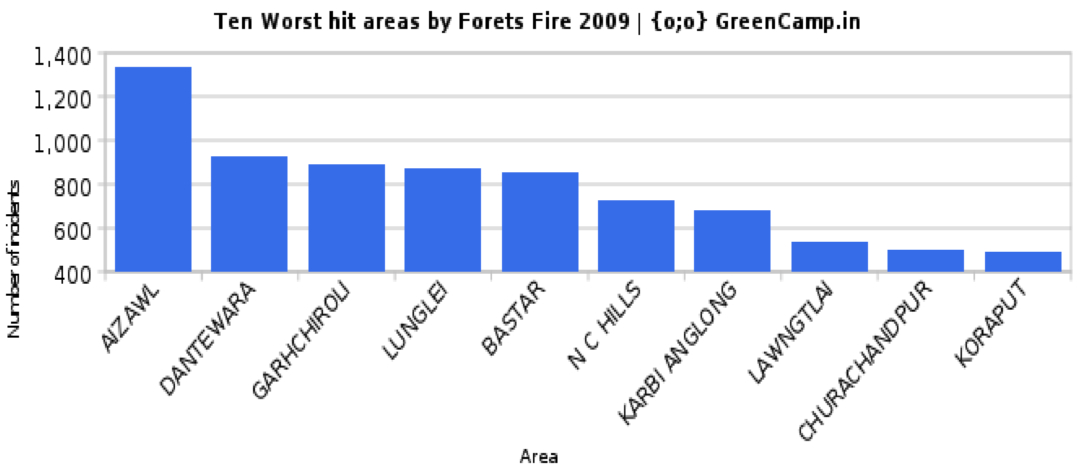


Fig. 3: The worst hit districts by forest fire in India during 2009.

2.2.1.2 Invasion of exotic weeds: The abandoned shifting cultivation areas are highly vulnerable to invasion by weeds. *Mikania micrantha* is a common weed of this region, which grows very fast, covers all open areas thus affecting regeneration and growth of local species. Most of the soils of this region have degraded due to shifting cultivation practice, and due to shortening of shifting cultivation cycle there is insufficient time between successive cycles for the soil to recover its nutrient status. Therefore, it does support slow-growing native species to grow and produce seeds, thus leading to a paucity of propagules for recolonisation. Such areas are immediately invaded by invasive weeds, both native species such as *Imperata cylindrica*, *Pteridium aquilinium*, and *Saccharum spontaneum,* and exotics viz., *Eupatorium odoratum*, *Eupatorium adenophorum*, and *Mikania micrantha* (Ramakrishnan and Vitousek, 1989). The native weeds are distinguished by their ability to resprout in response to fire, while exotic species are characterized by their high reproductive potential and by their greater efficiency at sequestering scarce resources from these degraded soils; the former affording them a demographic advantage, and the latter giving them a competitive edge over the native vegetation. The details of species, which occupies abandoned jhum areas, are mentioned in Table 6.

Table 6: Details of the species occupying abandoned jhum areas

Trees	**Grasses and bamboos**	**Weeds**
Bauhinia purpurea, Callicarpa arboretum, Glochidon lanceolarium, Macaranga denticulata, Mallotus tetracoccus, Melastomam alabathricum, Meliosma pinnata, Meyna laxiflora, Musa paradisiaca, Osbeckia nepalensis, Pholgacanthus thrysioflorus, Saurauia nepalensis, Xeromphis spinosa	*Bambusa pallida, Chiminobambusa callosa, Dendrocalamus hamiltonii, Melocanna baccifera, Phragmites karka, Saccharum spontaneum, Schizostachyum polymorphum, Thysanolena maxima,*	*Bidens pilosa, Eupatorium odoratum, Lantana camara, Mikania micrantha, Sida acuta, Trimphetar homboidea, Urena lobata,*

Invasion by weeds affects the availability of wild edible and medicinal plants thus impacting the food and health security of tribals, whose dependence on forest is very high in this region than other parts of the country.

2.2.1.3 Invasion by wild banana: It has been observed in Arunachal Pradesh and Mizoram, and may be true for other northeastern states also that large portion of abandoned shifting cultivation areas has been occupied by wild banana (*Musa paradisiaca*). One can see huge patches of wild banana covering the whole hillocks. Currently, wild banana is not much in use in this region. Farmers cut and burn it while taking up these areas for fresh cultivation. However, it does not burn properly due to high moisture content and sprouts from underground rhizomes immediately after the first rains thus affecting the productivity of crops grown by the farmers.

