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From the Director

I and my colleagues at the SAARC Forestry Centre (SFC) have the pleasure in bringing out our inaugural volume of the SAARC Forestry Journal coinciding with the commemoration of SAARC Charter Day, 8 December 2011. We would like to thank all the authors and co-authors for their valuable contribution of articles in this issue. While we congratulate all those authors whose articles have been selected and published, we sincerely apologise the rest whose articles have not featured in this issue due to various reasons, such as time constraints.

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An appraisal of tropical forest management approaches: Lessons for implementing REDD+ projects in South Asia

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Abstract

The alarming decline of forest areas in South Asian countries represents a major land use change contributing towards significant greenhouse gas emissions. Recently, the Reducing Emissions from Deforestation and Forest Degradation plus Enhanced Carbon Stocks (REDD+) approach has been advocated as a cost effective measure for reducing deforestation in these countries to mitigate climate change. The success of this approach would depend on proper integration of experiences from the past initiatives of conservation and sustainable management of tropical forests. Therefore, in this paper we review the major management approaches adopted to conserve tropical forest ecosystem with the objective to identify some major challenges of implementing REDD based projects in these countries. The information will be beneficial in streamlining successful implementation of REDD+ projects and thereby ensuring sustainable management and conservation of forests in South Asian countries.

Key words: *Deforestation and Forest Degradation; Habitat Conservation; Sustainable Forest Management; REDD+; Tropical forests*

Introduction

Forests provide a variety of socioeconomic and ecological services. Nevertheless the forest area is diminishing rapidly, at a rate 13000m ha yr^{-1} (FAO, 2010) globally due to various reasons. The problem is much more acute in the tropical region; as approximately 79% of total global deforestation is confined within tropical forests. The forests in South Asian countries are no exceptions as half of the countries are experiencing forest area decline (Figure 1).

The proportionate change in forest cover in this region was -0.59% during 2000-2005 period, whereas, globally the rate was -0.14% (FAO, 2010).

This huge land use change contributes to the climate change factors by emitting 17% (about 13% in from tropical forests) of the total greenhouse gas (Solomon, 2007; Solomon, Plattner, Knutti, & Friedlingstein, 2009). Hence, the concept of Reducing Emissions from Deforestation and Forest Degradation plus Enhanced Carbon Stocks (REDD+) has evolved as a cost effective option for reducing global greenhouse gas emissions through improved forest protection and afforestation (Petkova, Larson, & Pacheco, 2010).

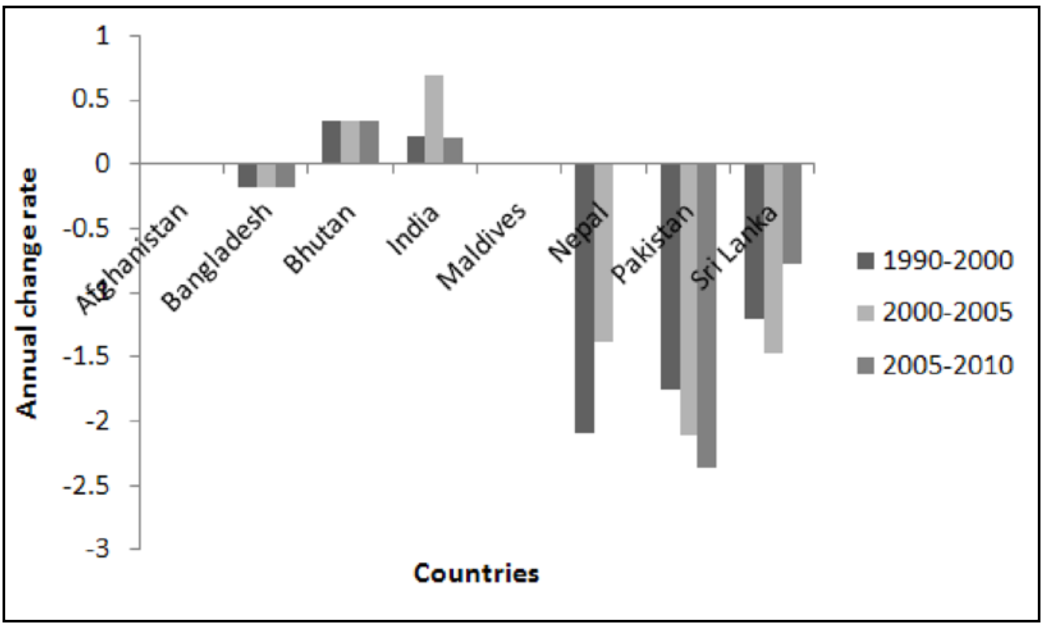

Figure 1: Trends in extent of forest in SAARC countries (1990-2010) (FAO, 2010)

REDD+ could be defined as a combination of policy mechanisms to reduce deforestation and forest degradation, and enhance forest carbon stocks (Palmer, 2010).

Under REDD+ interested parties (which could include donor agencies, corporations, NGOs, and individuals) from developed countries will finance projects in developing countries to reduce forest carbon emissions. Payments are contingent upon the demonstrated reduction of emissions (Phelps, Webb, & Agrawal, 2010).

It is expected that REDD+ will be able to deliver some additional benefits such as supporting biodiversity conservation and delivery of other environmental services; and will contribute to poverty reduction and improved rural livelihoods. As a result, a plethora of REDD+ related activities have been undertaken recently (Kanowski, McDermott, & Cashore, 2010).

REDD+ is expected to have significant changes in forest management approaches (Phelps, et al., 2010).

On the other hand, national level institutional arrangement is going to be crucial in REDD+ mechanism since incentives need to be negotiated with relevant stakeholders. South Asian countries have long a history of implementing multilateral institutional arrangements to curb deforestation. These countries are signatories to many international agreements related to forest conservation, such as: Convention on Biological Diversity, Indigenous Peoples Convention of the International Labor Organization, Framework Convention on Climate Change, Convention to Combat Desertification, Convention on International Trade in Endangered Species of Wild Flora and Fauna, Ramsar Convention on Wetlands of International Importance especially as Waterfowl habitat, World Heritage Convention (Hickey, 2004).

These arrangements have yielded a varied level of success and new challenges. Drawing from previous experiences REDD+ offers new avenue for the countries to engage in multilateral and bilateral forest conservation activities.

In this context, a review and synthesis of the institutional arrangements of tropical forest management will be relevant for both forest managers in South Asian countries and REDD fund providers. The fund providers can perceive what variations to expect and forest managers can look for alternative arrangements relevant for REDD focused forest management. After this short introduction different approaches of forest conservation practiced in tropical countries have been reviewed. Then some major challenges of these management measures for successful implementation of REDD projects have been elaborated. Finally, some forest management tools have been identified which could be useful in implementing REDD projects in these countries.

Institutional approaches of tropical forest management

Institutional approach is almost linked with the ownership of the forest area. In most of the cases the owner is the manger of the forest as well. The owner's purpose of managing the forest determines administrative and organizational arrangements. Forests were traditionally being managed as common resources until public authorities emerged and appropriated forest lands for benefits to people beyond adjacent community. As a result in tropical countries two main streams of institutional approaches could be identified: single agency approach and multiple agency approach.

Forest management through single agency approach

Globally three major ownership patterns could be identified: state ownership, private ownership and community ownership. According to the recent global forest resource assessment (FAO, 2010) on an average 71% of the forests are public owned, 27% are private owned and the rest are under other types of ownership. This ratio is not different for forest rich countries. White and Martin (2002) estimated that for the 30 most forest rich countries approximately 77% of their forests are public owned, 12% is under private ownership and the rest under community management. They also observed that proportion of public forests is higher in developed countries (80%) compared to developing countries (71%). The difference in ownership has significant influence on management pattern and potential for REDD+ based projects.

Forest management through public authorities

As mentioned above, government forest tenure is the dominant or exclusive category of forest ownership in many tropical countries. The reasons for which are the state's desires to appropriate the resources as well as to protect the wealth of the nation. Other reasons include the failure of markets to achieve social goals or to provide public goods such as watershed protection and biodiversity conservation. State ownership of forests dates back to the time of Pharaohs in Egypt and the Royal forests of countries like England and France in the medieval and early modern periods. In South Asia, Forest Department was first constituted during the Mauryan period (321-226 BC) (Iftekhar, 2006).

However, the tradition of government ownership and government-led forest management was most widely expanded by European colonizers to many colonies in the sixteenth and seventeenth centuries.

Most of the public forests are managed through a set mechanism – enactment of forest policies and laws, establishment of forest management authority, classification of forests in terms of utility, development of management plan, implementation of them and monitoring of the impact. Formulation of forest laws and their strict enforcement is a major part of traditional forest conservation. However, as evident from the annual deforestation rates in most of the countries state-led exclusionist approaches failed to ensure the sustainable management and conservation of forests. There are many reasons behind this:

Revenue from forests is often used to finance the development of other sectors rather than to reinvest it in sustaining production.

- Public sector management in many countries focuses on forests that have commercial potential or that can fulfill critical environmental functions. Governments manage these high-value forests, either directly or through concessionaires, primarily for timber production.

- Harvesting old growth or mature forests can generate high returns provided the institutional capacity is adequate to prevent leakages. However, many developing countries do not possess the institutional capacity. For example, in Bangladesh on an average one forest staff is responsible for managing 500 ha of forestland, which is far more than the optimal capacity (Iftekhar & Islam, 2004)

- The priority assigned to wood production has led to most other forest products being termed "minor forest products" because of the small contribution they make to government revenue.

- In addition, national parks and game reserves in most countries are managed for social, biological and environmental benefits instead of their economic benefits.

- As a result of declining returns from wood production caused by falling prices and the exclusion of large tracts of forests, many government organizations are struggling to make enough revenue to make up for the administrative costs.

As a consequence many governments have moved away from revenue generating traditional forestry practices towards realization of diversified ecosystem benefits. Many of them emphasize on capturing the values of ecosystem services, greater accountability, information sharing, coordination and integration, participatory decision-making and better delivery of goods and services. Delegation of more functions to local government and partnership with other stakeholders like communities, NGOs and private sectors are two important strategies of the government. Hence state owned forests could be readily available for implementation of $REDD^{+}$ projects.

Forest conservation through common property resource management

Common property regimes to manage forests and other resources, were once widespread around the globe. Some have disappeared naturally as communities opted for other arrangements, with technological and economic change, but in most instances common property regimes seem to have been legislated out of existence (McKean & Ostrom, 1995). In Africa and other developing countries, the introduction of colonialism was a major turning point in common property ownership. Upon arrival, the colonialist considered any land under common property or group ownership to be unoccupied or ownerless, and in effect appropriated it (Mather, Needle, & Fairbairn, 1998). Forests were declared public lands in order to generate revenue for the colonial power. Bearing this legacy, postcolonial governments often have continued to refer to people living on public forest lands as "squatters", or accuse them of "illegal use", even when land rights are in dispute because of a community's claims to prior, ancestral rights . This situation has led to considerable frustration among the local population, who have practiced a wide range of forest uses and developed sustainable management patterns before colonialism. This has caused a change in the management as well. Under traditional common property ownership the use of forest products was self regulated by an informal form of policy consisting of rules or guidelines handed down from generation to generation. Where common property regimes – however elaborate and long lasting - had never been codified, they may simply have been left out of a country's first attempt to formalize and codify property rights to the resources in question (for example, in Indonesia, Brazil and most countries of sub – Saharan Africa).

Many forest laws acknowledge usage rights as a matter of principle but they often lack adequate provisions to protect forest usage rights and to allow their practice in a sustainable manner and in determined areas. Even in some countries where common property regimes were legally recognized the forests were turned into either public property or into private property (as in case of United Kingdom) or a combination of the two (as in India and Japan). The arguments for this were to ensure enhanced efficiency in resource management and long-term sustainability. However, subsequently it has been observed that this shift in ownership has actually contributed to erosion and decline of local forests management institutions and social capital. Apparently the 'protectors' turned into 'exploiters' and exacerbated resource depletion (McKean & Ostrom, 1995). Everyone started to use the forests without reciprocal obligations to maintain them. Thus the state interventions have been ineffective in substituting formal systems for the previous informal social sanctions and customary arrangements for protecting, upgrading and regulating the use of common property (Kumar, 2005). Recognizing this limitation, many countries have responded with an enlivened common property resource management in different forms like social forestry, community forestry and joint forest management.

Forest management by private sector

In some regions, private forest ownership stemmed directly from common property ownership; but elsewhere it arose from state ownership, most notably in Central and Eastern Europe and parts of Asia. From a large single owner (the state) literally hundreds of thousands of small owners with different objectives are emerging (Anderson, Clément, & Crowder, 1998). For example, in the ten European Union accession countries in Central and Eastern Europe more than 20 percent of the forests were privately owned during 1990 – 2000 period (Rykowski, 2002).

Governments often use privatization as a measure to improve economic performance, especially since the 1970s. Forests, however, were not among the first assets to be privatized, partly because of the sovereignty issue, environmental roles, provision of ecosystem services to the society, and perceived high risks in forestry businesses. But since the 1990s privatization of forests has gained pace, although, this trend is less marked for natural forests than for planted forests; except in Central and Eastern Europe where forestland is being returned to its former owners. In addition, private entities and NGOs are increasingly purchasing forest areas and acquiring land through concession contracts for protection and conservation purposes. With privatization spree, corporations are becoming major players in forestry, including in the management of forests, logging and wood processing, and are a driving force behind the globalization of the sector, capable of moving investment, technology and raw material trans-nationally. Although the share of private forest varies considerably according to the country, it is growingly evident that private forests and private forest owners are important stakeholders in forest conservation in many parts of the world (Rykowski, 2002).

Forest management through multiple agency approach

With regard to forest conservation, various governments have tried to deal with the weaknesses in policy implementation to protect and sustainably manage the forest by broadening the responsibilities of the private sector and by focusing on a few key areas of the interface between the public and private sectors. Castrén (2005) has identified two broad driving factors behind this change: at macro level privatization processes and the decline of the role of the state in the economy and at sectoral level – introduction of sustainable livelihoods approach in forestry and rural development. Some countries (e.g. Colombia, Honduras, Peru) have launched initiatives to privatize control and management of forest resources traditionally in the hands of the public sector. Many governments have also made attempts to improve the interaction between the private and public sectors, mainly by eliminating some "perverse" subsidies (Malaysia, Brazil, etc.), by tackling illegal and corrupt activities and by rationalizing forest concession policies. Many countries have developed forest legislation to give the local communities a more significant role in decision making and activities. Some of these collaborative management approaches are described below.

Forest management through community participation in government programs

Recognizing the limitations of government led forest conservation effort and the need for the sustainable development of the forest dependent community much emphasis has been placed on the devolvement of forest management responsibilities to communities. Community forestry has formed one of the main thrusts of donor funding for forestry in the past few decades. It has been promoted as a way of improving the livelihoods of rural communities by generating income and employment, and by securing a long-term supply of forest goods and services (Castrén, 2005). In many countries this type of forestry has been reported to be successful. For example, in Nepal community forestry programs were started in 1978. The main objectives were to supply basic forest products for subsistence and to control ecological degradation. Since then community forestry has received favorable policy and legislative support (Gautam, Shivakoti, & Webb, 2004). Under this approach around 1.6 million ha of forest (25% of the national forest) has been brought under the control of 14,000 Community Forest User Groups (FUGs) (Ojha & Bhattarai, 2003; Staddon, 2009). In India, a Joint Forest Management Program (JFM) sets out to manage 'partnerships' between local forest-dependent communities and the state for the sustainable management and joint benefit sharing of public forestland. To accomplish this, JFM seeks to shift the existing inequitable distribution of management control by directly involving local people and institutions in forest management. JFM does not involve the transfer of ownership over forests, but attempts instead to restructure the formal system of access, decision-making, and sharing of benefits to account for the needs of local communities (Kaushal & Kala, 2004). Community based conservation is another set of conservation projects where local people are involved as an integral part and they participate in the resource planning and management and they gain economically from conservation (S. Kumar & Kant, 2005).

Forest management through local government and community partnership

Along with the privatization and community involvement in forest management another trend can be observed on the devolution and delegation of responsibilities to the local government and indigenous communities. Decentralization is most pronounced in countries with a traditional federal structure such as Belgium, Germany, and Switzerland or where regionalization has been introduced or reintroduced as in Italy and Spain. The assumption is that in decentralized decision making, lower level decision makers are likely to have better access to information, lower organization costs and a greater willingness to compete (Agrawal & Gupta, 2005). In many other countries, an increasing number of local political and administrative powers are emerging that are less dependent on central control. The results of the process have been mixed. In Bolivia, through recent legislative reforms, municipalities now play a much greater role in forest management (Anderson, et al., 1998). In Mexico, during the 20th century, state forests have been largely (> 80%) transferred to the community. Community Forest Enterprise (CFE), combining community government tradition and enterprise forms, are being formed (Antinori & Bray, 2005). In India, on the other hand, decentralization seems to have led to competition between sectors of government leading to confusion (sometimes conflicts) about who has the authority to grant ‘community forestry’ (Anderson, et al., 1998). Moreover, many private forest holdings are too small to remain as viable forest management unit. They may have short planning horizon and appropriate the resources as quick as possible (Castrén, 2005).

Forest conservation through government, community and donor partnership

At the beginning of the 1990s Integrated Conservation and

Development Projects (ICDPs) and Community Based Natural Resource Management (CBNRM) Projects were espoused as a mechanism to simultaneous development of forest and rural communities. Identifying rural communities as the main agent of degradation, measures were taken to provide alternative livelihoods to them and make conservation of the forest and protected areas more attractive through different social and financial means (S. Kumar & Kant, 2005). Large transboundary and regional projects were taken following this approach. These kinds of efforts are sometimes referred to as 'conservation by distraction' (Ferraro & Kiss, 2002). However, later it was observed that the projects are failing to achieve their goal. Better institutional linkages between biodiversity conservation and development, improved institutional policies and greater capacities of communities to participate in such programs were felt needed (Blom, Sunderland, & Murdiyarso, 2010).

Forest management through community, private sector and market partnership

There is a growing interest on the concept of markets to conserve the forest ecosystem. Commercialization of non-timber forest products (including medicinal plants) is promoted. Commercialization and greater market access for these products help the households to spread risk and modulate timing of income though the income from these products contributes to a smaller portion of the household income (Belcher, Ruíz-Pérez, & Achdiawan, 2005).

Ecotourism is another major mechanism of capturing benefits from the market to conserve the forest. The assumption is that ecotourism depends on maintaining attractive natural landscapes and a rich biodiversity, which therefore helps communities to earn money from ecotourism and provide both an incentive for conservation and an economic alternative to destructive activities. However, the benefits of such activities are limited by the factors like small areas, involvement of few people, limited earning, weak linkages between forest conservation and commercialized success and pressures of the competitive market (Kiss, 2004).

The concept of ecosystem services is not new. Costanza (1991) separated ecosystem goods and services, but incorporated both direct and indirect use value. Cork (2001) defined it as 'transformations of natural assets' into products that are beneficial to human beings. Millennium Ecosystem Assessment (MEA) has brought the term ecosystem services into limelight. MEA defined ecosystem services as 'the benefits that people obtain from ecosystems' (MEA, 2005). Boyd and Banzhaf (2007) tried to restrict ecosystem services to only 'natural' and 'direct use'; however, the scope of this definition is too narrow to be of practical use. So, for simplicity and inclusiveness, the MEA definition of ecosystem services remains widely adopted.