2.2.1.4 Invasion of natural bamboo areas: The most dangerous impact, which has been noticed in the region, is that the wild banana is gradually occupying those areas, which were previously occupied by bamboo species such as *Melocanna baccifera, Dendrocalamus longispathus, Bambusa tulda* etc. Bamboo is the most important species of this region as far as tribal culture and traditions are concerned. It is used for wide varieties of purposes such as house construction and repair, food, fuel, making temporary huts in jhum fields, poultry enclosure, water pipes, vessels for carrying water, storage of foods and various unimaginable uses, which are specific and unique to the region. Therefore, spreading of wild banana over bamboo areas is a serious issue for the entire northeastern region. It is impacting tribal life and putting extra pressure on them as well as on neighboring natural forest areas to meet the demand.

2.2.2 Adaptations

However with the changing time, people have also explored ways and means to adapt to these situations. It has been observed that with the overall development in the region especially in infrastructure, communication, education and awareness, and tourism etc., the income generating opportunities vis-a-vis paying capacity of people have also increased. It has affected the shifting cultivation practices too and studies have indicated that the average per family area under shifting cultivation is reducing gradually, and there is a shift from shifting cultivation practice towards permanent cultivation for which improvement in infrastructure, connectivity and market economy are major drivers (Table 6). The demand of fresh farm products has increased considerably in all major cities of the region due to increase in population, education, business and job opportunities and tourist inflow. Therefore, many farmers have now started cultivation of off season vegetables such as maize, tomato, carrot, reddish, capsicum, beans, cucurbits and other green vegetables, which provide good income in a short time. Earlier, the main objective of shifting cultivation was for food production and to meet other day-to-day needs of the family, but now the focus has shifted from food crops to commercial crops (Table 8).

Table 7: Temporal dynamics of jhum cultivation in Northeastern states (*Area in Hectare*)

Parameter	1970-71	1976-77	1980-81	1985-86	1990-91	1995-96
No. of families involved	78990	66499	78452	86038	94357	109093
Net area under jhum	87220	71901	66220	72555	73000	84002
Av. Jhum land/family	1.10	1.08	0.84	0.84	0.77	0.70
Net permanent agri. land	28006	40013	52012	76759	92616	81281
Av. per family agri. land	0.35	0.60	0.66	0.89	0.98	0.74

(Source: GBPIHED, 2006)

Table 8: Shift in cropping pattern in shifting cultivation areas

Items	Categories of crops	Crops grown in the past	Current practice
Principal crops (70% area)	Cereals	Paddy, maize, millet	Maize
	Tubers	Tapioca, Yam	Ginger
	Vegetables	Pumpkin, cucurbits	Bean, cabbage, cauliflower, chillies
Intermediate crops (20% area)	Spices, tubers	Chillies	Paddy, millet
	Vegetables	Brinjal, tomato	Cabbage, brinjal, cauliflower, beans, reddish, carrot
	Others	Cotton, jute, mesta	Tobacco, cannabis
Minor crops (5% area)	Oil seeds	Sesamum	Sesasum
	Others	Tobacco, cannabis	Hill tomato, beans
	Vegetables	Beans, spring onions	Cotton, mesta, jute

Some examples of successful cultivation of commercial crops, which have resulted into more or less permanent sort of agriculture practices are mentioned below:

- Cultivation of pine apple (Meghalaya, Manipur, Nagaland, Mizoram etc.)
- Iskut cultivation in Mizoram has completely stopped jhum cultivation and almost whole village is involved in its cultivation or indirectly supporting various activities such as collection from fields, packaging and transportation to various markets including export outside the state.
- Grapes
- Banana
- Oranges
- Anthurium
- Apple and Kiwi

3. Impacts of forest degradation on goods and services

3.1 Vulnerability of drinking water in selected cities of NE India

3.1.1Cherapunjee: Also known as the "Scotland of the East" was considered as the 'wettest place' on the earth. It is located just 56 kms from Shillong and hordes of tourists still throng the picturesque town to enjoy the incessant rains during monsoons and catch a glimpse of the grand waterfalls playing hide and seek with the clouds. The average annual rainfall is 11,443 mm; however, the clouds have altered their course due to the rapid shrinkage of forest cover in the area. Local people face an acute shortage of drinking water after the monsoons, when rainfall becomes scanty and many of the breath-taking waterfalls and springs, which used to be a source of potable water, have dried up now, and the people have to take walk long distances to fetch potable water.