After Millennium Ecosystem Assessment (MEA, 2005) had been established and spread the concept of ecosystem services payment gained momentum for its outstanding potential for conservation of forests. In practice, payment for ecosystem services has been naïve as it primarily focuses on promoting regulatory ecosystem services for which formal markets are not readily available in most of the cases. Four major forest based services identified to be paid for are carbon sequestration, watershed protection, biodiversity benefits and landscape beauty (Grieg-Gran, Porras, & Wunder, 2005). The only ecosystem service in marketing system was ecotourism which is categorized under cultural services in MEA.

There are three main payment mechanisms in place for various ecosystem services. These are (i) public payment (ii) formal market and (iii) private deals. Public payment is basically a national system where the government or public organizations on its behalf pays out private landowners for maintaining or enhancing ecosystem services of national or regional need, beyond the owners' marketing scope. Formal market mechanism, i.e. open trading between buyer and seller, has developed in two parallel domains – voluntary market and regulatory or capped market. In voluntary marketing, the buyer and seller enter into the market on voluntary basis. The best example is Chicago Climate Exchange for carbon credits. In here companies enter into the market as buyers to reduce their carbon foot print. The sellers are drawn in as demand for this commodity increases. On the other hand, the regulatory market is initiated by legal requirement or cap on some activity for example, carbon emission (Redford & Adams, 2009).

Challenges of implementing REDD projects in South Asia

Despite the outpouring of efforts, forests are depleting at an alarming rate. Different alternative approaches like direct payment to the communities for forest services (Ferraro, 2002; Ferraro & Gjertsen, 2009), shifting focus of protected areas from rare and endangered species to ecosystem services (Odling-Smee, 2005), forest conservation through ecosystem management, community based park management, environment management (or green) accounting , etc. are tried (Berkes & Adhikari, 2006). Based on their experiences the following challenges would be crucial in successful implementation of REDD based projects in South Asia.

Proper understanding of the forestry paradigm

The forestry sector is characterized by several peculiar characteristics - diverse natural and human-incurred ecosystems; links with other terrestrial and marine ecosystems; unknown and un-priced market services; high risks and uncertainty; the long time-frame of planning and management; irreversibility of certain actions and tenurial uncertainty. Conventionally the most widely adopted model of forest conservation is the project or program approach, which is also being considered under REDD+ projects (Sheil, Nasi, & Johnson, 2004). But this conservation and development model has some serious limitations (Van Dam, 2000).

It has a shorter time frame than required for any significant cycle of forest management. Due to its short-lived nature it isolates the project activities from the larger context, thus restricting the usefulness of project activities, and may even prevent governments and communities from dealing with larger, more important issues. "Project" thinking also excludes the project staff from being accountable for their actions and initiatives. The result has been isolated from learning, and many mistakes are repeated again and again. Even when long-term and permanent initiatives (like government structure) are adopted, most of them are led by single agency. But as forests are open ecosystems and their vitality depends on the health and proper functioning of other ecosystems, single agency led conservation efforts are not always successful (Cronkleton, Bray, & Medina, 2011; Stone & Stone, 2011).

Ensuring community participation

Recognizing the failure of state-led exclusionist development programs a new brand of development approach called 'community involvement in forestry', 'forestry for local people', 'participatory forestry' and 'social forestry' have been articulated and promoted by the aid agencies. Donors (both bilateral and multilateral) are promoting community forestry and other means of collaborative forest management (Castrén, 2005). As a result there is unmistakably a higher profile given to local forest management in recent legislation, though many of the reforms are characterized by significant limitations –

- Forest authorities in some countries, have embraced the concept of community-based approach mainly in depleted forest areas; there is frequently a reluctance to share control over richer, more intact areas.
- In many co-management schemes, people are not involved in the important decision making process, like the power to draft and approve management plans.
- Sometimes the long-term security

of the granted or recognized rights under local arrangements is not ensured, either because the term of the agreement is very short or because the government has vast power to terminate the agreement for any reason.

- In some instances, legal provisions that appear to protect the traditional rights of indigenous peoples may be so weakly drafted as to be unusable.

Even when the legal and administrative problems are solved, this approach is not free from few basic flaws. 'Community' is a vague and loose term. There are many sharp and contrasting cleavages in the community. The poorest section of the community is also the most vulnerable. They are usually busy with their livelihood activities from dawn to dusk and may not have enough time and resources to meet the 'transaction cost' required for joining forestry program activities. Most importantly, communities do not exist in isolation. They are not always 'natural' social unit and are often not cohesive, harmonious social entities. On the other hand, the notion of 'participation' assumes that "we (the government /project/NGO) do, and they (the community/the people) participate". This has proven ineffective in many countries and this conceptual flaw is compounded by an aid delivery form -the project- that is problematic in itself. Not only does it create little space for participation, but also, and more seriously, it isolates the project activities from the larger context (Adhikari & Goldey, 2010; Pokharel, 2009).

Governance of forestry sector

Absence of good governance is another major hindrance of successful forest conservation. According to the World Bank, illegal logging results in a loss of US$5 billion annually and a further loss of US$10 billion to the economies of timber-producing countries. In many cases, the proportion of illegally produced timber far exceeds legal production. The activity depresses prices, undermines profitability of legitimate enterprises and helps to finance wars and civil strife. It also causes environmental damage and threatens forests, which many people depend on. The indirect effects of illegal logging are - lost job opportunities, less government revenue, threats to physical security, loss of access to forest resources and forest degradation (Kaimowitz, 2003). One of the stimulating factors behind this is the widespread corruption (Laurance, 2004). It has been observed that in some cases adoption of participatory forestry programs has been opposed by the forestry professionals, who apprehend the decreased opportunities for collusion with powerful wood traders (Barbier, Damania, & Leonard, 2005; Smith & Walpole, 2005).

Donor supported conservation projects suffer from other kinds of governance and resource allocation problems. Priorities are set outside the national or local boundary and most often they do not match with the national government or communities priorities (Young, 2005). Expatriate experts of many kinds act as advisers, coordinators and assessors and have considerable influence in determining how project funds are used and what activities are endorsed. Most donor-led projects require a commitment of staff and resources by the local agencies as well. Interventions thus frequently divert scarce staff from activities that may have a higher immediate priority. Problems are most apparent when projects are viewed in situ. Project success is rarely defined in a manner that reflects conservation requirements.

Potential of REDD+ relevant forest management tools

The Cancun accord has recognized five key issues emphasizing linkage of forests and carbon focusing on climate change mitigation (Dooley, 2010). They are (i) Deforestation (ii) Forest Degradation (iii) Conservation of forest carbon (iv) Sustainable Forest Management and (v) Enhancement of Forest Carbon. Of these, reducing deforestation and forest degradation will avoid carbon emission and thus reduce the role of forest sector as a contributor to climate change. On the other hand, enhancement of carbon stock will focus on sequestering carbon to help offset emission from other sectors. Forest carbon conservation and sustainable forest management will ensure forests' role as carbon locker and avoid further contribution from forest sector to climate change. However, mechanism for achieving these objectives has not yet been detailed out. But the concepts are not new to forest management. The implication is that the concepts will need to be adjusted with considerations for carbon conservation, emission and sequestration. In this context the existing management tools, processes and mechanisms need to be revisited to understand which would still be relevant and how they can contribute towards developing a sustainable forest management scheme accommodating REDD+ mechanisms in South Asia.

National forest regulatory framework

To reap full benefits from REDD+ several functions of the recipient governments will be critical such as development of strategies for national land-use and forest-sector planning, stakeholder negotiations, tenure clarification, carbon brokering, national level carbon accounting, and provision of funds and services to local actors (Phelps, et al., 2010). Therefore, an appropriate regulatory framework is integral. Legal regime is important at national and regional administrative level tool to define forest boundaries. These legal boundaries are very much the baseline for monitoring deforestation. However, forest boundary delineation is rather ineffective in measuring and monitoring forest degradation. But some legal regimes classify forest areas into forest types and thereby provide criteria and / or indicator for looking into degradation aspect. Legal regime also sets out forest ownership, rights on forest products and services as well as designates authority to manage the forests.

Sustainable yield principle

Sustainable yield approach is widely used after concept of sustainability that has been incorporated in traditional forestry practices. The focus remains on extraction of resources, but includes active elements for maintaining the productivity over a longer time horizon. Sustainable yield of renewable resources depends on growth surplus, defined by births, deaths, and growth of existing stock. Carbon stock surplus will also differ spatially and temporally with varying inherent growth capacity and encompassing environmental condition as described for reproductive surplus concept of renewable resources by Hilborn et al. (1995).

While reducing deforestation and forest degradation only refers to static carbon stock concept, sustained yield approach refers to a dynamic carbon stock concept. The carbon stock changes naturally within a forest with tree growth, natural recruitment minus deaths or removal. Thus surplus carbon can be removed as timber or other wood products. Sometimes this removal may even be necessary to maintain forest health and retain the carbon stock sustainably. If the stock is depleting then restoration or other efforts may be put in place to replenish the carbon stock.

However, the experience of sustainable yield approach has not been very successful, due to misuse of the concept. The unregulated regime pushes the resources to overexploitation. On the other hand, with regulations in place, the ill motive exploiters have been successful in modifying the removals in a manner to leave the regulations less effective. Often the successful institutions at maintaining sustainability through this approach have been small-scale community or private ownership (Hilborn, et al., 1995). So, if this concept is to be used in dynamic carbon stock management, innovative adjustments will be required to make this effective at larger scale.

Protected Area system

A protected area (PA) system is one of the hard-core forest conservation mechanisms of the state. The idea of nature conservation through protected area arose in the 19th century in the USA. Its goal consists of conserving and maintaining fragments of primeval nature in the natural condition. This was followed by the creation of Yellowstone National Park in 1872, the first such park in the United States. Protected areas were interpreted as zones in which particular elements were of such importance that the entire zone needed to be shielded from all human activities. In most countries up to 1990s most protected areas were based on the American model of limited, if not zero, human presence. At present almost 133,000 PAs are designated covering 25.8 million km^2; roughly about 12% of the terrestrial surface (Chape, Harrison, Spalding, & Lysenko, 2005).

However in many developing countries conflicts have erupted between local people and protected area managers (Maikhuri, Nautiyal, Rao, & Saxena, 2001). Many of these reserves are not well safeguarded and are subject to illegal resource exploitation and extensive encroachment by small-scale cultivators. In Africa, protected areas are gradually becoming ecologically isolated as people populate the buffer zone. Recently in some countries, participatory approaches in the protection of the national parks have brought some success, but despite that further improvement is needed.

Community involvement and partnership

The main challenge for successful implementation of REDD+ projects would be to align interests of different parties. Conservation will only be successful if its benefits can be successfully transferred to the local level and if local people are able to see the link between the existence of biodiversity and benefits they receive. The available evidence based review reveals some benefits of community based forest management in terms of forest stand quality. This could potentially indicate a global benefit through an increase in carbon sequestration. Moreover, involvement of the local people reduces conflicts in forest management objectives and implementation. Based on a review of ICDP projects Blom et al. (2010) have prepared a set of recommendation for successful community involvement in REDD projects, such as, recognizing and acknowledging tradeoffs between conservation and development, understanding of community heterogeneity and complexity, understanding of community livelihood needs, design adaptive and flexible projects and involving the community in all phases of the project.

Integration with existing market mechanisms for ecosystem services

There are some on-going initiatives of using market based instruments for ecosystem services. The certification scheme of the Forest Stewardship Council (FSC) is one of the most prominent examples of them. FSC has a set of ten Principles and related

Criteria (P&C) of Forest Stewardship, which apply to all types of forests, both natural and planted. Along with FSC some other international bodies like Pan-European Forest Certification Framework (PEFC), International Organization of Standardization (ISO) provide certificates based either on certificates or on processes (Gullison, 2003).

Forest certification is a market-based initiative aimed at improving the quality of forest management and promoting higher prices or better market access for wood products derived from sustainably managed forests. It has been estimated that certified forest area has increased to 271 million hectare in 2006 (Durst, McKenzie, Brown, & Appanah, 2006). An earlier estimation showed that around 1% of the world forest products come from the certified forests and the trend is increasing (Atyi & Simula, 2002). Though it was primarily designed for improving tropical forest management, majority of the certified forests (91.8%) are located in Europe and North America (Durst, et al., 2006). The increase in certified forests in tropical countries is not significant. In terms of percentage it has rather decreased from about 10% in 2003 (Rametsteiner & Simula, 2003) to 5% of the total forest area certified (Durst, et al., 2006).

Ebeling and Yasué (2009) assessed that forest certification can only be successful in very few tropical countries. There is huge uncertainty in extending the scheme in developing regions where forests are used to meet subsistence needs; where very few resources are available for forest management and where the forests are most threatened by overexploitation, degradation or conversion to other uses. Small-scale and community based enterprises have difficulties in getting certified (Nebel, Quevedo, Bredahl Jacobsen, & Helles, 2005) and the certification is generally not cost-effective. Even for larger estates, the price premium is not significant. The only incentive is market access and if the certification becomes mandatory it will become a fixed cost to running forestry business. Economic stress on some forest estate can even induce a change from forestry business; which would be a net loss to forestry in general and REDD objectives in particular.

Gullison (2003) stressed that more investment to reduce certification cost and increase benefits of certification would be necessary if forest certification have to make any significant role in sustainable management of tropical countries. Most of the forest lands in tropical countries are owned by the country. Unless the forest estate is oriented in export of wood production, there is no market incentive for the countries to get their forest certified. The only existing incentive is to showcase the proenvironmental attitude. Hence many started to consider forest certification a policy tool with potential to play a role in global environmental governance (Marx & Cuypers, 2010).

IPCC guideline currently excludes harvested wood products from carbon pool as these carbons are destined for emission through wood decomposition. However, wood products from sustainably managed forest, through their service life, can also be potentially included in carbon reservoir at national scale. There are prospective dialogues going on to incorporate the harvested wood product in carbon pool. Chain of Custody (CoC) of wood products which is associated with forest certification can be an important component for effective monitoring of the carbon in harvested wood products.

Concluding remarks

In this paper we have reviewed different institutional approaches for forest management in tropical countries in relation to successful implementation of REDD projects in South Asian countries. Government ownership and single agency management approach is the predominant form of forest management globally. Implementation of REDD projects in the forests managed under this approach could be feasible and less complex since contracts could be signed with the government agencies and they could take the responsibilities of delivering project outcomes. However, in most of the South Asian countries the capacity of government agencies to sustainably manage their forests is seriously compromised. To reduce forest depletion different management strategies have evolved in these countries. Main thrusts identified are the social or community forestry, multi-stakeholder management and international collaboration to forest conservation. Traditional ownership and common property resources management are emerging as an alternative management options at some places. The impact and consequences of these management measures are yet to be determined. Therefore, it is important that REDD implementers and negotiators are aware of these paradigm shift in forest management.

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Soil responses to reforestation in Southeastern part of Bangladesh

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Abstract

To examine the effect of reforestation on the soil properties, an empirical study was conducted in the reforested area with the three tree species in the Southeastern part of Bangladesh. *Acacia auriculiformis* for 4, 11 and 12 year-old-stand, *Syzygium grande* for 43, 48 and 49 year-old-stand and *Tectona grandis* for 52, 53, and 56 year-old-stands were considered for the study. The study examined changes in soil physical properties, i.e., bulk density, moisture content, and maximum water holding capacity at 0-10 cm depth, and soil chemical properties, i.e., organic carbon, nitrogen, phosphorus, potassium and soil acidity at both 0-10 cm and 10-20 cm soil depth due to the reforestation. A decrease of the bulk density with the increasing ages of the stands was observed for *A. auriculiformis* and *S. grande.* For *T. grandis*, the same stand age-bulk density relationship was found for the 52 and 53 year-old-stands. With the increasing ages of the stands of *A. auriculiformis* and *S. grande*, an increasing moisture content and maximum water holding capacity was found. This positive relationship was found only for the 52 and 53 year-old-stands of *T. grandis*. For *A. auriculiformis* at both the soil layers, organic carbon increased with the increase of the ages of the stands. The same relationship was found at the stands of 43, 48 years *S. grande* and 53, 56 years *T. grandis* at the soil layer 10-20 cm. The Phosphorus-stand age relationship was positive for all the stands of *S. grande* and 4, 11 year-old-stands of *A. auriculiformis* at both soil layers. The Potassium-stand age relationship was found positive for all the stands of *S. grande* at both the soil layers and for *T. grandis* at 10-20 cm soil layer. The findings of the study can be useful for the forest rehabilitation practitioners in Bangladesh.

Keywords: *Forest rehabilitation, soil properties, plantation species, stand age, Acacia auriculiformis*, *Syzygium grande*, *Tectona grandis*.

Introduction

Afforestation or reforestation plays a potential role in the conservation of the soils on land by reducing soil erosion (Cacho, 2001). It can also add soil organic matter, improve soil structure and act as a carbon sink (Jackson, Banner, Jobbagy, Pockman, & Wall, 2002; van Kooten, Shaikh, & Suchanek, 2002). All of these functions happen due to the growth and distribution of vegetation on soil's physical and chemical properties (Cao, Chen, Xu, & Liu, 2007).

The sustainability of reforestation operations often depends on the impacts of the planting on soil properties (Van Eetvelde & Antrop, 2005). Following reforestation, changes inevitably occur in quality, quantity, timing and spatial distribution of soil properties (Liu, Fu, Lu, & Chen, 2002). The Plant cover and dominant tree species both have fundamental effects on soil's physical, biological and chemical properties (Cao et al., 2007; Ritter, Vesterdal, & Gundersen, 2003). As noted by Richter et al. (1994), it is frequently assumed that forests will have a beneficial effect on soils.

Several studies have been conducted on the effect of reforestation or afforestation in different countries throughout the world. Groenendijk et al. (2002) conducted a study on New Zealand's hilly soils about the effects of afforestation on organic carbon, nitrogen and sulfur concentrations. They confirmed that afforestation of hilly pasture soils resulted in net mineralization of soil organic sulfur in addition to organic carbon and nitrogen. Jaiyeoba (2001) conducted a study in Nigeria on *Eucalyptus camaldulensis* and *Pinus oocarpa* plantations, which had been established as satisfying both land rehabilitation and agro-industrial objectives. He found that the rate of regeneration in the context of present silvicultural practices was extremely slow. The soil texture, bulk density, infiltration rate, nutrient element and pH showed only slight improvement. Farley & Kelly (2004) conducted a study in North America on the effect of afforestation on soil nutrient, which had been established in páramo grassland. They examined that changes in vegetation can affect soil properties on a decadal time scale, with implications for long-term site productivity. Cao et al. (2007) in China, found a positive impact of reforestation on soils. Hossain & Chowdhury (1984) in Chittagong, Bangladesh concluded that plantation of *T. grandis* plays an important role in nitrogen status in soil. Islam & Weil (2000) for moist deciduous forests in Bangladesh found that reforestation with fast-growing *Acacia* improved 6-16% soil qualities. Chowdhury et al. (2007; 2007) also confirmed the improvement of soil's physical and chemical properties through the establishment of orange orchards in the deforested sites of Bandarban, Bangladesh. Islam et al. (1999) confirmed an improvement in the reforested soil properties in Chittagong, Bangladesh. Soil quality improvement in the coastal area of Bangladesh was also confirmed by Shaifullah et al. (2009).

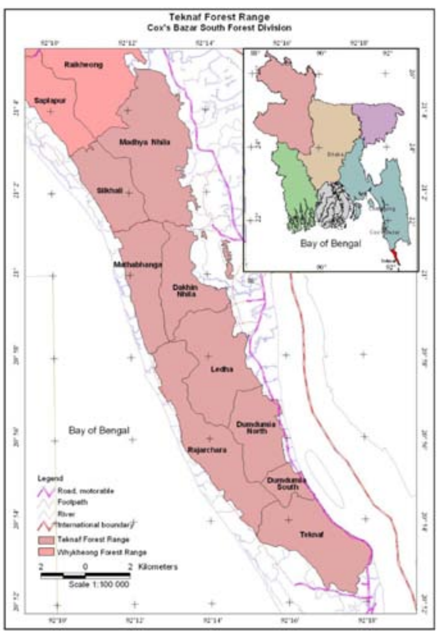
Soil is regarded as a basic resource for nearly all land uses and the most important component of sustainable production (Bouma, 2002; Nambiar, Gupta, Fu, & Li, 2001). Determining soil quality and its variability with land-use changes is an ideal and primary indicator of sustainable land management (Doran, 2002; Karlen et al., 1997). Despite the availability of the studies mentioned above on the effect of reforestation on the soil qualities in different forest ecosystems in Bangladesh, such studies can so far not be found in the Southeastern part of Bangladesh. Different case studies on assessing soil qualities in the reforested areas can firmly confirm the effect of reforestation on the soil properties. Like other forest areas in Bangladesh, deforested areas of the Cox's forest division (South) under the Southeastern part of Bangladesh were also reforested with many plantation species since five to six decades (*pers. comm.*). Thus, a research question arises: What is the effect of reforestation on the soil properties in the Cox's Bazar forest division (South) of Bangladesh. The study hypothesizes that reforestation improves the soil properties in the Cox's Bazar forest division (South). A study was undertaken to answer the above research question based on this hypothesis. The findings of the study are expected to contribute to the arena of forest rehabilitation in Bangladesh.

Methodology

To determine the precise effects of reforestation on soil properties, vegetation and soil samples were collected from the nine plantation sites located in the Mochoni and Teknaf beat under Teknaf forest range, Cox's Bazar forest division (South), Bangladesh. The primary data collection was completed within five months from December 2008 to April 2008. Cox's Bazar forest division (South) under the Southeastern part of Bangladesh was deliberately selected because this region has witnessed a significant initiative of reforestation in the deforested and degraded forestlands (*pers. comm.*).

The study area lies between 20º53'51"-20º56'58" North latitudes and 92º15'22"-92º17'09" E longitudes and is located in the far southeastern corner of the country (Figure 1). The topography of the study areas is generally characterized by low mountains separated by broad valleys, making the landform extremely irregular. Parts of the mountainous range reach an altitude of 700 meters above mean sea level. The soil ranges from gray piedmont soils to brown hill soils (Bari & Dutta, 2004). Being situated in the tropical zone, Cox's Bazar forest division is subjected to tropical maritime climate (BBS, 2009). The extremes of climate are neutralized to a considerable extent because the area is in close proximity with the sea to the west and ranges of hills to the east. These consist of high temperature with some variations, high humidity (70-85%) and heavy rainfall concentrated in the monsoon period, from June to September. Pre-monsoon storms (March to May in the Bay of Bengal) often cause severe damage to human habitations and vegetations. The mean monthly temperature ranges from 22.3°C to 30.1ºC, with a mean annual temperature of 26.24°C (Bari & Dutta, 2004). Ecologically, the forest type of this area is tropical semi-evergreen. The area was once covered with dominant *Dipterocarpus* spp. and *Syzygium* spp., which had been deforested by over-exploitation and encroachment (Bari & Dutta, 2004). However, reforestation has gained momentum over the last two decades. For reforestation purposes, seeds were germinated in 15 cm × 10 cm plastic bags filled with a mixture of sand, forest topsoil, compost, and ash. All seedlings were grown in the nursery managed by the forest department. Four-month-old seedlings were transplanted in stands at 1.82 m × 1.82 m spacing. Weeding continued once per year through the second year. No fertilizer was applied in the plantation.

***Fig. 1** Study site in the Cox's Bazar forest division (South), Bangladesh*



Sampling procedure

A reconnaissance survey was conducted in November 2007 to have a general idea about the topography, slope and species composition of the reforested sites and their adjacent deforested/degraded area. The reconnaissance survey revealed severe deforestation in the study area due to heavy pressures by the surrounding people. However, some successfully reforested sites with varying ages were observed. The surrounding people of the forests were mainly farmers. They go to the forest very often and collect fuelwood, thatching materials and other materials. Because of the subsistence economic status of most rural people, it may be noted that many school-age children were involved in the collection of fuelwood or other forest materials, which were sold in local market to procure their daily necessities.

To assess the effect of the reforestation on soil properties, the species selected for the study was the frequently-used plantation species, based on the higher frequency of the species used in the reforestation throughout the study sites. The data on the frequency of reforestation were collected from the research division of the Forestry Department of Bangladesh. It was also confirmed by discussions with the officers in the Divisional Forest Office in Cox's Bazar and the Teknaf Forest Range Office (*pers. comm.*). Age-wise distribution of the stands of the species was then enlisted with their corresponding area planted. Based on the descending ranking of the area planted by age, the first three plantation ages were identified. For each age of each species, three stands were selected randomly. Thus, nine stands were used for vegetation and soil sampling. The study covered the stands of three plantation species, i.e., *Acacia auriculiformis* of 4, 11 and 12 year-old, *Syzygium grande* of 43, 48 and 49 year-old and *Tectona grandis* of 52, 53 and 56 year-old. For vegetation study in each stand, three plots were sampled randomly with the size 20 m × 20 m. Thus, for the nine stands, 27 plots were selected for the vegetation study. In the same plots, soil samples were collected at two depths of 0 to10 cm and 10 to 20 cm using an earth augor for analyzing soil chemical properties.

Thus, 54 soil samples were used for the study in the reforested sites. To compare the soil properties of the reforested sites with that of the deforested sites, three deforested sites were selected near the reforested sites. In each site, soil samples were collected at two depths of 0 to 10 cm and 10 to 20 cm for soil chemical properties with three replications. Thus, it made 18 soil samples for the study in the deforested areas. However, each soil sample was a composite of three sub-samples beside the soil samples collected for analyzing physical properties. Soil physical properties were measured with the samples (soil core) collected from only 0 to 10 cm soil depth. The age of the sampled stands was not uniform for all the species, because different stands were established at different times in the study area, forming different stands with different ages (Table 1). The average stand density ranged from 117 ± 12 ha^{-1} for 52 years *T. grandis* to 625 ± 195 ha^{-1} for 4 years *A. auriculiformis*. The reasons for the under-stocking of some stands might be over extraction of forest resources, encroachment and natural calamities like cyclone and tornado. However, the reasons for the under-stocking of the stands were not studied.

To measure the growing stock of trees planted in the stands, total height in meters (m) and diameter at breast height (dbh) at 1.3 m in centimeters (cm) of each individual tree in the sampled plot were measured with diameter tape, Spiegel relaskope and meter tape. The soil samples were carefully taken to the laboratory for the assessment of some selected physical and chemical properties, i.e. bulk density, moisture content, maximum water- holding capacity, organic carbon, nitrogen, phosphorus, potassium and soil acidity.

The assessment of the soil properties being limited to the above parameters was only due to the limited budget, time frame and laboratory facilities. However, it indicates the limitations of the study.

Table 1 Stand ages, densities and plot number sampled in the Cox's Bazar forest division (South), Bangladesh.

Name of the species	Age of the stand	Sampled plot numbers for measuring trees (*n*)	Stand density (tree ha^{-1})	Number of soil samples (*n*)	
				Reforested sites	Deforested sites
Acacia auriculiformis	12	3	200 ± 125	2 3 = 6	
	11	3	442 ± 31	6	2 3 = 6
	4	3	625 ± 195	6	
Syzygium grande	49	3	250 ± 20	6	
	48	3	167 ± 31	6	2 3 = 6
	43	3	283 ± 31	6	
Tectona grandis	56	3	133 ± 31	6	
	53	3	233 ± 60	6	2 3 = 6
	52	3	117 ± 12	6	
Total number of stands = 9		*N = 27*		*N = 54*	*N = 18*

Laboratory analysis

Core method was used to determine the soil bulk density. The procedure is described by Black et al. (1965). Particle density was measured according to Brady (1996). Moisture content, field capacity and maximum water-holding capacity were determined from core samples collected for

bulk density (Brady, 1996; Lemenih, Karltun, & Olsson, 2005). The soil organic carbon and organic matter were determined by loss of ignition method (Ball, 1964). Soil pH was determined in a 1:1 soil/water suspension using a digital pH meter (HM-25R pH meter, TOA, Japan) suggested by Peech (1965). Available phosphorus was determined by Bray-1 method (Watnable & Olsen, 1965). Total nitrogen was determined by the Kjeldahl digestion, distillation and titration method (Bremner & Mulvaney, 1982). Available potassium was determined by flame photometry (Black, Evans, White, Ensminger, & Clark, 1965).

Statistical analysis

Statistical analysis was carried out using SPSS program version 13.0. To show the differences in soil properties among the stands and ages separately, One-way analysis of variance (ANOVA) was carried out. Linear regression analysis was also carried out to show the effect of plantation age on the soil properties. Spearman's rho correlation test was carried out to show the relationship between the variables.

Results

Growing stock

The total height of *A. auriculiformis* of 12, 11 and 4 year-old-stands were 16.26 ± 0.41 (SE) m, 13.83 ± 0.43 m and 7.22 ± 0.19 m, respectively (Table 2). The dbh of the same species of the above ages were 16.78 ± 0.59 cm, 17.52 ± 0.74 cm and 9.39 ± 0.18 cm, respectively. The total height of *S. grande* of 49, 48 and 43 year-old-stands were 22.89 ± 0.66 m, 24.71 ± 0.55 m and 21.37 ± 0.39 m, respectively, while the dbh were 35.11 ± 1.52 cm, 45.64 ± 3.43 cm and 24.00 ± 1.28 cm, respectively. *T. grandis* of 56, 53 and 52 year-old-stands had the total height 17.23 ± 1.29 m, 21.30 ± 0.93 m and 18.21 ± 1.04 m, respectively, while the dbh were 42.64 ± 3.17 cm, 39.76 ± 1.67 cm and 31.50 ± 1.54 cm, respectively.

Table 2 *Stand growing stock (height and dbh) in the Cox's Bazar forest division (South), Bangladesh*

Name of the species	Stand age (year)	Height (m)	dbh (cm)
A. auriculiformis	12	16.26 ± 0.41	16.78 ± 0.59
	11	13.83 ± 0.43	17.52 ± 0.74
	4	7.22 ± 0.19	9.39 ± 0.18
S. grande	49	22.89 ± 0.66	35.11 ± 1.52
	48	24.71 ± 0.55	45.64 ± 3.43
	43	21.37 ± 0.39	24.00 ± 1.28
T. grandis	56	17.23 ± 1.29	42.64 ± 3.17
	53	21.30 ± 0.93	39.76 ± 1.67
	52	18.21 ± 1.04	31.50 ± 1.54

Effect of reforestation on soil physical properties

The value of bulk density ranged from 1.20 ± 0.01 to 1.46 ± 0.05 gm/cc under different stands of all the species (Table 3). For *A. auriculiformis* and *S. grande*, the increasing ages of the stands meant that a decreasing trend of the bulk density was observed. For *T. grandis*, the stand age-bulk density relationship was found for the 52 and 53 year-old-stands. The bulk density of the 56 year-old-stand of *T. grandis* was 1.32 ± 0.04 gm/cc, which was higher than the 53 and 52 year-old-stands. However, this age-bulk density relationship for this particular age of *T. grandis* stand is surprising. Moisture contents of the soils ranged from 9.97 ± 1.12% to 18.27 ± 3.54% for all the stands of the species. For all the stands of the species, maximum water-holding capacity ranged from 30.37 ± 2.54 % to 47.06 ± 3.54%. With the increasing ages of the stands of *A. auriculiformis* and *S. grande*, an increasing moisture content and maximum water-holding capacity was found. This positive relationship was found only for the 53 and 52 year-old-stands of *T. grandis*. This relationship was negative at the age of 56 years of the same species. This is also a surprising result for this species at this particular age.

Bulk density for the species *A. auriculiformis* and *T. grandis* was significantly (at $p < 0.05$) different among the different ages of the stands. However, bulk density in the 43 year-old-stand of *S. grande* was significantly different than that of the 48 and 49 year-old-stands. Moisture content was significantly (at $p < 0.05$) different among the different stands of *S. grande* and *T. grandis*.

Maximum water-holding capacity was significantly (at $p < 0.05$) different among the different stands of *A. auriculiformis* and *S. grande*. Height and dbh of the stands had a significant $(at\ p < 0.05\ and\ p < 0.01)$ negative correlation $(r = -0.800\ and\ r = -0.845, respectively)$ with the bulk density, a positive correlation ($r = 0.837\ and\ r = 0.830, respectively$) with the moisture content, and a positive correlation $(r = 0.824\ and\ r = 0.768, respectively)$ with maximum water-holding capacity. However, soil bulk density had a significant $(at\ p < 0.05\ and\ p < 0.01)$ negative correlation $(r = -0.983\ and\ r = -0.953, respectively)$ with the moisture content and maximum water-holding capacity. Linear regression analysis showed that ages of the stands had a highly significant $(at\ p < 0.05\ and\ p < 0.01)$ effect on the bulk density ($R^2 = 0.843$), moisture content ($R^2 = 0.871$) and maximum water-holding capacity ($R^2 = 0.703$) in all the species.

The bulk density was found significantly $(at\ p < 0.05\ and\ p < 0.01)$ higher in the deforested top soil than that of the reforested sites with all the noted tree species (Table 3).

On the other hand, the moisture content and maximum water holding capacity were significantly $(at\ p < 0.05\ and\ p < 0.01)$ higher in the reforested soils than that of the deforested soils.

Table 3: Effect of reforestation on soil physical properties in the Cox's Bazar forest division (South), Bangladesh

Land use	Age of the stand	Bulk density (gm/cc)	Moisture content (%)	Maximum water holding capacity (%)
A. auriculiformis	12	1.38 ± 0.04[a]	11.93 ± 1.23[a]	39.97 ± 1.45[a]
	11	1.41 ± 0.02[b]	10.34 ± 1.56[a]	34.74 ± 1.54[b]
	4	1.46 ± 0.05[c]	9.97 ± 1.12[b]	30.37 ± 2.54[c]
S. grande	49	1.27 ± 0.02[a]	18.27 ± 3.54[a]	47.06 ± 3.54[a]
	48	1.29 ± 0.01[a]	16.3 ± 2.65[b]	44.19 ± 4.25[b]
	43	1.33 ± 0.04[b]	15.53 ± 2.54[c]	41.47 ± 2.36[c]

T. grandis	56	1.32 ± 0.04^{a}	13.90 ± 3.54^{a}	39.60 ± 2.67^{a}
	53	1.20 ± 0.01^{b}	18.08 ± 1.45^{b}	46.69 ± 3.65^{b}
	52	1.25 ± 0.04^{c}	15.97 ± 2.34^{c}	45.76 ± 3.54^{b}
Deforested soils		1.55±0.04	6.81±0.53	30.20±0.79

Notes: Letters a, b and c denote a comparison of different stand ages within a species based on the one-way ANOVA

Effect of reforestation on soil chemical properties

Organic carbon for all the stands of the species ranged from 0.98 ± 0.01% to 2.27 ± 0.01% at the soil layer 0-10 cm (upper) and 0.96±0.01% to 1.38±0.01% at the soil layer 10-20 cm (lower) (Table 4). For *A. auriculiformis* at both soil layers, organic carbon increased with the increase of the ages of the stands. The same relationship was found with the 48, 43 year-old-stands of *S. grande* and 56, 53 year-old-stands of *T. grandis* at the lower soil layer. However, the organic carbon and stand age relationship was negative for *S. grande* and *T. grandis* at the upper soil layer. Soil organic carbon of the stands had a significant $(at\ p < 0.05\ and\ p < 0.01)$ positive correlation $(r = 0.717)$ with nitrogen and negative correlation $(r = -0.695)$ with pH.

Nitrogen in the soils ranged from 0.12 ± 0.01% to 0.22 ± 0.02% at the upper layer and 0.07 ± 0.01% to 0.15 ± 0.03% at the lower layer for all ages of the stands. For *A. auriculiformis*, nitrogen-stand age relationship was found to be positive for both the soil layers. This positive relationship was also found for *S. grande* for all the stand ages and 52, 53 years *T. grandis* stands at the 10 to 20 cm soil layer. However, this relationship was negative for *S. grande* at the 0 to 10 cm soil layer. Phosphorus ranged from 2.45 ± 0.04 $\mu g/g\ soil$ to 5.05 ± 1.33 $\mu g/g\ soil$ at the upper soil layer and 0.82 ± 0.04 $\mu g/g\ soil$ to 5.23 ± 1.12 $\mu g/g\ soil$ at the lower soil layer. The Phosphorus-stand age relationship was positive for all stands of *S. grande* and 11, 4 year-old-stands of *A. auriculiformis* at both the soil layers. However, it was positive at the upper soil layer for all ages of the stands and 56, 53 year-old-stands of *T. grandis* at the lower soil layer.

Potassium ranged from 0.10 ± 0.03 $meq/100\ g\ soil$ to 0.25 ± 0.02 $meq/100\ g\ soil$ at the upper soil layer and 0.06 ± 0.03 $meq/100\ g\ soil$ to 0.35 ± 0.03 $meq/100\ g\ soil$ at the lower soil layer. The Potassium-stand age relationship was found to be positive for all the stands of *S. grande* at both the soil layers and for *T. grandis* at the lower layer. *T. grandis* at the upper soil layer and *A. auriculiformis* for all the soil layers did not maintain any particular trend of containing Potassium. The pH ranged from 3.30 ± 0.02 to 4.04 ± 0.07 at the upper soil layer and 3.38±0.01 to 3.95±0.13 at the lower soil layer. The pH-stand age relationship was found to be negative for *A. auriculiformis* at both the soil layers. However, this relationship was not found to be common for other stands of the other species.