3.1.2 Kohima: Kohima, the capital city of Nagaland is lucky in the sense that water supply of the town comes mainly from Dzuna River and Phesama stream. These rivers originate in the forests and because of strict communities' norms, conditions of these forest vis a vis flow of water is comparatively good in these rivers. However, the situation of water supply is unique in Kohima in the sense that there are three different sources of water supply in the town i.e. govt. supply, private supply through tankers and private supply through water cables. The normal govt. supply of water is around twice a week during lean season, therefore, people depend more on private suppliers than govt. supply. The private suppliers supply water through tankers (2000 liters) @ Rs. 2000.00 per trip. During severe situations, people buy water @ Rs. 20.00 per bucket.

The water cable system i.e. overhead water pipes may be unique in the country, where few individuals have natural springs in their lands. They have made water tanks, where water is stored and then it is supplied through pumping by laying individual overhead pipelines on telephone posts or along the roads to the individual customers. These are called water cables and the average daily supply of water is around one hour @ Rs. 1000.00 per month.

However, poor people do not have access to this water. They either compromise with the quantity of water required for various day to day purposes or have to spend extra time for fetching water from distant natural springs. The crisis of water supply is so high in Kohima that opposition leaders have threatened to move a proposal to shift the capital from Kohima to some other suitable place where water is available in plenty.

3.1.3 Aizawl, Mizoram: Aizawl, the capital town of Mizoram, is located at the hill top; therefore water supply has always been a problem there. The first water reservoir of the state was built as early as in 1900 followed by another in 1953-54. Most people are dependent on the piped water supply, which presently provides water for only an hour a week. The average consumption of water during the rainy season is not more than 80 liters per capita per day (lpcd) and it is much less, perhaps as little as 50 or 60 lpcd, during the dry season (SIPMIU, 2011). Tlawng River, the main source of water for Aizawl, is located about 12 km from the city. Water supply from Tlawng involves a high static lift of 1,017 m from the riverbed level at 146 m; hence energy cost is very high. Due to this, it is considered as one of the most expensive water supply systems of the country. The annual expenditure on the maintenance of water supply was Rs. 172.87 million in 2012, of which, electricity charges and cost of diesel was to the tune of Rs. 87.52 Rs. 57.65 million, respectively.

3.1.4 Adaptations

The Meghalaya state government has developed Greater Cherrapunjee Water Supply Scheme costing about Rs 4.13 crore to provide drinking water to nearly 25,000 families. The state government is also planning to promote rainwater harvesting in selected villages in Cherrapunjee area by importing specially-designed water tanks from Israel to encourage locals to save rainwater during the monsoon season.

However, the people of the region have developed way and means to tackle this issue to some extent. In most of the northeastern states people rely more on rain water harvesting than government supply. One can find huge water tanks in front of the houses for rain water harvesting. In the village areas, everyone keeps huge water tank in front of their house, which is connected through a pipe from the roof of their houses. The types and size of the tank vary with the economic condition of the family i.e. earlier GI sheet tanks were popular, which is now being replaced by PVC tanks. However, the lower income group families still use huge bamboo basket by putting a lining of polythene sheet inside it for water storage.

Another way, which these communities have adopted, is that in most of the villages communities have constructed water tanks near the natural springs and most of the villagers go there for bathing and washing of clothes instead of transporting water to their houses for this purpose, which requires both time and labour.

Looking at the importance of the catchment areas along the rivers, the Mizoram govt. has taken a very wise step by declaring half a mile area on both sides of 16 important rives of the state as Riverine Reserve Forests under Mizoram Forest Act, 1955.

3.2 Availability of fresh bamboo shoots: Consumption of fresh bamboo shoots is very high in all northeastern states. An average Mizo consumes over one hundred fresh shoots in a year, therefore per capita consumption of fresh shoots may be highest in the country. However, production of bamboo shoots has gone down considerably after gregarious flowering of muli bamboo and other species as well. After flowering, these areas are yet to develop sufficient growing stock so as to produce good quantity of fresh shoots every year.

3.3 Supply of bamboo culms: It was observed in Mizoram and the situation is same for other NE states too, that the availability of mature bamboo culms has reduced greatly due to poor regeneration, establishment and growth of *Melocanna baccifera* after its gregarious flowering. Because of this, Hindustan Paper Mill at Panchgram, Silchar, Assam is facing acute shortage of bamboo supply from these states. These states are also losing huge revenue, which they were earning previously from the supply of bamboos to this paper mill. For example, Mizoram is losing around twenty million rupees annually. The paper mill is also a great sufferer as it has to shut down production for most part of the year thus losing both in terms of revenue as well as manpower.

3.4 Supply of fuel wood from forests: Fuelwood is the main source of cooking energy and dependency of people is very high on forests for its collection. The consumption of fuel wood is very high in this region due to poor supply of LPG, and one has to pay heavy charges to transport it to remote villages. Besides this, due to heavy pressure, availability of fuel wood has reduced near village areas; therefore villagers have to spend extra time for its collection. Fuel wood is normally collected during winter months when jhum areas are cleared and one can see both men and women carrying fuel wood on their back while coming back from jhumfields. One can also find huge quantities of fuel wood stacked in front of rural houses or stored in the ground floor to protect it from rainfall. The poor people, mostly outside labourers, are highly vulnerable to fuel wood shortage and have to pay a large portion of their income/wages to purchase fuel wood. The prices have gone so high that no one would believe that fuel wood in most of the cities is now sold by number and not by bundle. The average price of 2.5 feet long piece of fuel wood is Rs. 5.00 in Aizawl town.

4. Indicators of climate change vulnerability in Northeast India

Climate change is one of the biggest environmental threats impacting food security, water supply, biodiversity, human health and settlements. There are practically not many studies in the northeastern region for assessing the impacts of climate change on natural resources (Telwala, 2012; ICFRE, 2013). Ravindranath *et al.* (2011) developed district level climate change vulnerability profiles for agriculture, water and forestry sectors for all the northeastern states for the current and future potential climates. Their study indicated that majority of districts of this region are subject to climate induced vulnerability currently and in the near future. Since more than 70% population of this region lives is in rural areas, and their dependence on natural resource or forests is very high; therefore their vulnerability to climate change is also very high. Changes in the climate also impacts biodiversity thereby affecting ecosystems' ability to deliver goods and services for human well being. An example of the status of various indicators for Mizoram is mentioned in Table 9.

Table 9: Status of climate induced vulnerability indicators in Mizoram

Indicators	Remarks
A. Agriculture	
Relative variability in rainfall	The region experiences high variability in monsoon pattern e.g. 25% to 45% variation in precipitation, which is very high than the normal range i.e. 5% to 10%.
% inter annual variability in rainfall	Very high
Area under rainfed/dryland crops	89.56% of the grossed cropped area is under rainfed condition
Rural population density	48.50% in Mizoram but very high in other NE states
Number of small land holdings	Land normally belongs to community. However, annual jhum areas and other cultivation areas are small.
Net sown area	0.109 million hectare (6.31% of the geographical area of the state) Potential area 0.630 million ha
Area under irrigation	10.44% of the grossed cropped area
Area under high yielding varieties	HYV are normally grown in wet rice cultivation areas
Amount of fertilizers used	9,567 metric tonnes in 2009-10
Amount of manure used	2,765 quintals (Vikash) and 1000 qt. vermin-compost in 2009-10
Net annual ground water availability	Not available.
Mean rainfed crop yield	Paddy 1,5 tonnes in jhum areas; 1.7 tonnes in WRC areas

B. Water	
Water availability	Rain fall very high but most of it goes as run off
Drought indicator	Most of the big cities face shortage of drinking water specially during winters when rainfall is very less
Flood discharge	Very high in Assam and a large population is affected every year
Crop water demand	Normally single crop is taken in most of the areas
C. Forest	
Disturbances	Very high due to jhum cultivation, roads and other infrastructure development activities
Fragmentation status	- do -
Biological richness	Initially very high but many species are under threat due to disturbances and fragmentation

(After Ravindranath *et al*., 2011)

References

Anonymous (2009). Draft report of the inter-ministerial national task force on rehabilitation of shifting cultivation land. Report submitted to the Ministry of Environment and Forests, Government of India. pp 95.