Table 4: *Effect of reforestation on soil chemical properties in the Cox's Bazar forest division (South), Bangladesh*

Land use	Stand age (year)	Organic carbon (%)	Nitrogen (%)	Phosphorus (µg/g soil)	Potassium (meg/100 g soil	pH
A. auriculiformis	12	2.06 ± 0.07^{A} 1.26±0.01^{a}	0.18 ±0.01^{A} 0.13 ± 0.01	4.92 ± 1.23^{A} 3.42 ± 0.98^{a}	0.25 ± 0.02^{A} 0.07 ± 0.01	3.30 ± 0.02^{A} 3.38±0.01
	11	1.94 ± 0.00^{B} 1.00±0.00^{b}	0.16 ± 0.02^{A} 0.10 ± 0.00	5.90 ± 0.75^{B} 5.23 ± 1.12^{b}	0.10 ± 0.03^{B} 0.10 ± 0.02	3.38 ± 0.03^{A} 3.42±0.06
	4	1.30 ± 0.00^{C} 0.99±0.00^{b}	0.12 ± 0.01^{B} 0.07 ± 0.01	5.05 ± 1.33^{C} 4.75 ± 0.65^{c}	0.12 ± 0.01^{B} 0.10 ± 0.03	3.72 ± 0.05^{B} 3.44±0.03
S. grande	49	1.59 ± 0.01^{A} 1.07±0.02^{a}	0.16 ± 0.02 0.15 ± 0.03	8.89 ± 0.12^{A} 6.1 ± 0.14^{a}	0.22 ± 0.04^{A} 0.35 ± 0.03^{a}	3.46 ± 0.01^{A} 3.78±0.05^{a}
	48	2.14 ± 0.02^{B} 1.29±0.01^{b}	0.19 ± 0.04 0.14 ± 0.01	4.15 ± 1.22^{B} 2.63 ± 0.87^{b}	0.13 ± 0.04^{B} 0.11 ± 0.01^{b}	3.81 ± 0.07^{B} 3.76±0.06^{a}
	43	2.27 ± 0.01^{C} 1.24±0.01^{c}	0.22 ± 0.02 0.12 ± 0.01	3.33 ± 1.22^{B} 1.66 ± 0.08^{c}	0.10 ± 0.02^{B} 0.06 ± 0.01^{c}	3.42 ± 0.03^{A} 3.47±0.01^{b}

T. grandis	56	0.98 ± 0.01^{A} 1.26±0.01^{a}	0.10 ± 0.01^{A} 0.10 ± 0.02	2.56 ± 0.87 1.35 ± 0.07^{a}	0.25 ± 0.04^{A} 0.17 ± 0.02^{a}	4.19 ± 0.10^{A} 3.95±0.13
	53	1.27 ± 0.01^{B} 0.96±0.01^{b}	0.16 ± 0.03^{B} 0.14 ± 0.03	2.55 ± 0.65 0.82 ± 0.04^{b}	0.11 ± 0.05^{B} 0.13 ± 0.06^{b}	3.81 ± 0.02^{B} 3.77±0.08
	52	1.73 ± 0.01^{C} 1.38±0.01^{c}	0.18 ± 0.05^{B} 0.12 ± 0.03	2.45 ± 0.04 0.91 ± 0.03^{b}	0.13 ± 0.04^{B} 0.06 ± 0.03^{c}	4.04 ± 0.07^{C} 3.74±0.03
Deforested soils		0.94±0.03 0.84±0.05	0.09±0.02 0.08±0.02	2.08±0.24 1.11±0.08	0.10 0.07±0.01	4.13±0.11 4.02±0.22

Notes: The upper and lower figure in the column (3rd through 7th) indicate the soil properties analyzed from the samples collected from the upper soil layer (0-10 cm) and lower soil layer (10-20 cm), respectively.

Letters A, B and C for upper soil layer and a, b and c for lower soil layer denote a comparison of different stand ages within a species based on the one-way ANOVA

Organic carbon among the different stands of all the species was significantly (at $p < 0.05$) different at the upper soil layer. It was also significantly (at $p < 0.05$) different for all the stands of *S. grande* and *T. grandis* at the lower soil layer. Phosphorus for *A. auriculiformis* among all the stands at the upper soil layer was significantly (at $p < 0.05$) different. At the lower soil layer of *T. grandis*, Phosphorus was significantly (at $p < 0.05$) different among all the stands. Potassium for *S. grande and T. grandis* at the lower soil layer was found to be significantly (at $p < 0.05$) different among the stands. pH was significantly (at $p < 0.05$) different at the upper soil layer of *T. grandis* among its stands. Linear regression analysis showed that ages of the stands had a highly significant $(at\ p < 0.05\ and\ p < 0.01)$ effect on the organic carbon for *S. grande* ($R^2 = 0.668$) and *T. grandis* ($R^2 = 0.765$) and Nitrogen for *A. auriculiformis* ($R^2 = 0.0.958$) and *S. grande* ($R^2 = 0.917$).

Soil organic carbon, nitrogen (%), phosphorus and potassium in all the plantations of all the soil depths were found significantly $(at\ p < 0.05\ and\ p < 0.01)$ higher than that of the deforested soils (Table 4). However, pH was significantly $(at\ p < 0.05\ and\ p < 0.01)$ lower in most of the plantations than that of the deforested sites.

Discussion

Reforestation adds organic matter to the soil, which usually increases with the increase of the stand ages (Brady, 1996). Increasing input of organic matter to the soil along with the increasing rate of decomposition of the existing organic matter results in an improvement in soil structural properties and thus a decrease in bulk density (Lal, 1987). Hossain & Chowdhury (1984) found that soil moisture and water-holding capacity in the reforested soil increased with the age of the stands of *T. grandis* at Ichamoti forest beat under Chittagong forest division in Bangladesh. Chowdhury et al. (2007) found this trend in Thanchi Upazila of Bandarban district of Bangladesh while natural forests were being converted into orange orchards. The same trend was found by Islam & Weil (2000) for tropical deciduous forest ecosystem in Bangladesh while deforested sites were being converted into plantations. Ritter et al. (2003) and Vesterdal et al. (2002) in Denmark found no difference in bulk density among the tree species, but they found a significant decrease in bulk density of the upper soils (0 to 5 cm) with the increase of stand ages. Hajabbasi et al. (1997) for Lordegan area of Iran & Liu et al. (2002) for Sichuan Province of China also observed the same trend. The present study finding the lower bulk density with the increase of stand age is thus supported by the other observations. However, Hajabbasi et al. (1997) conclude that higher bulk density in comparison to the lower ones indicates a lower soil quality. Hajabbasi et al. suggest an appropriate agroforestry practice to prevent and cure soil compaction and higher bulk density. Islam & Weil also emphasize reforestation with appropriate tree species as a means of reviving the soil quality in Bangladesh. Reforestation usually results in an increase in macro-porosity and hydraulic conductivity, and a decline in susceptibility to erosion (Allen, 1985; Seubert, Sanchez, & Valverde, 1977; Spaans et al., 1989). This phenomenon can support the present observation of increasing higher moisture content and maximum water-holding capacity with the increase of the age of stands. A similar trend was observed in the Thanchi Upazila of Bandarban district of Bangladesh while natural forests were being converted into orange orchards (Chowdhury et al., 2007). In Arunachal Pradesh of India, Singh et al. (2001) also observed the same trend.

Change in land-use has the potential to either release or sequester soil carbon.

Clearing of native vegetation for agricultural production often leads to a reduction in soil organic carbon (SOC) (Davidson & Ackerman, 1993; Mann, 1986), whilst the potential exists for a significant increase in SOC through changed management practices (Lal, 2001) or reforestation (Post & Kwon, 2000). The rate of accumulation or loss of SOC after change in land-use is governed by the balance between addition and decomposition of organic material, which in turn is influenced by changes in net primary productivity and allocation (van Cleve & Powers, 1995), quality of organic input (Berg, 2000), tillage practices (Balesdent, Chenu, & Balabane, 2000), rooting patterns (Jobbágy & Jackson, 2000) and climate. Other site factors also influence SOC dynamics, including soil texture (Golchin, Oades, Skjemstad, & Clarke, 1994) and climate (van Cleve & Powers, 1995). The chief source of organic carbon in forest soil is from the litter fall, which is largely found on the surface of the soil. Its content gradually decreases with depth. This discussion substantiates the findings of more SOC at the surface (0 to 10 cm) of reforested soils than at the lower soil layers. Scot et al. (1999) reported that conversion of pastureland to plantation forests is accompanied by major changes in soil properties and processes, some of which could influence the soil carbon reservoir. The stand age and organic carbon relationship was surprisingly negative for *S. grande* and *T. grandis* in the present study. This could be attributed to the excessive illegal collection of biomass from the specific plantation by the local peoples. The lower stand density of the plantation can prove the lower accumulation of biomass in the soil. Vesterdal et al. (2002) conducted a study in Denmark in which seven stands of each tree species on nutrient rich soils made up a chrono-sequence ranging from 1 to 29 years. They found carbon concentration and storage increased in the upper layer (5 cm) of mineral soil with increasing stand age. Farley et al. (2004) conducted a study in Ecuador using a chrono-sequence of stands ranging from 0 to 25 years of age. They found that total nitrogen concentrations in the litter and upper A-horizon were both significantly different among age classes, as Nitrogen concentrations in the litter declined from grasslands to young pine, with highest in the intermediate age pine stands, and declined again after 20 years under pine. This result largely supports the present study for *S. grande* and *T. grandis*. However, Ritter et al. (2003) reported that nitrogen concentration in the total forest floors of oak and Norway spruce did not change with increasing stand age.

Farley et al. (2004) found no significant differences in available phosphorus among age classes for the upper or lower tier of the A-horizon. The same was found for *S. grande* and *T. grandis* in the present study. However, the results from this study indicate phosphorous was highly influenced by tree species, as the reforested area of *S. grande* had much higher available phosphorus than the reforested area of *T. grandis* at both upper and lower layers. Another study conducted by Jaiyeoba (2001) in Nigeria found that for soils of the plantation and adjacent degraded sites, the rate of soil regeneration in the context of present silvicultural practices was extremely slow. Of the soil parameters, he found that only organic matter showed significant improvement within the examined period. Bulk density and soil pH also showed slight improvement.

A decrease in pH had often been found to result from reforestation/afforestation with conifers, as well as some broad leaf plantations due to the greater acidity of litter relative to the native vegetation (Beyer, Blume, Schleuss, Frund, & Schulten, 1992). This should be reflected in maximum acidification at the soil surface (Jobbagy & Jackson, 2003). Another source of acidification may come from nitrification (Parfitt, Percival, Dahlgren, & Hill, 1997), which could also produce a pattern in which acidification occurs primarily at the soil surface.

Conclusion

A comparatively lower bulk density, higher moisture content and maximum water holding-capacity in the soils with the increase of the stand age in the Cox's Bazar (South) forest division of Bangladesh show an improvement in the soils due to reforestation. The higher presence of organic carbon and nitrogen in the soils of the stands with the increase of the stand age also provides some partial evidence of the improvement of the soils being due to reforestation. The comparison of these soil properties with the adjoining deforested soils also confirms the improvement of soils with reforestation. However, it partially proves the hypothesis. The findings of the study are therefore not surprising for most of the soil parameters considered. As the assessment of the soil properties in regard to reforestation is limited to a few physical and chemical parameters, the present findings only partially support the improvement of the soil properties as having been due to reforestation. Forests are particularly important in the context of present environmental degradation and ecological purposes. The present study recommends reforestation in the deforested sites with the proper selection of tree species. The findings of the study would be of importance for the rehabilitation of the forest ecosystems in Bangladesh.

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Influence of farm road on the herbaceous composition of the Black-necked Crane (***Grus negricollis***) habitat at Phobjikha valley.

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Abstract

The herbaceous composition along old trail and newly constructed farm road at Phobjikha Black Necked Crane habitat was studied to clarify the impact of human intervention. Based on the quantitative ground vegetation data from two study sites, a total of fifty five (55) species belonging to 37 families was found along forest edge to wet-land through the old trail and forty three (43) herb species from 28 families below the farm road. There were seven (7) annual herbs and twenty (20) perennial herbs common to both the sites. Fifteen (15) invasive/exotic herbs were only found below the farm road while twenty eight herbs of mainly native were found along transect of the old trail. Four different vegetation types were classified by using cluster analysis and each types were categorized based on their dominance, viz. (1) Roadside vegetation (*Eragrostis, Trifolium, Rumex, Cotoneaster*), (2) Below roadside vegetation (*Trifolium, Yushania, Eragrostis, Cotoneasters*), (3) Wet-land vegetation (*Carex, Anaphalis, Ainsliaea, Agrostis, Yushania*), and (4) Pine forest edge vegetation (*Arundinella, Agrostis, Drosera, Pteridium*). Floristically, the vegetation along the old trail showed higher number species compared to the species along the farm road side. Low number of annual and higher perennial herbs were found in the old trail side compared to higher annual and lower perennials along the farm road sides. Interestingly, diverse life-form was observed along the old trail side. It was clarified that invasive weeds and a few exotic herbs found with the introduction of roads in the crane habitat of Phobjikha valley. For sustainable utilization of resources and protection of Crane Habitat, it is recommended to limit the network of farm roads within the Crane Habitat sites.

Key words: *Farm road, nature trail, exotic weeds, invasive plants, wet-land, habitat*

Introduction

Phobjikha valley is c. 161.9 km^2 with a mean elevation of 3500 m a.s.l. Gangtey Goenpa, an important religious site, is located in the heart of Phobjikha valley on a small hill top facing the crane roosting area (wet-land). Phobjikha valley is one of the most important valleys in the country. The entire wet-land is a habitat for the endangered Black-necked Crane (*Grus negricollis*). However, with the introduction of potato farming in early 1980s, settlements have spread along the forest edge valley bottom (Phobjikha management plan 2006-2010). Farmers besides potato farming also rear livestock considering vast pastures especially during the summer months. Since then, a farm road was also constructed to ease the transport facilities especially potatoes. Modernization also introduces chemical fertilizers to boost the potato production in the valley.

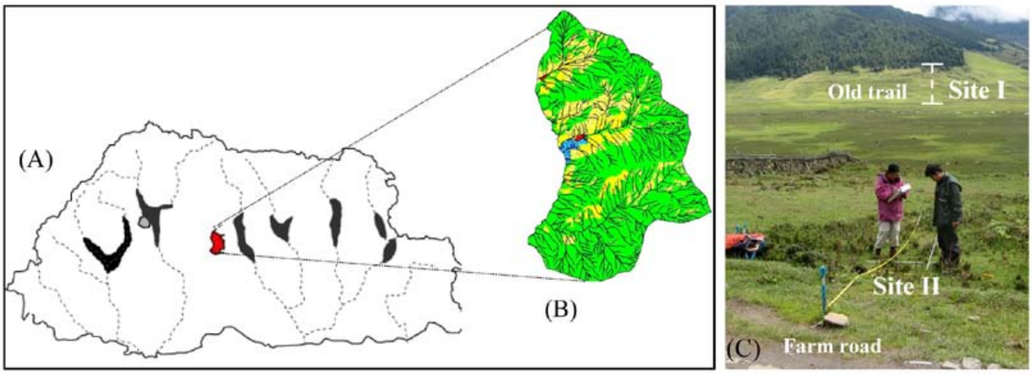
In early 1990s, tourism was introduced mainly for watching Black-necked Crane during the winter months (Phobjikha management plan 2006-2010). This initiative attracted small scale business in the valley and gradually saw infrastructure developments such as resorts, farm roads and schools. Accordingly, the number of vehicles (cars, trucks, farm machines) plying on the farm roads also increased. All these activities pose threat to the winter habitat of Black-necked cranes.

Although, the wet-land crane habitat is under the conservation area of the Royal Society for Protection of Nature (RSPN), the study on the wetland ecology mainly enumeration of herbs was not carried out. Therefore, such study was necessary to understand the impact of developmental activities on floristic composition of the wet-land at Phobjikha valley.

Study site

Phobjikha valley is situated in a cold temperate region under Wangduephodrang Dzongkhag (Fig. 1A,B). It is about three and half hour drive from Thimphu. The present study was carried out at Phobjikha valley specifically in front of RSPN office below the farm road and on the opposite side of RSPN along the old trail.

Figure 1: *Map of the study area (A) Map of Bhutan showing dry river valleys (shaded portion), (B) map of Phobjikha valley, & (C) Vegetation survey in the two study sites*



Problem statement

Farmers of Phobjikha valley are living in harmony with Back-necked Cranes for decades and shared the habitat. However, with the developmental activities such as introduction of network of farm roads, electricity, tourism, conventional farming & sprouting of expensive resorts within the valley deter the stability of Black-necked Crane habitat. Such trends may affect the ecological carrying capacity of the wet-land crane habitat. Particularly, with the introduction of potato farming, farmers use 106.43 tons of sulphate and 54.5 tons of urea annually (RSPN 2003). There is also threat of exotic and invasive weeds as a result of conventional farming and farm roads. Introduction of such exotic, alien and invasive weeds may cause threat to the native plants within the valley.

Objectives

The general objective of the study is to understand the impact of human intervention on the floristic composition of herbs along the Phobjikha valley. Specifically the study aims to meet the following:

1. Understand the climatic condition and wet-land habitat of the valley
2. Compare herbaceous composition between farm road below RSPN visiting Centre and old trail on the opposite side of the valley
3. Clarify the impact of farm roads on the herbaceous composition and
4. Recommend measures for future management of the Black-necked Crane habitat

Materials and Method

Environmental data measurement

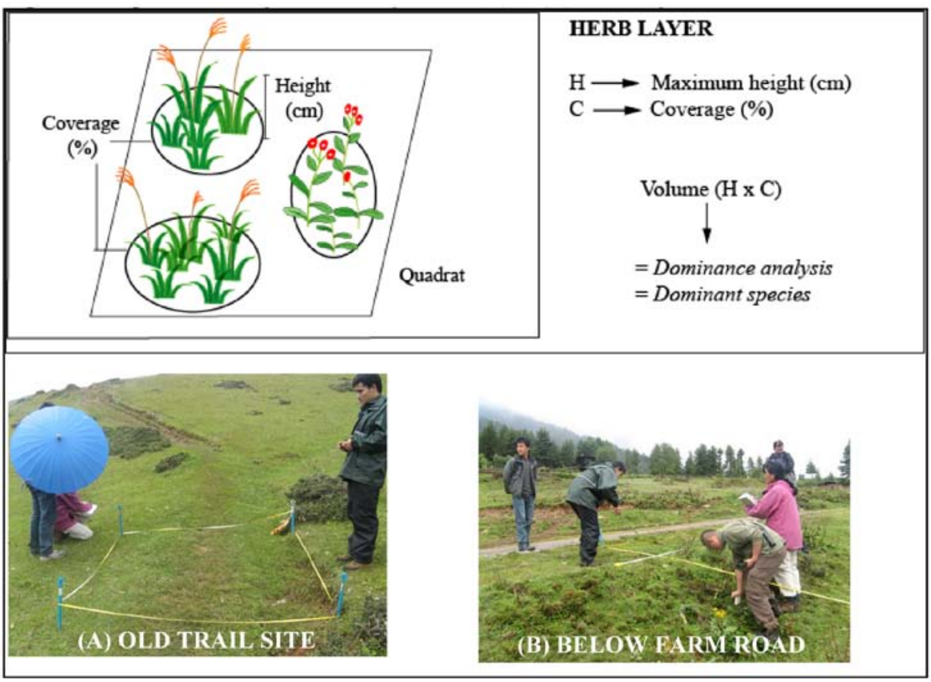
Air temperature measurement was recorded using HOBO Onset data logger enclosed in solar radiation shield (Onset Computer Co. MA, USA) mounted on a pole about 1.3 m above the ground since 2001.The rainfall data (1990-2008) was collected from the office of hydro-met Division, Ministry of Economic Affairs.