Bisht, N. S. and Naithani, H. B. (2011). Bamboos of Mizoram. Environment and Forest Department. Govt. of Mizoram, Aizawl. Mizoram. 206p.

Bisht, N. S. and Singsit, S. (2011). Valuation of Forestry Resources of Manipur. Forest Department, Govt. of Manipur. 144p.

Bisht, N. S. (2010). Wood Decaying Fungi of Mizoram. Environment and Forest Department, Mizoram. 98p.

Bisht, N. S. (2013). Valuation of the role of forests in providing water supply to the people of Aizawl, Mizoram. Indian Forester.139 (3). 187-192.

Deb, P. and Sundriyal, R. C. (2011). Vegetation dynamics of an old-growth lowland tropical rainforest in North-east India: Species composition and stand heterogeneity. International Journal of Biodiversity and Conservation Vol. 3(9): 405-430.

ICFRE (2013).Forest Types of India. Revisited. Indian Council of Forestry Research and Education. Ministry of Environment and Forest. Dehradun, Uttarakhand, India. 473p.

ISFR (2001).India State of Forest Report, 2011.Forest Survey of India, Ministry of Environment and Forests, Govt. of India. Dehradun. 286p.

Lalnunmawia, F. and Lalzarliana, C. (2013). Land use system in Mizoram. Akansha Publishing House, New Delhi. 292p.

Meghalayatimes.info/18833. Shillong. Shillong continues to reel under water woes. Meghalaya times.

Myers, Norman, Mittermeier, R. A.,Mittermeier, C. G., Fonseca, Gustavo A. B. da and Kent, Jennifer. (2000). Biodiversity hotspots for conservation priorities. Nature. Vol. 403:853-858.

Naithani, H.B., Chandra, Anup and Biswas, S. (2007). Gregarious flowering of a hill bamboo, *Sinarundinaria maling* in Arunachal Pradesh. Indian Forester. 373-274.

Olson, D.M. and Dinerstein, E. (1998.) The Global 200: A Representation Approach to conserving the Earth's Most Biologically Valuable Ecoregions. *Conservation Biology* 12: 502 – 515.

Ramakrishnan, P.S. and Vitousek, P.M. (1989). Ecosystem level processes and consequences of biological invasion. In Biological Invasions: A Global Perspective. Eds.:J.A.Drake, H.A.Mooney, F.diCastri, R.H.Groves,F.J.Kruger, M. Rejmanck and M. Williamson. 281-300. New York. John Willey.

Ravindranath, N.H., Rao, Sandhya, Sharma, Nitisha, Nair, Malini, Gopalakrishnan, Ranjith, Rao, A.S., Malaviya, S., Tiwari, R., Sagadevan, A., Munsi, M., Krishna, N. and Bala, G. (2011). Climate change vulnerability profiles for North East India. Current Science. 101(3):384-394.

Silva, J. M. N., Carreiras, J. M. B., Rosa, I. and Pereira, J. M. C. (2011). Greenhouse gas emissions from shifting cultivation in the tropics, including uncertainty and sensitivity analysis. Journal of Geophysical Research. Vol. 116:1-21.

Telwala, Y. (2012). Climate change and alpine flora in Sikkim Himalaya. In: http://www.sikenvis. nic.in/writeraddata/7Chapter_Climate_Change_and_alpine_Flora_ in Sikkim_Himalaya.

www.theshillongtimes.com/2012/07/22. States stares at water crisis. The Shillong Times,

www.assamtribune.com/scripts/details news.asp.July8,2011. Water shortage in Shillong.

ANNEXURE I

Expert Group Meeting on
Adaptation to Climate Change Impacts and risks to
Different forest types of South Asia
RFRI, Jorhat, Assam, India

Organised by
SAARC Forestry Centre, Bhutan and Rain Forest Research Institute, Jorhat

22-24 October, 2013

Programme

Day 1, 22nd October 2013 (Tuesday)		
Opening session		
08:30–09:00	Registration	
09:00–09:15	Seating of participants and Arrival of Chief Guest	
09.15-10.30	**Inaugural Session**	
	Introduction – Mr. Gautam Banerjee, Coordinator (Facilities), RFRI	
	Introduction of Participants	
	Lighting of Lamp by Chief Guest	
	Felicitation of participants	
	Welcome address by Dr. N.S. Bisht, Director, RFRI	
	Technical statement by Dr. Sangay Wangchuk, Director, SFC	
	Address to the gatherings by the Chief Guest - Mr. A.K. Wahal IFS., PCCF & HoFF, Arunachal Pradesh	
	Vote of Thanks – Udhayan A., SFC	
10.30-11.00	Group Photo and High tea	
Session 1: Overview on the Forest Types in the Member States of the SAARC Region – Chair: Dr. Rajiv Kumar Garg		
11.00-11.15	Forest Types in Bhutan – Dr. Purna Bdr. Chhetri	
11.15-11.30	Forest Types in India – Dr. Renu Singh	
11.30-11.45	Forest types in Maldives – Ms. Aishath Najath	
11.45-12.00	Forest Types in Nepal – Mr. Ramesh Basnet	
12.00-12.15	Forest Types in Sri Lanka – Mr. W. Dissanayake	
12.15-12.30	Forest Types in Bangladesh – Mr. Mozammel Chowdhury	
12.30-12.50	**An overview of the activities of Rain Forest Research Institute**	
12.50 – 14.00	Lunch	
14.00-14.30	**Quick tour of the RFRI Campus**	
Session 2: Overview on Impact of Climate Change on forest types in South Asia – Chair: Dr. Sangay Wangchuk		
14.30-15.15	An Assessment of Climate Change Impacts and Risks to Different Forest Types Associated with Coal Mining in India – **Dr. Rajiv Kumar Garg** – India	
15.15-16.00	Some information on forests and climate change in Nepal – **Mr. Ramesh Basnet** – Nepal	
16.00-16.15	Tea	
Session 2 (Continued)		
16.15-17.00	Influence of Climate Changes on forest fires in Sri Lanka – **Mr. Mohan Heenatigala** – Sri Lanka	
17.00-17.30	Climate Change and Island Forestry – **Mr. Hussain Faisal -**	

	Maldives	
17.30-18.00	Presentation by **Ms. Aishath Najaath** - Maldives	
18.30-21.00	**Welcome Dinner at Hotel Jironi, Jorhat**	
Day 2, 23rd October 2013 (Wednesday)		
Start at 0700 hrs with packed breakfast – **Field Trip to Kaziranga National Park** Resource Person: **Mr. N.K. Vasu IFS,** Director, Kaziranga National Park Two hour drive by road to the National Park Objective is to observe the Impacts of Climate Change on the forests and grassland ecosystems of Kaziranga National Park - Expected back at RFRI, Jorhat at 1800 hrs		
Day 3, 24th October 2013 (Thursday)		
Session 3: Impacts, Vulnerability and Adaptation measures - Chair: Dr. N.S. Bisht		
09.00-09.45	Likely impacts of Climate Change on forests of Western Himalayan Region and adaptation strategies – **Dr. Mohit Gera** – India	
09.45-10.30	Climate change and forests in India: Impacts, vulnerability and adaptation options – **Dr. Renu Singh** – India	
10.30-10.45	Tea	
Session 4: Impact of Climate Change on forest and other ecosystems - Chair: Dr. Renu Singh		
10.45-11.30	Impact of climate Change on forest ecosystems: A review – **Dr. Purna Bdr. Chhetri** - Bhutan	
11.30-12.15	Climate change and possible impacts of invasive species in the Knuckles World Heritage Forest in Sri Lanka – **Mr. Wasantha Dissanayake** – Sri Lanka	
Session 5: Impacts with special focus on dependent human communities – Chair: Mr. W. Dissanayake		
12.15-13.00	Impacts of anthropogenic and climatic factors on forest degradation and goods and services in Northeast India – **Dr. N.S. Bisht** – India	
13.00-14.00	Lunch	
Session 6: The Way forward– Chair: Dr. Sangay Wangchuk		
14.00-15.00	Deliberation on listing out country specific adaptation and mitigation measures	
15.00-15.30	Discussion and Recommendations	
15.30-16.00	Closing Session and Tea	
Day 4, 25th October 2013 (Friday) OPTIONAL PROGRAMME		
Start at 0600 hrs before breakfast – Field Trip to **Hoollongapar Gibbon Sanctuary** Resource Person: **Mr. N.C. Malakar,** DFO, Jorhat Half hour drive by road to the Sanctuary Objective is to visit and learn about the sanctuary famous for the only ape found in the forests of South Asia – The Hoolock Gibbon Expected back at RFRI, Jorhat at 1000 hrs		