Similarly, soil moisture content was measured by using Hydro-sense (CD 620 + CS 620) (CAMPBELL SCIENTIFIC INC., Logan, Utah) bearing 12 cm and 20 cm probes during the field survey. Soil hardness was measured by 5 to 10 random penetrations into the soil surface at each sub-quadrat sampling plot using Push Cone instrument called Yamanaka's soil hardness tester (KIYA SEISAKUSHO, Tokyo).

Vegetation survey

Ground/herb layer vegetation survey was conducted by measuring the height (cm) of the tallest living herb measured at the tip of the foliage and its percent coverage (%) in each quadrat or transect (Fig. 2). Several quadrates with a size of 2x2 m plots were set along the transect from forest edge to wet-land and from below farm road. Fieldworks were carried out from September 2008 and August 2010 respectively.

Figure 2: Vegetation survey & data analysis and (A) & (B) two study sites



Data analysis

Climatic data analysis

Climate diagram was drawn by Walter and Lieth's method (Walter *et al.* 1961-1967; Lieth *et al.* 1999);

Vegetation data analysis

Herbaceous data was analyzed using volume or biomass estimate by multiplying height of the herb species (cm) with its coverage (%) within the sample quadrat. The volume estimate or relative biomass was then used for the analysis of dominance or dominant species and for further statistical tests. Further, the data was analyzed by PC-ORD version 4 (McCune and Mefford 1999) and cluster analysis was performed using distance measure of Sorensen (Bray-Curtis method).

Results

Climatic condition of Phobjikha wetland (Crane Habitat)

The annual mean temperature of Phobjikha valley is 8.3 °C with a maximum temperature of 15.3 °C in July and a minimum of -0.3 °C in January (HOBO ONSET logger 2001-2010). In the past ten years (2001-2010), the maximum absolute temperature recorded was 23.6 °C on August 10, 2007 at 1 PM and the absolute minimum temperature was -11.9 °C on December 10, 2010 at 6 AM.

Quantitative data analysis of the past seven years showed that Phobjikha experienced relatively warm winter in 2009 and 2006 with a cold winters in 2008 and 2010 (Fig. 3).

However, mean temperature and summer mean temperature remain more or less constant throughout (Fig 3).

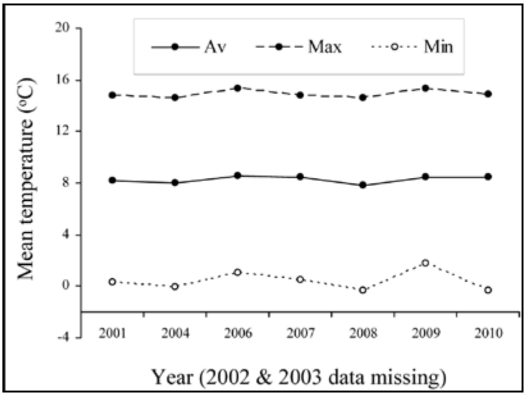


Figure 3: Temperature condition of the study area indicating average, maximum and minimum temperature between 2001-2010.

The total mean annual rainfall was 1324 mm (1990-2008) with a maximum rainfall in August (299.2 mm). Walter climate diagram showed that Phobjikha valley receives adequate rainfall and no dry spell was observed throughout the year (Fig. 4 A). The summer months of June-August received the highest rainfall and a least rainfall in the months of Jan-Mar & Oct-Dec. respectively (Fig. 4 A).

It was observed that relatively low soil moisture content and high soil hardness was coincided along the trail while high soil moisture content and low soil hardness at the wet land (Fig. 4 B). at the forest edge the soil moisture content was relatively low and increases towards the valley bottom (wet-land).

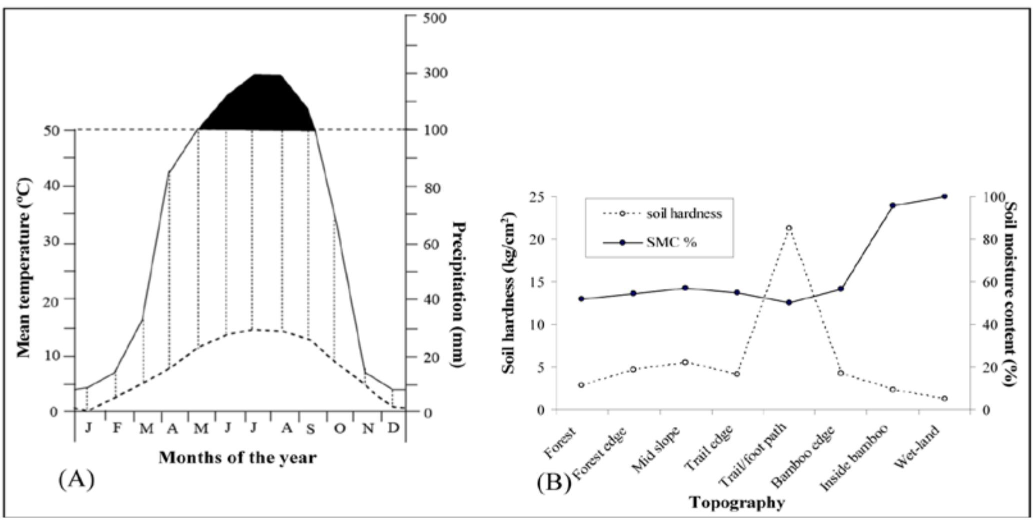


Figure 4: *Climatic background of the study area; (A) Walter climate diagram (Data measured from 1990-2008 for rainfall & 2001-2007 for temperature) & (B) Soil moisture and soil hardness (data measured during the study period)*

Floristic composition

The vegetation survey along two study sites (old trail & below farm road) at Phobjikha valley showed diverse species compositions (Tab. 1). A total of 71 herbaceous species comprising of 42 families were depicted. Compositae, Rosaceae and Cyperaceae were the dominant families with 5 species in each family. The most common species which were widely distributed to both sites of the study area were *Carex nigra, Yushania microphylla, Potentilla peduncularis, Prunella vulgaris, Sphagnum, Arundinella racemosa,* and *Cyanotis vaga* (Tab. 1).

Interestingly, *Eriocaulon bhutanicum* an endemic herb and two ground orchids (*Satyrium nepalense* & *Spiranthus sinensis*) were also recorded from the intact sites (old trail) (Photo 1).

***Photo 1**. Spiranthus sinensis a ground orchid and Eriocaulon bhutanicum an endemic herb.*

***Table 1**. Floristic composition of herbaceous plant species of the study area*

Species	LF	BELOW FARM ROAD SIDE (Below RSPN office)											OLD TRAIL SIDE							
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	N1	N2	N3	N4	N5	N6	N7	N8
Poa annua	A	10.6	6.3		0.1	1.2							4.6							
Plantago erosa	A	8.8			0.1	3.8	2.3	0.2	0.2	0.4		0.9					5.7	0.1		
Ageratum conyzoides	A	0.9	2.0	0.5			0.9		2.7		1.2	0.5								
Mazus delavayi	A	0.1	0.4								0.1						0.2			
Digitaria ciliaris	A		7.1	1.2	1.2	3.1	0.6				0.6	1.2								
Oxalis corniculata	A		0.8	1.7								0.0								
Galium aparine	A			0.3						0.1										
Spergula arvensis	A			0.3		1.2	0.1	0.5	0.1	0.4								0.0		
Campanula pallida	A			0.2								0.2	0.6	0.5						
Stellaria media	A			0.2		0.3	0.2		0.4		0.2									
Kyllinga squamulata	A					2.1	1.0	0.4	4.2	2.6							1.6	0.2		
Persicaria nepalensis	A						0.4					0.1								
Geranium	A						0.1		0.1			0.2								
Primula denticulata	A							0.4	0.7		2.0	0.8								
Primula spathulifolia	A								0.3			0.0	0.5	3.6	1.0	1.0	3.4	1.0	0.4	0.1
Chenopodium album	A													0.6				0.1		
Juncus sp	A														1.2				3.8	11.0
Polygonum plebeium	A															3.1			0.2	
Swertia bimaculata	A																	0.5	1.5	
Corydalis sp.	A																		0.6	0.1
Eragrostis nigra	P	76.6	3.8	27.3	51.8	20.7	12.8	52.2		9.3	14.9	5.6							2.0	
Cyperus cyperoides	P	2.2		3.7	1.1							0.3					5.1			
Trifolium repens	P	0.3	15.1	5.9	1.9	29.1	20.2	13.0	3.7	5.2	11.9	16.8					13.6	7.4	0.3	
Potentilla peduncularis	P	0.3	0.0		0.1	1.4		0.1	0.2	0.2	0.2			0.2	1.8	2.1	3.4	0.6	0.3	
Geum	P	0.3			0.0	1.2					0.4									
Rumex nepalensis	P		19.3	1.6	43.2				0.7											
Brachypodium sylvaticum	P		10.5	3.1			2.8	2.8	2.8	5.0	2.2	3.0	1.1	3.2	4.9					
Yushania microphylla	P		9.2	9.8	0.5	29.1	40.4	19.3	62.6	57.0	51.6	54.2						29.8	60.2	4.0
Carex nigra	P		3.7	3.0		3.8	9.2	1.6	2.4	1.2	3.2	1.7	14.1	1.1	2.6	2.6	8.9		2.1	20.4
Viola biflora	P		1.8	0.4									0.3	0.3					2.3	
Fragaria nubicola	P		1.6	0.9			1.0	3.7	0.7	1.2		1.2	3.1				1.4		0.7	
Prunella vulgaris	P		0.6	2.0	0.0	0.5	0.9	1.7	1.7	1.6	7.9	1.9				0.1	3.4	0.1		3.9
Senecio densiflora	P			11.0					0.9					0.3						
Ophiopogon	P			0.7		0.6	2.6													
Clinopodium umbrosum	P			0.4		0.6		0.2		0.1										
Sellaginella	P			0.3																
Anaphalis nepalensis	P			0.3						0.4		1.2	20.2	7.3	7.0	0.1	5.5		0.9	7.5
Hemiphragma	P				0.0					0.8	0.9	0.5		2.3	0.1	0.2	2.3	0.3		
Sphagnum	P					0.6	1.8	2.1	0.7	1.1		1.2	2.8	0.5	5.5	1.9	4.5	0.9		5.4
Fimbristylis aestivalis	P					0.5	0.8	0.1	4.5	0.8	0.6	0.2								
Arundinella bengalensis	P						1.6	1.3	8.2	9.3	1.7	1.0		33.8	28.5	34.7		6.5	0.5	
Anemone	P						0.3													
Cyanotis vaga	P							0.1	1.8	0.8		0.9	0.4	8.6	1.6	3.2	0.0	0.3	1.7	
Hypoxis aurea	P								0.2		0.3	0.4			2.0	5.1	0.0	0.7	0.5	
Roscoea alpina	P									0.8		0.2	0.1	0.2	0.2					
Arisaema sp	P											1.4								
Ainsliaea aptera	P												27.5							
Euphrasia	P												3.7							
Agrostis nervosa	P													8.3	5.7	26.0	34.8	49.6	4.3	14.7
Origanum vulgare	P													2.1						
Drosera peltata	P														15.8	17.3	1.1			
Aster sp	P														16.4		2.0	1.3	14.0	2.1
Halenia elliptica	P														3.9				0.2	12.1
Nepeta clarkei	P														0.3	0.3				
Gerbera	P															0.6				
Gueldenstaedtia himalaica	P															0.1	0.5	0.4		
Cirsium verutum	P																0.5	0.1		
Utricularia minor	P																			5.6
Eriocaulon bhutanicum	P																			4.0
Pedicularis siphonantha	P																			3.6
Cortia depressa	P																			2.7
Sanguesorba sp	P																		1.7	1.9
Caltha sp.	P																		0.9	
Gentiana sp.	P																		0.5	0.0
Cotoneaster microphyllus	DS		17.6	25.4									0.2							
Hypericum	DS													0.2	1.4	1.4	2.3		0.7	0.8
Gaultheria pyroloides	ES												6.9							
Satyrium nepalense	OR												0.2							
Spiranthus sinensis	OR															0.0				
Pteridium aquilinum	F							0.3		1.5		4.1	13.8	27.1						
Athyrium	F												0.1							
Total		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

***Note:** **A**=Annual, **P**=Perennial, **DS**=Deciduous shrub, **ES**=Evergreen shrub**,** **F**=Fern, **LF**=Life-form*

The herb species which were not recorded below the farm road but were recorded along the transect from pine forest to wet-land through the old trail were annual herbs of *Juncus, Polygonum plebeium, Swertia, Cordyalis,* and perennial herbs of *Ainsliaea, Euphrasia, Agrostis, Origanum, Drosera, Aster, Halenia, Nepeta, Gerbera, Gueldenstaedtia, Cirsium, Utricularia, Eriocaulon, Pedicularies, Cortia, Sanguesorba, Caltha, Gentiana*. Two ground orchid species of *Satyrium* and *Spiranthus* were also recorded from the old trial transect which were not found below the farm road.

On the other hand, weedy herbs and grass such as *Ageratum, Digitaria, Kyllinga, Persicaria, Eragrostis, Trifolium, Rumex, Senecio*, and *Clinopodium* were recorded below the farm road.

Vegetation types by cluster analysis

Four broad vegetation types were classified arbitrarily c. 50 % similarity index threshold; (I) Roadside vegetation, (II) Below farm road vegetation, (III) Wet-land vegetation, & (IV) Pine-forest edge vegetation respectively (Fig. 5). Vegetation type I & II were mainly found below the farm road while vegetation type III & IV were found along the line transect from pine forest edge to wet-land through the old trail. The most dominant herb species in type I & II were either exotic or invasive weeds such as *Trifolium, Rumex, Eragrostis, Cotoneaster, Senecio* while native herbs such as *Arundinella, Anaphalis, Drosera, Ainsilaea, Carex, Agrostis* were the dominants in the relatively intact site (old trails) (Fig. 5).

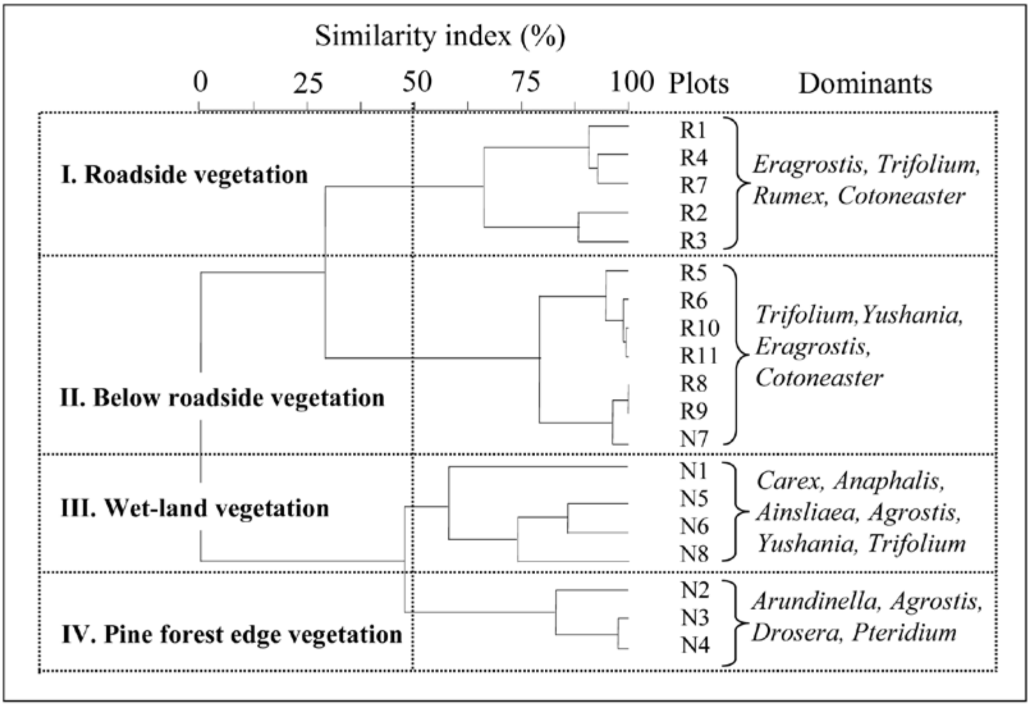


***Figure 5**. Cluster dendrogram depicting four vegetation types with its dominant species*

Two sites were further compared based on the life-form distribution (Fig. 6). A diverse life-form distribution was observed in the trail site vegetation including evergreen scrub, orchid which was not found in farm road side. On the other hand farm road side vegetation showed higher annual herbs and relatively lower perennial herbs. On the contrary, old trail site showed lower annual herbs and higher perennial herbs.

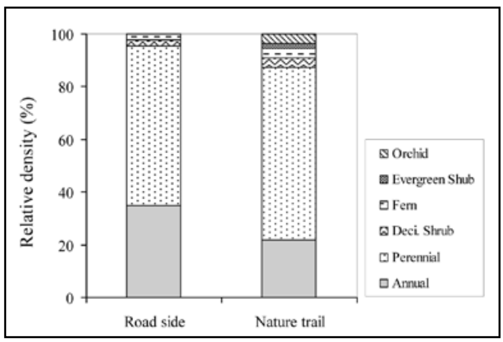


Figure 6. *Life-form distribution in the two study sites.*

Discussion

The introduction of farm-road at Phobjikha brought both positive and negative impacts. Positively, the farmers of Phobjikha valley can travel faster and ease their transport with the introduction of road which brings higher economic return from the sale of their farm products. However, negative impact of road was not seen as significant at present. The valley is known for winter roosting of Black-necked crane, an endangered bird. For this birds and wet-land habitat, the number of visitors both outside world and from within country increased yearly. Hence it is important to protect and conserve the wet-land habitat. However, the network of farm roads along the valley damages the habitat and several weeds and invasive plants were introduced (Photo 2). These alien weeds invade into the wet land and slowly reduce the habitat including the encroachment of pine forest (Photo 3). It is recommended to minimize the road networks and monitor wet-land regularly by installing gauging stations. It is also recommended to monitor the streams flowing into the wetland and how aquatic life is being affected. Such studies can be collaborated with the NSSC, Semtokha where the laboratory at Semtokha can analyze the water quality coming from the conventional potato farming up stream.

Photo 2. *Farm machine plying along the wet-land causing damage to the native herb vegatation*

Photo 3. *Young pine encroaching (succession) into the wet-land*

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Sundarbans Carbon Inventory 2010, a Comparison with 1997 Inventory

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Abstract

This document presents field-based carbon (C) stock estimates for the Sundarbans Reserve Forest of Bangladesh. First, it presents an estimate of current C stocks, obtained from the 2010 field-based forest inventory. Second, it contains an estimate of change in C stocks since the previous inventory, which was conducted in 1997. This latter analysis provides an estimate of certain "emission factors" over the recent past, which, when combined with remote sensing and other data on land-cover change ("activity data"), can be used to establish a baseline C trend against which future changes in C stocks can be evaluated.