ANNEXURE II

Details of participants

Sl. No.	Name of the Participant& designation	Country	e-mail	Phone No.
1.	Sri A K Wahal, IFS, PCCF & HOFF, Arunachal Pradesh	India	akw_1954@yahoo.com	+913602212310
2.	Dr. Sangay Wangchuk, Director, SAARC Forestry Centre	Bhutan	sangaywangchuk33@yahoo.com	+97517637867
3.	Dr N S Bisht, IFS, Director, International Co-operation, ICFRE & Director, Rain Forest Research Institute, Jorhat, Assam	India	nsbisht@icfre.org	+919412054229
4.	Dr. Renu Singh IFS, ADG, ICFRE	India	renusingh@icfre.org	+91 135 2758348
5.	Dr. Rajiv Garg IFS, Advisor (E&M), Coal India Limited	India	advisor.cil@gmail.com	+91-9717466448
6.	Dr. Mohit Gera IFS, Additional Prof. & Member Secretary- REDD-plus cell, Dehradun	India	mohitgera87@gmail	+91 135-2751835
7.	Mr. MGWMWTB Dissanayake, Deputy Conservator of Forests	Sri Lanka	rdcfne@yahoo.com	+94718014998 +94522235932
8.	Mr. M. Heenatigala, Assistant Conservator of Forests	Sri Lanka	mohanhee@gmail.com	+94711863348 94112866634
9.	Mr. Hussain Faisal, Assistant Director, Agribusiness Development services	Maldives	hussain.faisal@fishagri.gov.mv	+960 3339219
10	Ms. Aishath Najaath	Maldives	aishath.najaath@fishagri.gov.mv	+960 3339261
11	Mr. Ramesh Bahadur Basnet, Department of Plant Resources, Ministry of Forests and Soil Conservation	Nepal	basnetbt@yahoo.com	+9747002176
12	Ms. Momena Khatun, Deputy Secretary, MoEF, Bangladesh	Bangladesh	momena5628@yahoo.com	+88 1712113380
13	Mr. Mozammel Hauque Shah,	Bangladesh	mozammelhsc@yahoo.com	+8801716075616

	DFO, Pulpwood Plantation Divn. Bangladesh			
14	Dr. Purna Bahadur Chhetri, Deputy CRO, PNR-RDC	Bhutan	purnab_zooo@yahoo.com	+975 17659516
15	Mr. Udhayan A., IFS, Specialist (MED) SFC	Bhutan	udaywild@gmail.com	+975 2 365148
16	Mr. Pasang W. Norbu , Specialist (SFM), SFC	Bhutan	pwnorbu@gmail.com	+975 2 365148
17	Dr R K Borah, Scientist- E	RFRI	borahrk@icfre.org	+919435051669
18	Sri R K Kalita, Scientist- D	RFRI	kalitark@icfre.org	+919435351736
19	Sri Vipin Prakash, Scientist-D	RFRI	bhardwajvpnpark@rediffmail	+919435570331
20	Sri Ranjeet Kumar, Scientist- D	RFRI	ranjeetshimla@gmail.com	+918473071528
21	Dr T. N. Manohara, Scientist-C	RFRI	manohara_tn@yahoo.com	+919435351304
22	Dr Tarachand, Scientist-C	RFRI	tarachand@icfre.org	+919435738591
23	Sri A K Deka, DCF	RFRI	dekaak@rediffmail.com	+919435084098
24	Sri G Banerjee, DCF	RFRI	banerjeeg@icfre.org	+919435700050
25	Sri B Pradhan, DCF	RFRI	dfopradhan@gmail.com	+919402275539

The campus of the Rain Forest Research Institute campus, Jorhat, Assam, India

The Expert Group Meeting in progress at the Conference Hall, RFRI, Jorhat

The participants on the boat in River Brahmaputra in Kaziranga National Park

The participants in Kaziranga National park after visiting an Anti-poaching camp

A huge tusker elephant in Kaziranga National Park

A single Indian one-horned Rhinoceros grazing in the Kaziranga grasslands