This write up provides some of the quantitative information necessary for carbon market/monitoring projects (e.g., REDD+ proposals)—specifically current Carbon stocks, their distribution among aboveground and belowground pools, and recent trends in Carbon stocks (relevant to baseline). Out of measured 155 plots, increase of carbon found in 68% plots and 32% showed decrease. Mean Carbon density (without soil) for 2010 was found 117 Mgm/ha and for 1997 inventory was found 76 Mgm/ha. Findings of this Carbon inventory enable Bangladesh Forest Department to prepare a Collaborative REDD+Integrated Forest Management Sundarbans Project.

Introduction

The Sundarbans, world's largest contiguous natural mangrove forest and its habitant the royal Bengal tiger represent Bangladesh to the globe. Out of nearly 10000 square kilometers Bangladesh encompasses 6017 square kilometers. The reserve represents more than 40% of Bangladesh forests, and likely represents a key terrestrial carbon stock or sink/source for the country.

Three complete forest inventories were done for Sundarbans in 1959, 1983 and 1997. Reasons for these three inventories were similar in nature and that was: assessment of resources for felling prescriptions. Reasons for Sundarbans carbon inventory were different than those of previous three. It was done mainly to get a baseline carbon stock and make opportunity to sale Sundarbans carbon to international market.

A total of 155 sample plots were selected for the carbon inventory. These plots have been systemically extracted from 1200 sample plots of 1997 inventory. Each plot was divided into 5 sub plots of 10 meter radius. It followed the individual plot lay out 1997 inventory. Measurements were taken in these plots as per protocol. Two inventory teams collected data during December 2009 to April 2010.

Objectives:

Following objectives were set for the carbon inventory 2010:

a. To estimate existing Carbon stock of the Sundarbans Reserved Forests

b. To Prepare a REDD+ project on the basis of the carbon inventory

c. To provide necessary information to prepare a forest management plan for the Sundarbans

Methodology

Methodology of this Carbon inventory consists of series of operations. These are as follows:

a. Determination of Carbon pools

b. Sample plot design & layout.

c. Taking measurements in each plot

d. Keeping records for data analysis in computer and soil analysis in laboratory.

Carbon Pools

Most international standards divide forests into roughly five carbon pools: 1) aboveground and belowground biomass of live trees, 2) non-tree vegetation, 3) dead wood, 4) forest floor (litter), and 5) soil. Not all pools are required to be measured in every project; decisions can be made at the project level to streamline the effort involved in carbon assessment. A pool should be measured if it is large, if it is likely to be affected by land use, or if the land-use effects or size of the pool are uncertain. Small pools or those unlikely to be affected by land use may be excluded. For the SRF carbon assessment, FD suggested a recommendation to measure trees, non-tree vegetation, dead wood, and soil. Trees are the most susceptible to land use activities, and soil may be the largest and most uncertain carbon pool in mangroves. Dead wood and non-tree vegetation may be a significant biomass component in SRF and may change significantly with logging activities. Forest floor is usually a minor or even negligible biomass component in Asian-Pacific mangroves; as SRF is similar, this pool was excluded.

Methods for measuring trees, non-tree vegetation, and dead wood were adapted from relevant IPCC-associated sourcebooks. In brief, trees were quantified by stem surveys for large and small trees, non-tree vegetation was quantified by counts combined with allometric destructive harvests, and dead wood was quantified by line-intercept transects. Because mangrove soils are often C-rich and vulnerable to land-use change to deeper layers, soils were measured to 1-meter depth rather than only 30 cm as commonly recommended. To reduce the amount of material to be processed, sub-sampling was employed, taking advantage of the fact that mangrove soils are typically non-differentiated over the top meter of soil. Thus, rather than taking a core of the entire top meter, manageable sub-samples of 5 cm were taken representing 0-30 cm depth and 30-100 cm depth, respectively.

Designing sample plots:

The last SRF inventory, conducted in 1997, sampled approximately 1200 plots situated on a systematic grid at 1-minute intervals of latitude/longitude. The original plot grid was sub-sampled by selecting every second plot in both the x and y directions. This yielded 295 plots. To attain a lower plot density, every second row of this new grid was sampled; this yielded 155 plots. This systematic plot layout represents every compartment of the SRF (Total 55 compartments) and accepted by Bangladesh forest department and US forest service.

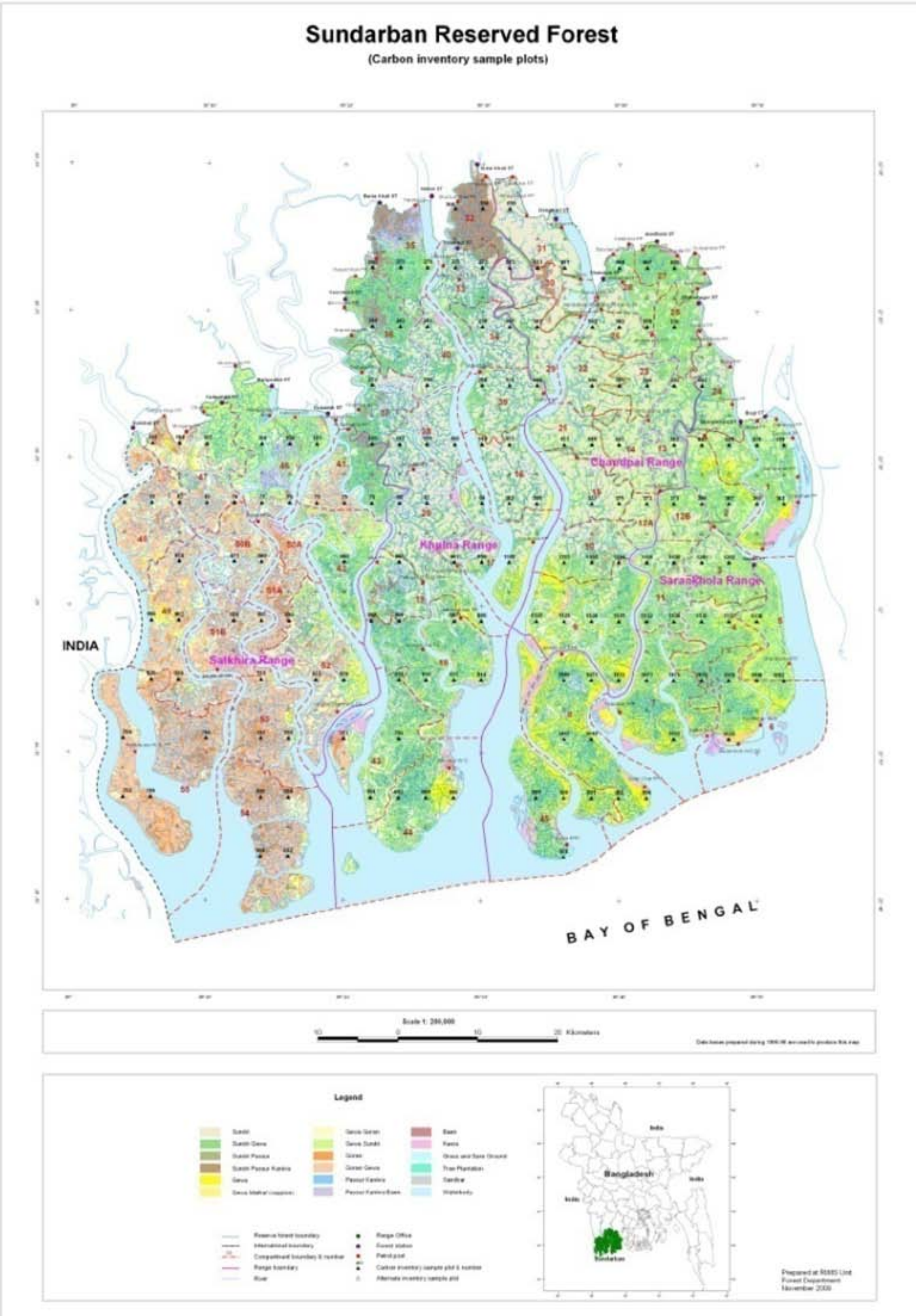


Figure 1: Sample plot lay out for 2010 SRF C Inventory

Field Measurement

The field inventory started with four days of in-situ field training, during which the first plots were surveyed. Officials from the USFS, Bangladesh Forest Department accompanied the participants. Participants learned the field protocols, practiced the use of instruments, and discussed probable questions regarding the inventory process. The actual inventory started in December, 2009, led by two Assistant Conservators of Forests (ACFs).

Of the 155 inventory plots (originally established in 1997) targeted for re-sampling, 5 were now under water due to erosion, subsidence, or canal migration (and possibly sea-level rise). At least two of these five losses were apparently due to recent cyclone damage. Thus, a total of 150 plots were sampled in the 2010 inventory. Plots which were partially under large canals were recorded as such, with an estimate of the percent of the plot area under water and measurements taken as normal in above-water portions.

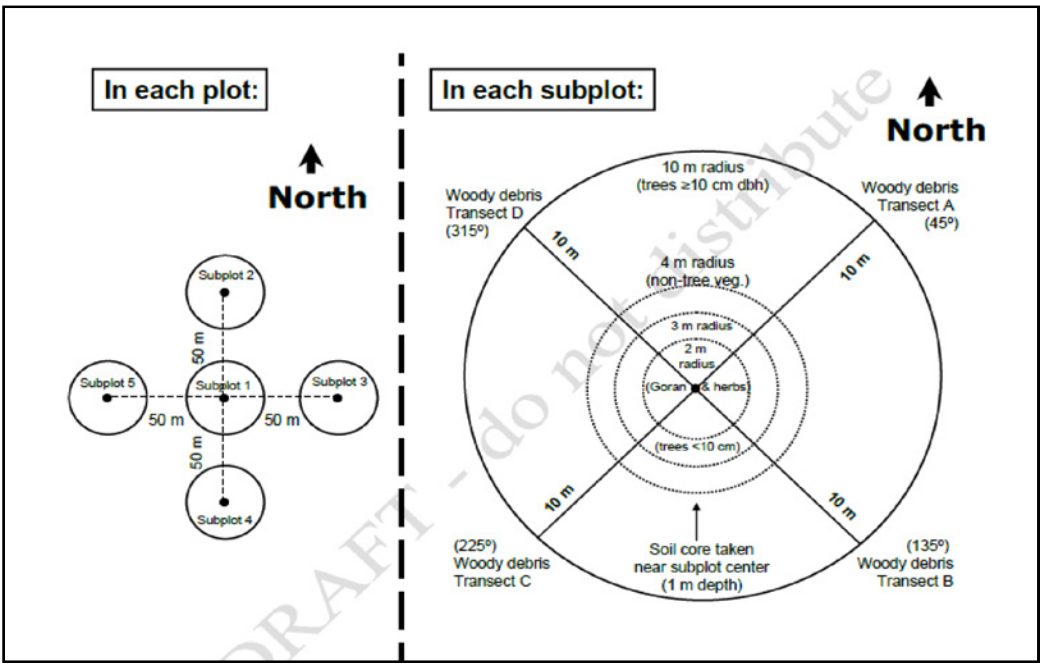


Figure 2: Layout of individual plot (showing what to measure)

Data Analysis & Result

Aboveground and root C pools were computed using both locally derived allometries (via destructive harvests of various shrub species outside the plots) and international standard common mangrove tree allometries combined with local tables of wood density by tree species. Soil C storage was calculated as the product of soil C concentration (% of dry mass determined by wet oxidation techniques by BFRI), soil bulk density, and soil depth range. All plot-level computations were corrected for the portion of the plot falling on a canal >30 m width, so as not to bias the land-based C density estimates with areas that are officially considered water. The bulk density was estimated (by dividing the mass of the oven-dry soil sample by the volume of the sample) at the office whereas %OC carbon was estimated by the BFRI based on wet oxidation method. The following formula was employed for calculating soil carbon per ha:

Soil C (Mg/ha) = bulk density (g/m3) x soil depth interval (m) x %OC x 0.01

Carbon Density

Mean C density (including soil) is found 256.7 Mg/ha (95%CI: ±17 Mg/ha). Total SRF C was found 105.06 mega ton. Estimated current carbon pools are shown in

Carbon pool	**Carbon Density** Mega gram/ hectare	**Percentage**
Trees aboveground (stems + foliage)	82.4	32.08
Trees belowground (roots)	35.9	14.07
Saplings + seedlings aboveground	1.4	0.55
Saplings + seedlings belowground	1.0	0.39
Non tree vegetation	2.8	1.10
Goran	7.9	3.10
Down wood	4.3	1.68
Soil 0-100 cm	121	47.0
Total	**256.7**	**100.00**

Table 1: Mean carbon pools in the Sundarbans Reserve Forest, 2009-10 inventory.

Table 1. Mean total C density (excluding soil) was 136 Mg/ha (95%CI: ±16 Mg/ha), or moderate to high compared to other mangroves around the world. C density of non-soil pools ranged from a low of 20 Mg/ha in one Gewa- dominated stand to a high of 446 Mg/ha in one Sundri-dominated

stand. Trees constituted the bulk of the C density across the forest reserve, with a mean of 82 Mg/ha aboveground and 36 Mg/ha belowground, which combines to account for 87% of all non-soil C. Soil C density ranged from a low of 53 Mg/ha to a high of 438 Mg/ha. Both of them belong to Sundri-dominated stand. Soil C contributes 47% and the rest 53% coming from non-soil pools of Sundarbans.

Uncertainty estimates (95% confidence intervals or 95% CIs) were computed using standard techniques outlined in the protocol. The 95% CI for the total C density was derived through basic error propagation (square root of the summed squares of component pools), as outlined in the protocol. Note that, because certain pools were highly correlated, we aggregated those pools in an ecologically sensible way for error propagation (e.g., tree aboveground and below ground pools were obviously correlated and were combined into a single 'tree' pool for the uncertainty propagation step).

Although the plot sampling was not strictly stratified a priori, the grid-based sample covered all major land types and allowed post hoc analysis of different strata (e.g., vegetation types, management units). With respect to vegetation type, plots classified as Sundri-dominated forest contained by far the highest C density at 169 Mg/ha, followed by Gewa-dominated classifications which contained 102 Mg/ha . Low-stature Goran-dominated vegetation contained the lowest C density at 64 Mg/ha.

Carbon stock of SRF

Total C stock and CO_2 equivalents across the Sundarbans Reserve Forest are given below:

Table 2: Carbon stock and CO_2 equivalents of SRF

Mean Total C Density (Mega gram/ha)	SRF land area (ha)	Total SRF C stock (Mega ton)	CO_2 Equivalents (Mega ton)	95% Cl of Total C stock (Mega ton)	95% Cl for CO_2 Equivalents (Mega ton)
256.7 (± 17)	411693	105.70	387.90	99-112	362-413

Notes: *- 1 Mega tone = 10^6 Mg.*

- Land area is from RIMS, FD GIS data.

- 95% confidence limits for total C stock and CO_2 equivalents are simple propagation of lower and upper confidence limits of C density multiplied by the land area. No uncertainty estimate was available for land area, precluding full error propagation incorporating uncertainties in both parameters.

Assessing Carbon Stock Change 1997-2010

The current inventory re-sampled a subset of a previous field inventory, which was conducted in 1997. This allows a direct comparison between C stocks at the different time points, and an assessment of associated C emissions or uptake during the interim.

All effort was made to conduct the change assessment using consistent methodologies. Computations of C density and C stocks in the 1997 inventory followed the same procedures as that for the 2010 inventory. For consistency, only the 155 plots in common between both surveys were included in the change assessment (rather than using all 1200 from the 1997 inventory). It should be noted that the re-sampled plots were in the same locations in both inventories, but some spatial error likely existed.

Certain differences existed in the 1997 dataset, requiring some adjustment of method and limiting what could actually be compared between time points. Mainly, the 1997 inventory was largely a timber resource inventory rather than a carbon inventory, so effectively only trees were measured. Non-tree pools were largely ignored in the previous survey. Golpata *(Nypa Fruticans)* was measured in some plots in 1997, but the sample size was insufficient to include in the change assessment. Therefore, only tree pools (aboveground and belowground) could be tracked over time. Trees are the most ready indicator of forest change and degradation, so this change assessment should still yield quite valuable insight.

For the five inventory plots that were surveyed in 1997 but were under water in 2010 due to land subsidence, erosion, channel migration, or cyclone damage, we included these in the change assessment. The loss of standing C stock in these sites (reduction to zero tree biomass) was factored into the estimate of change. Note that, because these five plots were included, this necessarily used an adjusted estimate of mean C density for the 2010 dataset compared to the estimate presented above, which excluded areas now under large canals. This difference was relatively minor.

Table 3: Comparison of mean C pools in SRF between the 1996-97 and 2009-10 inventories:

C Pool	1997 inventory		2010 inventory		Change(2010 minus 1997)	
	C density (Mega gram/ ha)	95% CI	C density (Mega gram/ha)	95% CI	C density (Mega gram/ ha)	95% CI
Trees Above ground (Stem+ foliage)	46	± 4.3	80	±11	+34	±12
Trees below ground (Roots)	27.4	±2.3	35	±4.2	+7.6	± 4.6
Sapling+ Seedling (Above ground)	1.6	± 0.2	1.3	± 0.1	- 0.3	± 0.2
Sapling + Seedling (Below ground)	1.0	±0.1	1.0	± 0.1	0	± 0.1
Tota(Trees, Sap-Seedling Only)	76	± 6.6	117	± 15	+ 41	± 17

Note: Only tree and sapling/seedling pools could be compared because these were the only pools measured in the 1997 inventory.
(+) and (-) in change column indicate increases or decreases, respectively, during the 1997 to 2010 time period. Estimates for 2010 pools are slightly adjusted from previous section because this analysis included plots that were land in 1997 but now submerged in 2010 (land subsidence, etc.). These were excluded from the land-based C density estimate for the current C stock analysis, but were included as negatively changing plots in the change assessment. The difference is minor. It is clear from table 3 that in 2010 C density has been increased nearly 54% than that of 1997.

Comparing the two time points, the 2010 tree C pools were significantly higher than those from the same plots in 1997, suggesting an increase in C storage over this time period . The estimated total increase, accounting for trees only, was 41 Mg/ha (95%CI: ±17 Mg/ha). The majority of plots, 68%, showed an increase in C density between the time points, while 32% showed a decrease. The distribution of changes was positively skewed, with the median change being +17 Mg/ha, but the mean change being +41 Mg/ha due to several plots that apparently showed very large increases.

Converting this difference to changes in C stocks (multiplying the mean per-hectare change by the entire land area of SRF) indicates an increase of 16.9 Mt of C storage over this time period (95% CI: 10.0 – 23.7 Mt). The confidence interval is strongly different from zero and suggests the change is significant. Over the 13-year time interval, this change in C stocks suggests an average annual sequestration rate of 1.3 Mt C per year (95% CI: 0.8 – 1.8 Mt C per year).

In CO2 equivalents, the estimated change in stocks was 62.0 Mt CO2 (95% CI: 36.7 – 87.0 Mt C). The estimated annual sequestration rate over the 13-year period was 4.8 Mt CO2 per year (95% CI: 2.9 – 6.6 Mt CO2 per year), or ~10% of Bangladesh's annual fossil fuel CO2 emissions.

Table-4: Estimated change in total Carbon stock and CO2 equivalents, 1997-2010.

Δ in Carbon Stock For Whole SRF (Million tons)	Δ in CO_2 Equivalents (Million tons)	Annual Sequestration Rate (Million tons/ year)
16.9	62	4.4

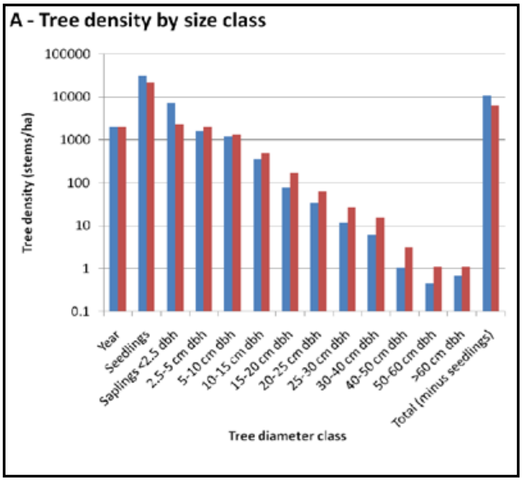
Comparison by size and basal area classes

Table-5: Tree density by size class (No. of stem per hectare)

Year	Seedling	Sapling <2.5cm	Pole 2.5-5.0 cm	Tree 5-10 cm	Tree 10-15 cm	Tree 15-20 cm	Tree 20-25 cm	Tree 25-30 Cm	Tree 30-40 cm	Tree 40-50 cm	Tree 50-60 cm	Tree >60 cm
1997	31256	7306	1617	1189	348.8	77.3	34	11.4	6.1	1.1	0.4	0.7
2010	21599	2227	2008	1286	482.4	167.9	63.0	26.6	15.2	3.1	1.1	1.1

Table-6: Basal Area by size class (Square meter per hectare)

Year	Sapling <2.5cm	Pole 2.5-5.0 cm	Tree 5-10 cm	Tree 10-15 cm	Tree 15-20 cm	Tree 20-25 cm	Tree 25-30 Cm	Tree 30-40 cm	Tree 40-50 cm	Tree 50-60 cm	Tree >60cm	Total
1997	0.8	2.5	4.8	3.8	1.8	1.3	0.7	0.5	0.2	0.1	0.4	15.9
2010	0.5	2.0	5.1	5.5	3.8	2.4	1.5	1.4	0.5	0.2	0.7	23.5



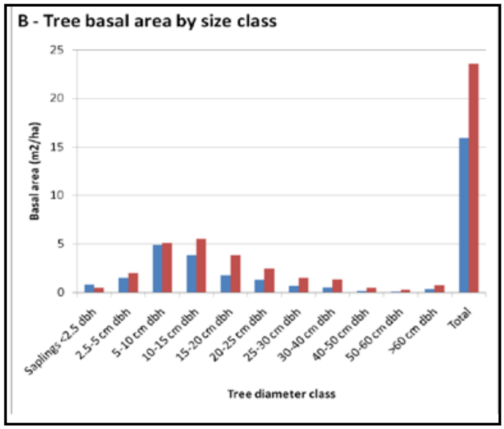
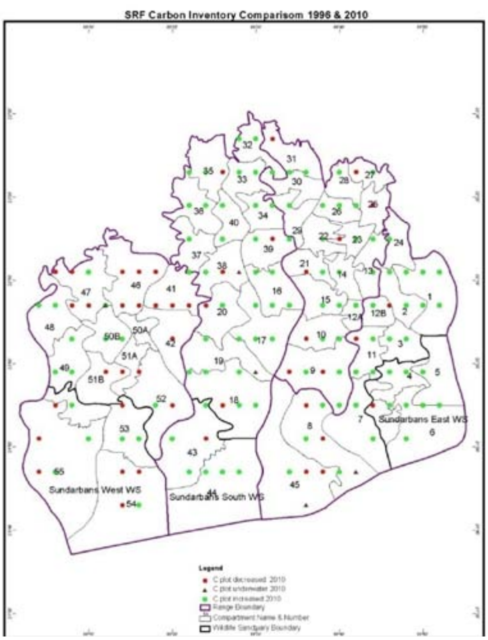


Figure 3 & 4: Comparison of 1997 & 2010 by diameter class and basal area/ha. Table-5, & 6 and figure-3&4 clearly show that number of trees per ha, basal area per ha have increased during last 13 years but number of seedling and saplings decreased.

Discussion & Conclusion

Reasons for change and change pattern

Figure-5: Carbon inventory plot change map 2010-1997.



Tree felling has been banned in the Sundarbans since 1990, only selection felling of Non Timber products (Nypa palm and Ceriops stem) was allowed outside protected areas. But after super cyclone "Sidr" in November 2002, there exist a moratorium on extraction of Non Timber Products. Though there are illegal felling throughout this mangrove but it was never been alarming. So, there was an expectation of positive change.

Out of measured 155 plots, increase of carbon found in 68% plots and 32% showed decrease. Satkhira range showed most negative among the administrative four ranges. Out of 41 plots of this range 24 found negative changes. 1390 square kilometer of Sundarbans are Protected area. All types of felling are prohibited in these areas, even then 07 plots (total plots 13) of Sundarbans west wildlife sanctuary showed negative change. But the overall change quantified here was strongly positive, with confidence intervals significantly different from zero. A significant portion of this difference could be an artifact of sampling error. Some of the changes in C density within particular plots were extremely high (e.g., >200 Mg/ha change in 13 years) and likely unrealistic in biological terms. Errors in re-locating exact plot locations could also play a role. In addition, metadata and protocol descriptions for the 1997 inventory were lacking, meaning that the data had to be interpreted through the inventory report results only. Moreover, dead trees were not measured in that survey and adding those would have increased the 1997 C stocks and reduced the amount of positive change between surveys. The quality of the 2010 field data collection and data management was documented for the current inventory, but documentation of QA/QC for the 1997 inventory was not available. The degree to which any or all of these errors may have affected the change estimate is almost impossible to know with certainty.

The general pattern of observed change is ecologically sensible. In the absence of commercial harvesting, a typical stand development pattern is that tree densities thin out over time (through competitive exclusion and other mortality), with the remaining trees increasing in size. Indeed, compared to the 1997 data, the 2010 inventory showed lower stem densities, especially of small trees, but larger mean stem size and total basal area . The magnitude of this difference was large for a 13-year period, but the general pattern is fairly reasonable. Whether due to actual successional dynamics, sampling error, or some combination of the two, this difference is largely what explains the higher C stocks in 2010.

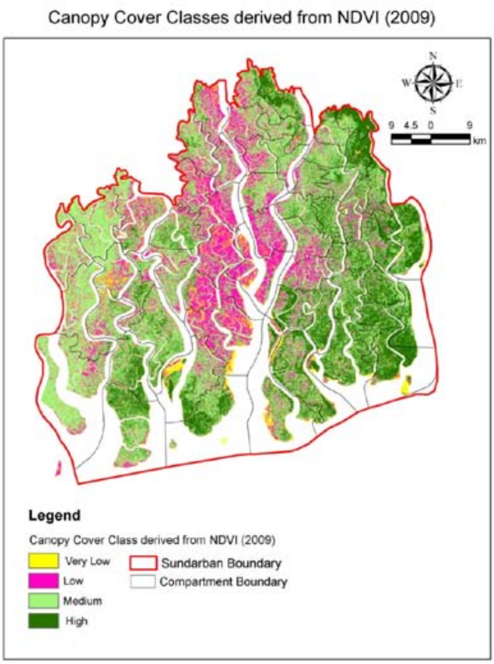


Figure-6 : NDVI Class of 2009 Landsat image

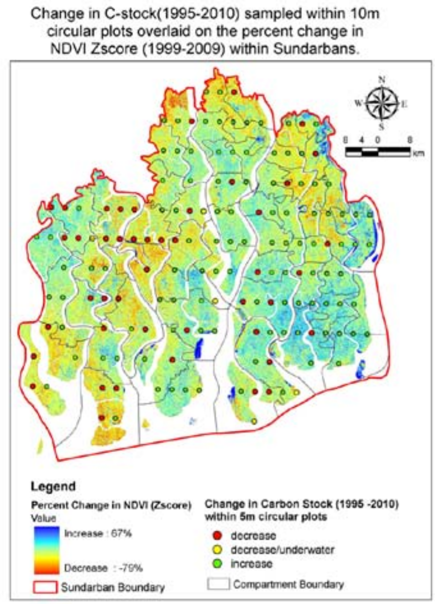


Figure-7 : C Stock change plots overlaid on change in NDVI Z - score.

Two Landsat images of year 1999 and 2009 were taken to find changes within this period. High , medium, low and very low; four classes were derived from NDVI. Z-score analysis (outlier change detection method) , more recent (2008) and best known to capture subtle changes in wetlands (Neilson et al., 2008) used detect changes. Analysis done for each pixel, based on how different each pixel from class median.

Carbon stock change in between 1997 to 2010 map was overlaid on the percentage in NDVI Z-score (1999-2009). Yellow to red colour in figure-7 represents decrease in NDVI Z score, cyan to blue represents increase and green to nearly green represents unchanged. Figure-7 shows that most of decreased sample plots are situated in NDVI Z-score decreased regions and vice versa. Thus remote sensing analysis also support the result of this change found in field inventory.

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Diversity of macroinvertebrates in Toebrongchu stream – a tributary of Punatsangchu

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ABSTRACT

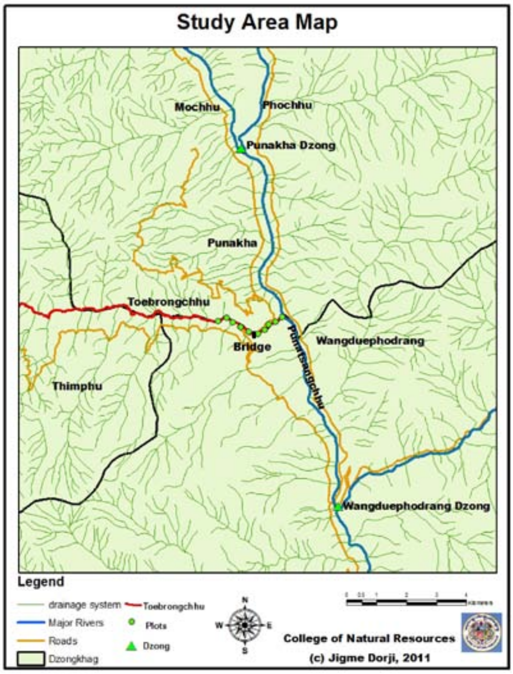
There are no evidences to prove that macroinvertebrates in Bhutan's river systems are studied. Hence, it is important that such studies are initiated. Further, it is more important to study the ecology of tributaries of the Punatsangchu owing to the impending impact the upcoming mega hydro power dam is expected to bring on the river ecology. Therefore, this study evaluates the diversity of macroinvertebrates, the bioindicators of river systems of a single tributary of the main river replicable for other tributaries. Using time bound kick sampling method, macroinvertebrates were collected from at least ten sample plots along the Toebrongchu stream. The results showed at least 20 different species of benthos belonging to 13 orders which included species tolerant as well as sensitive to pollution. Chemical analysis confirmed the stream fit for consumption with slight or no treatment. The comparative analysis between the plots (five each) above and below the Toebrongchu Bridge indicated the lower reaches to be slightly polluted, proving that fact that the rivers get polluted when they enter the settlements. This study warrants further detail studies in future to compare the pre dam and post dam scenario as species composition is expected to change due to the damming of the main river.

Key words: *bioindicators, diversity, macroinvertebrates, Toebrongchu*

INTRODUCTION

Being a less popular subject, the number of species found on the earth surface has not been affirmed. But being the "middlemen" in the aquatic food chain, the taxon is considered important by the ecologists, worldwide. Fishes feed on them and they live on algae and bacteria, the members of the lower level of the food chain. Some of them also are known to feed on leaves, shreds and other organic matter that gets in the water (Balogun, Ladigbolu & Ariyo, 2011). Thus, macroinvertebrates have a critical role in the natural flow of energy and nutrients. When they die, they get decomposed, leaving behind nutrients that can be reused by others (aquatic plants and organisms) in the food chain. Environmentalists use them as a source of information to confirm water pollution because unlike fish they cannot move around and are not capable of escaping the other pollution agents like sediments, chemical deposits, etc. (Uyanik, Yilmaz, Yesilnacar, Aslan & Demir, 2005; Bhat & Pandit, 2010; Kalyoncu & Zeybek, 2011; Kantzaris, Iliopoulou–Georgudaki, Katharios & Kaspiris, 2002). Further, they have long life cycles; they give data about quality of streams over a long period allowing proper assessment of environmental quality decline (Hewitt, 1991). Also, being extremely diverse, lots of species possesse a broad range of reactions to stressing agents like organic pollutants, sediments and other chemical toxicants, making them handy source of information (Jackson & Fureder, 2006).

Thus, it is important to understand what sort of benthos our river systems have in Bhutan. Therefore, this study aims to document the macroinvertebrate diversity of Toebrongchu, a tributary (see map of the study area) of the main Punatsangchu River which will be dammed downstream that could bring certain changes in the composition of the macroinvertebrates. The study is relevant because of the fact that the pollution level would bring changes in the composition of benthos. Further, assessment of water quality is easier and less costly that the laboratory analysis (Iliopoulou-Georgudaki, Kantzaris, Katharios, Kaspiris, Georgiadis & Montesantou, 2003; Sekiranda, Okot-Okumu, Bugenyi, Ndawula & Gandhi, 2004).



Map of the Study Area 1

LITERATURE REVIEW

Literatures concerning the aquatic macroinvertebrates in Bhutan do not seem to exist. Therefore, review in our perspective makes very little sense unless others are used. Macroinvertebrates according to Rosenberg and Resh (1993), are those organisms are retained by mesh sizes of ~ 200–500 mm. Different kinds of macro invertebrates occupy different spaces based on the natural variables of rivers, such as depth, width, type of substrate, water speed and physico-chemical variables, which are altered by both natural and human activities (Kantzaris *et al*., 2002). So, they are one of the best sources of water quality information. Water analysis parameters such as pH and dissolved oxygen alone may not be good to ascertain stream pollution as they provide data only for the time of sampling. Water would keep flowing with different chemical contents in it depending on the types of organic and inorganic materials it receives on the flow way. Even the availability of fish in the stream cannot give idea about water pollution since fishes can move away to prevent polluted water and then reappear when conditions improve (Hawkes, 1997). The case of most aquatic macro invertebrates is different in that they cannot move away to avoid pollution. Therefore, a macro invertebrate sample may be able to give information about even the pollution that was not present at the time of sample collection.

The aim of this study is to investigate number of macroinvertebrates species vis-à-vis the ecological status of Toebrongchu stream using macro-invertebrates by looking at the quality of water through laboratory analysis of physico-chemical contents and macroinvertebrates presence. The greater the numbers of macro invertebrate species with less tolerance to pollution better the quality of water. Further, the study using MS Excel takes a look at species composition and diversity in the stream and tries to compare the ecological characteristics below and above the bridge.

MATERIALS AND METHODS

To collect the macro invertebrates, a five-minute kick-and-sweep sampling method was used. A mosquito net of 2m by 2m length was placed across the water course of choice in the stream with the lower ends of the net held by stones placed over its edges while the upper end was held by the surveyors. An area of 1m x 1m in front of the net was disturbed by manually turning and moving the stones in the stream scrubbing them with hands for 5 minutes. The net than was lifted from the water and taken to the bank where all the insects caught in the net were counted, photographed, identified and released back into the river after retaining a voucher specimens each of insects collected (Plate 1). The euthanized insects were preserved in 70% ethyl alcohol for reference and further analysis. For physico-chemical analysis in the laboratory, water samples were collected from all the sampling sites in a standard water bottle of 1 litre each for testing pH, total dissolved solids, electrical conductivity, sediment load, acidity, etc. in the laboratory. Other physical information collected from stream included temperature, pH and coordinates and altitudes of all sampling plots.

Plate 1. Collecting the macroinvertebrates

RESULTS AND DISCUSSIONS

Diversity analysis revealed 20 species of macroinvertebrates including an unknown bug belonging to 13 orders (Table 1), with coleopterons dominating the Toebrongchu stream with a maximum of 5 species followed by Dipterons with 3 species.

Table 1: Diversity and total individuals

Order	Diversity	Total individuals
Diptera	3	48
Coleoptera	5	72
Trichoptera	1	705
Plecoptera	1	112
Ephemeroptera	1	80
Annelida	1	4
Odonata	2	8
Gastropoda	1	1
Megaloptera	1	4
Himiptera	1	2
Catenulida	1	1
Araneae	1	1
Unknown bug	1	1
Total	**20**	**1039**

Planaria, damselfly larva, and an

unknown bug were found on the plots below the Toebrongchu Bridge while water scavenger larva, midge fly larva, riffle beetle, lung breathing snail and predaceous diving beetle were found only on the plots above the bridge. Rests of the species were found in both the stretches in different numbers which could be used to find the quality of Toebrongchu stream (Annexure I).

We looked at the Shannon Weiner Diversity Index of the plots on the stream and found that evenness (E) and diversity (H) better in the stretch above the bridge (Fig. 1) which could be due to the better quality of water.

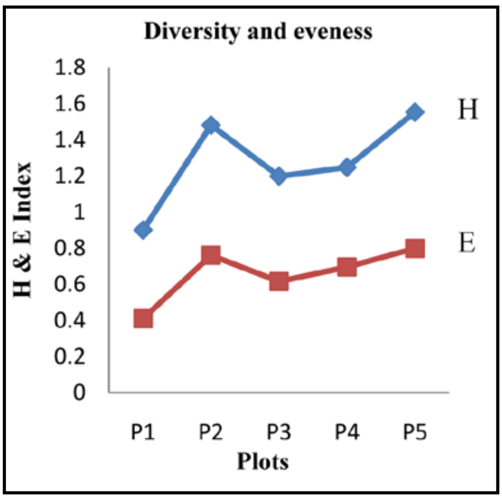


Figure 1. H & E index above the bridge

Poor diversity index and evenness (Fig. 2) below the bridge could be attributed to the anthropogenic pressure on the stream which is subjected to excessive use for cattle feeding and irrigation.

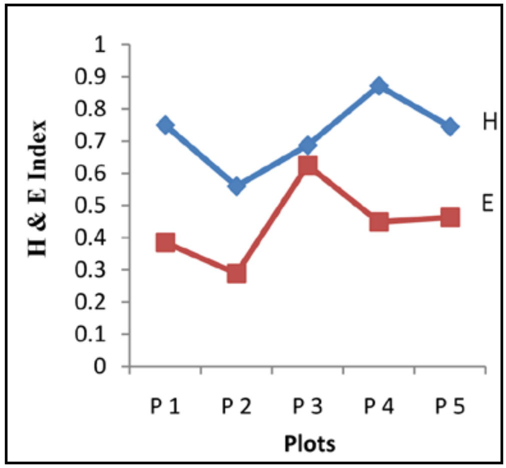


Figure 2. H & E index below the bridge

Two look at the quality of water, we calculated water quality index using the method proposed by National Environment Commission (NEC) of Bhutan according to which the category of water between 2.1 to 2.5 is fit for drinking with sanitary precautions. The upper stretch had value of 2.13 while the lower stretch has 2.09. Further laboratory analysis of the water quality based on the averages of reading of all the sample plots revealed the water to be quite good quality (Table 2) against the assumption that the stream might be polluted.

Table 2. Laboratory analysis report

Water quality parameters	*Values*
pH	7.5
Temp (°C)	17.8
TDS (ppm)	29
EC (μ^S)	60
Hardness	10

A step-ahead analysis conducted to compare the water quality between the two stretches revealed that the stretch above the bridge to be better in quality proving the assumption the water downstream that flow towards settlements get polluted (Fig. 3). While pH, temperature and hardness have no significant difference, the TDS and conductivity increases in the stretch below the bridge indicating the stream stretch to be polluted. More minerals mean more conductivity which means more pollution. Similarly, higher value of TDS means high pollution.

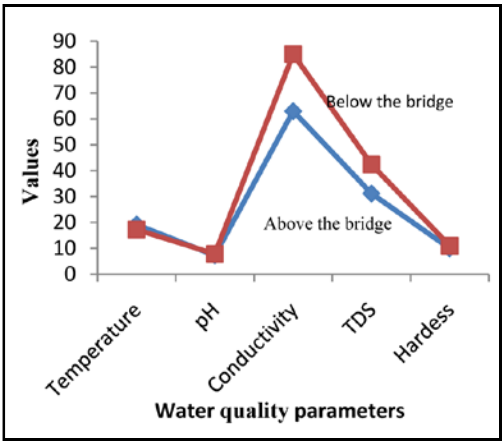


Figure 3. Water quality comparison of two stretches

Therefore, it is concluded that the stretch below the bridge is slightly polluted compared to the upper stretch as pH, conductivity, TDS are comparatively higher in the stretch.

SPECIES ACCOUNTS

AQUATIC WORM (Photo: Authors, Plate 2)


Plate 2. Aquatic Worm

Class: *Oligochaeta*

Maximum size: Up to 30mm

Description: Looks like ordinary earthworms but are thinner and smaller.

Habitat: Found in soft sediment, rich in organic matter. Found in plot below the bridge.


Plate 3. Caddis Fly Larva

CADDIS FLY LARVA (Photo: Authors, Plate 3)

Order: Trichoptera

Family: Brachycentridae

Maximum size: Up to 25mm

Description: Caddis fly larvae look like caterpillars and often build portable cases from fine sand grains, small sticks, leaves, silk and algae. They can also be case-less.

Habitat: Found among rocks, plants, wood and leaf litter, in a variety of flow conditions.

DAMSEL FLY LARVA (Photo: Authors, Plate 4)

Order: Odonata

They are narrow and elongated with three gill structures extending from the tail. Found on plants, among rocks and leaf litter or burrowing into the sediments of the stream bed, in a variety of flow conditions. Common species.


Plate 4. Damsel Fly Larva

Plate 5. Dragon Fly Larva

DRAGON FLY LARVA (Photo: Authors, Plate 5)

Order: Odonata

Maximum size: Up to 50mm, have extendable mouth parts.
Dragonfly nymphs have a stocky build.
Common species.

DOBSON FLY LARVA (Photo: Authors, Plate 6)

Plate 6. Dobson Fly Larva

Order: Megaloptera

Family: Corydalidae

Maximum size: Up to 30mm

Description: Dobsonfly larvae are robust animals with a hard-shelled head. Their bodies are fleshy with long extensions on either side.

Habitat: Found among rocks, in a variety of flow conditions.

Plate 7. Horse Fly Larva

HORSE FLY LARVA (Photo: Authors, Plate 7)

Order: Diptera

Family: Tabanidae

Description: 10 – 19mm segmented

Habitat: Eggs are laid on vegetation. When the larvae hatch they drop into water or mud. After a month they move back to vegetation to pupate.

MAY FLY LARVA (Photo: Authors, Plate 8)


Plate 8. May Fly Larva

Order: Ephemeroptera

Family: Oligoneuniidae

Maximum size: Up to 25mm.

Description: Mayfly nymphs have short antennae and three long thin tails. They usually have gills along the sides of their bodies.

Habitat: Found on or under rocks or among plants and leaf litter, in a variety of flow conditions.


Plate 9. Planaria (Flatworm)

PLANARIA (Flatworm) (Photo: Authors, Plate 9) **Class:** Turbellaria

Maximum size: Up to 20mm

Description: Flatworms are flat, thin, slow-moving worms with two simple eye spots.

Habitat: Found gliding over rocks, wood and other parts of the stream bed, in a variety of flow conditions.


Plate 10. Riffle Beetle Larva

RIFFLE BEETLE LARVA (Photo: Authors, Plate 10)

Order: Coleoptera

Family: Elmidae

Maximum size: Riffle beetle larvae are elongate, up to 16 mm long.

Description: Riffle beetle larvae are elongate, up to 16 mm long (most less than

8), with the head and all 3 pairs of legs visible from above.

Habitat: Freshwater streams.

STONE FLY LARVA (Photo: Authors, Plate 11)

Plate 11. Stone Fly Larva

Order: Plecoptera

Family: Perlidae

Maximum size: Up to 60mm

Description: Stonefly nymphs have long antennae and two thin tails. They often have gills extending from their rear ends between the tails.

Habitat: Found among rocks or plants, in fast-moving waters.

Plate 12. Water Penny

WATER PENNY (Photo: Authors, Plate 12)

Order: Coleoptera

Family: Psephenidae

Maximum size: Up to 35mm

Description: Adult aquatic beetles look similar to terrestrial beetles, with a hard-shelled body and a streamlined shape. Aquatic beetle larvae look very different from adults and can vary widely in appearance. Larvae are usually elongated with well-developed legs. Larvae resemble circular encrustations on rocks; sucker-like; colored green, black, but usually tan or brown; length usually no more than 1/2 inch.

Habitat: Found swimming in water at all levels, including the surface, or living on the stream bed, in a variety of flow conditions.

WHIRLIGIG BEETLE (Photo: http://www.en.wikipedia.org, Plate 13)

Plate 13. Whirligig Beetle

Order: Coleoptera

Family: Gyrinidae

Description: Whirligig beetles are black, or nearly black, and 1/8 to 1-3/8 inches (3 to 35 mm) long.

Habitat: Lakes, ponds and streams throughout tropical and temperate regions worldwide.

WATER SCORPION (http://www.cleanwater.uwex.edu, Plate 14)

Plate 14. Water Scorpion

Order: Hemiptera

Family: Nepidae

Description: Water scorpions are dark brown or blackish-brown in color. They are about 1 – 2 inch in length. They have two pairs of wings and three pairs of legs.

Habitat: Water scorpions are known to live among the stems of aquatic weeds and in the mud of ponds, streams and rivers. Sometimes, they are found under the rocks in a flowing stream. Water scorpions, like most of the other insects, are air breathers.

WATER SCAVENGER BEETLE (Photo: scientificillustrator.com, Plate 15)

Plate 15. Water Scavenger Beetle

Order: Coleoptera

Family: Hydrophilidae

Description: Water Scavenger beetles are generally tiny, small, less than 15 mm and most of the time only a few mm long.

Habitat: Fresh water bodies

Plate 16. Marsh Treader

MARSH TREADER (Photo: http://www.islandwood.org, Plate 16)

Order: Hemiptera

Family: Hydrometridae

Description: Also called water measurer they are slim, fragile-looking insects with long threadlike legs and antennae; their body length reaching about 2/5 inch. Usually, the head is longer in relation to the body, with the eyes a little behind the midpoint. Although some adults have wings and are capable of flight, most are wingless. The general body colour is light brown, rendering these insects inconspicuous in their usual habitat.

Habitat: They occur on floating vegetation such as mats of decaying reeds or cattail stems, filamentous algae, or duckweed, or on leaves of water lilies in marshes, ponds, or lakes. They also occur along the margins of ponds or slow-moving streams.

MIDGE LARVA (Photo: http://www.swittersb.wordpress.com, Plate 17)

Plate 17. Midge Larva

Order: Diptera

Family: Chironomidae

Description: Midge larvae are segmented and get to about 1-inch long. They have no legs or other external appendages, so they twist and wiggle to move around.

Habitat: Midge larvae share their habitat with fairy shrimp, clam (mollusc) shrimp, tadpole shrimp, and other tiny creatures.

Plate 18. Lung-breathing Snail

LUNG-BREATHING SNAIL (Photo: http://www.indianetzone.com, Plate 18)

Order: Gastropoda

Family: Lymnaeidae

Description: Unlike the others they have no operculum or hard cover over the opening to its body cavity and they are either “right-handed” or “left-handed,” and the pouch snails are “left-handed.

Habitat: Found in streams those are fairly clean and are often found creeping along on all types of submerged surfaces in waters from 10 cm to 2 m deep.

PREDACEOUS DIVING BEETLE (Photo: http://www.freelearners.wordpress.com, Plate 19)


Plate 19. Predaceous Diving Beetle

Order: Coleoptera

Family: Dytiscidae

Description: Predaceous diving beetles range in size from 1/16 inch to almost 2 inches long. Many of them are black or brown with markings in some.

Habitat: Freshwater streams


Plate 20. Water Snipe Fly Larva

WATER SNIPE FLY LARVA (Photo: http://www.Atherixlanthampbase.com, plate 20)

Order: Diptera

Family: Athericidae

Description: Up to 2 inches long. Body soft and fleshy, tapered at the head end and has two feathery-like horns at the back end of the body. Have many pairs of caterpillar-like legs on the underside. Tiny soft pairs of fleshy filaments extend from the top and sides of the body. It's pale to green in colour.

Habitat: Snipe flies only inhabit the bottoms of very clean flowing stream ecosystem.

WATER SPIDER (Photo: http://www.flickr.com, Plate 21)

Plate 21. Water Spider

Order: Araneae

Family: Cybaeidae

Description: Water spiders require waters with high oxygen levels lacking pollution. Structurally same with the mainland spiders.

Habitat: These spiders can be found in ponds near the Palaearctic region, this includes Europe, northern Asia and Africa

AN UNIDENTIFIED BUG (Photo: Authors, Plate 22)

Plate 22. An unidentified bug

This bug was trapped in plot number 4 (below the bridge). But for lack of reference and other means the macroinvertebrates could not be identified. We however do not rule out its possibility of being new to science.

CONCLUSION

The assessment of the biodiversity of Toebrongchu stream revealed 20 species of macroinvertebrates which is significant due to the fact that these species for the first time in Bhutan would now go on record. The pH of the water samples averaged 7.5 indicating that the water to be fit for use. Acidity, TDS, electricity conductivity tests and sediment load analysis all favoured Toebrongchu's cleanliness and its capacity to hold diverse species of benthos.

The comparison of the number of species availability and physical water quality between the two stretches (below and above the bridge) showed better species diversity and water quality above the bridge confirming that fact that the water is better towards the source. Species diversity seem to increase in two kinds of the stream condition as more species were found in fresh sample plots and plots where more nutrient seem to be present due to added organic matters by the people (waste dump sites).

To sum up the results, both the physico-chemical water quality and biological data suggested that better water quality support better diversity of benthic organisms. Thus, the outcome of the study confirmed the hypothesis that the benthos can be used to assess the quality of water body while physico-chemical analysis of water can also be used to predict what kind of benthos can survive in what sort of water.

The study found Toebrongchu stream the lifeline of residents of Toebesa Gewog and Sopsokha village to be very clean with diverse benthic organisms. However, some kind of protection may be required below the bridge as the river has become physically dirty due to anthropogenic pressure. It's to be seen if the species composition changes post Punatsangchu Dam constructions.

ACKNOWLEDGEMENT

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Effectiveness of Integrated Conservation and Development Program (ICDP) Approach in Conserving Wildlife Populationin Himalayan Protecte Areas: A Case Study of Annapurna Conservation Area in Nepal

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Abstract

The country of Nepal has established many protected areas with the primary aim of conserving biodiversity. The protected area system of Nepal has gone through various stages of trial and learning. Various problems relating to management of protected areas have emerged during such trials and processes. In the course of this process, the Integrated Conservation and Development Program (ICDP) approach in protected area management has emerged as an important tool to link conservation and development with aim of resolving various problems associated with protected area management regime in the country. We investigated the success of the ICDP approach from perspective of wildlife conservation. The perceived success of ICDP approach in conserving wildlife in protected area management system was examined in the Annapurna Conservation Area (ACA), Nepal. An extensive field study was carried out in the selected Village Development Committees (VDCs) in ACA. We employed a social survey method using tools such as Participatory Rural Appraisal (PRA), structured and semi-structured interviews and a questionnaire survey conducted in two VDCs; participatory tools such as matrices were also used to gain further insights into impact of the ICDP approach. We found a significant positive impact of ICDP approach in study sites compared to before its intervention. The study suggests that the Snow Leopard *(Uncia uncial),* Blue Sheep *(Psedois naur)* and Musk Deer *(Moschus moischiferous)* population has been increased from the ICDP approach. Based on these findings, we argue that the ICDP approach is reasonably assisting in conserving wildlife population in ACA and it can also be stated that ICDP approach could be a better alternative to the conventional approach of protected area management system in Nepal.

Key words: *Wildlife conservation, Integrated Conservation and Development Program, Nepal.*

INTRODUCTION

Protected areas are cornerstones of biodiversity and species conservation (Buddhathoki, 2003). Protected areas such as national park, wildlife sanctuaries and game reserve, conservation areas are considered as the foundations to conserve biodiversity in Nepal. National Parks represent the outcomes of the prime ideology where people are functionally and theoretically excluded from conservation policies. This pro-conservation without considering people strategy from west has been replicated by the Government of Nepal since 1972. There is a growing body of evidence that National Park designation is not an effective method of promoting bio-diversity conservation (Pretty and Pimbert, 1997). Protected area management regime in Nepal has experienced various paradigm changes in biodiversity conservation realm. During 1970's, the thrust was mainly focused to create national parks and wildlife reserves with command and control approach, the late1980's decade was focused on the creation of conservation areas and ecotourism as a mean of conservation and the present approach since late 1990's has been focused on linking conservation and development with the aim of resolving park-people conflict and integrating g economical, social and environmental aspects (Heinen and Yonzon, 1994). The emergence of Integrated Conservation and Development Program (ICDP) approach in Nepal follows the global biodiversity conservation scenario. The recognition of the limitations of National parks and wildlife reserves within Nepal led to alternative approaches like ICDP, the first ICDP approach in protected area management system in Nepal, and the emergence of the Annapurna Conservation Area Project (ACAP), launched in 1986 (Parker, 2004).

By the late 1990s, most plans or proposals for protected area management in Nepal devoted significant consideration to relation with local people, as ICDPs have been summoned as a radical new approach for the management of protected areas. But now, more than one and half decades after the ICDP approach was vigorously promoted, there are still very few clearly successful cases in which local people's needs and aspirations have been reconciled with the protected area management domain. There is growing recognition of the risk that ICDPs may not contribute effectively either to conservation or to development (Katheleen, 2003)

This study examines the effectiveness of ICDP approach in addressing the conservation issues through examining the wildlife conservation aspects in ACA, however the effectiveness of ICDP approach in protected area management is very difficult to measure because the conservation issues have social, economic and ecological dimensions, although the particular mix varies according to circumstances (Mangel et al., 1996). It is also argued that measuring effectiveness, particularly in ICDPs, is value-laden. Local people value biodiversity for its aesthetic, cultural and spiritual values besides its utilitarian values, therefore different stakeholders may hold different values to biodiversity conservation through ICDP approach (Lawrence and Elphick, 2002). However, the effectiveness of ICDP approach can be assessed in terms of the objectives and goals of establishing the protected area, and is also one of the acknowledged parameters for measuring conservation of wildlife population worldwide (Brandon and wells, 1992).

Methodology

Study area

The study areas – Jomsom VDC (Village Development Committee) and Marpha VDC (Village Development Committee) – are located on the northern slopes of the Annapurna range in central Nepal (Figure 1). The study sites are located in the villages of Mustang district, one of the trans-Himalayan regions of Nepal in ACA representing the habitat of cold desert type of vegetation and wild animals. Jomsom VDC is situated at an altitude of 2710 meters, lies in the Trans-Himalayan zone and Marpha VDC is situated at an altitude of 2670 meters, situated in the inner Himalayan region of Annapurna and Dhaulagiri range. It is one of the famous villages on ACA due to its picturesque appearance and apple orchards.

Figure 1. Location of Jomsom VDC and Marpha VDC (circled) within the An napu rna Conservation Area (ACA)

Sampling Design

The study was conducted in the Annapurna Conservation Area (ACA), where ICDPs have been implemented for more than a decade now. Measuring effectiveness of ICDP is difficult because of lack of baseline information and in order to find out the impacts of ICDPs, assessment of the sites in terms of socio-economy and ecology was carried out with the help of different field based approaches. The resultant of different factors like socio-economy, biodiversity, infrastructural development, local people's capacity development, policy effectiveness, etc. provides an ideal situation to examine the variables and questions with which this study is concerned. Sampling was necessary to measure defined variables in order to represent the entire population. Sample size at +10% was set in each VDC to administer questionnaires and random sampling method was applied to proportionally represent all the stakeholders irrespective of their age and position in the community for the study. Table below depicts the design of sample size.

Table 1. *Design and Statistics of Sample*

Particulars	*Study Sites*		Total
	Jomsom VDC	Marpha VDC	
Number of Total Households	410	434	844
Number of Selected Households	52	52	104
% of Selected Households	12	11	12

Data Collection

The study used both primary and secondary source of data. Primary data was collected using a wide range of data collection techniques including questionnaire survey, focus group interview, formal and informal interviews as well as adopting a participatory rural appraisal (PRA) method. Secondary data was obtained from various published reports and websites including WWF, FAO and UNDP.

Primary Data

(a) *Questionnaire Survey*

The questionnaire survey was administered in the sampled VDCs in order to get qualitative and quantitative data for set objectives. A semi–structured questionnaire was prepared for this purpose.

(b) *Focus Group Interview*

A focus group discussion was organized to discuss ICDP approach and wildlife conservation aspects. 2 Chairpersons and 14 members from Marpha and Jomsom Conservation Area Management Committee (CAMC)[1] and 4 ACAP staffs were present in the discussion. The focus group discussion was directed towards the periphery of ICDP approach in wildlife conservation regime.

(c) *Formal Interviews*

Formal interviews were conducted with the persons, who were attached with ACAP directly and indirectly, with

1 Conservation Area Management Committee (CAMC) is the focal institution in conservation areas in Nepal. Conservation Area Management Regulations 1996 of Nepal has clearly outlined the functions and authorities of CAMC.

an intention to know their perspective. Altogether, 36 persons were formally interviewed during the study period.

(d) *In formal Interviews*

The need for some informal interviews was felt to cross check the validity and some more objective pictures on ACAP activities, and prevailing scenario of the selected areas. In all, 47 persons were interviewed during the study.

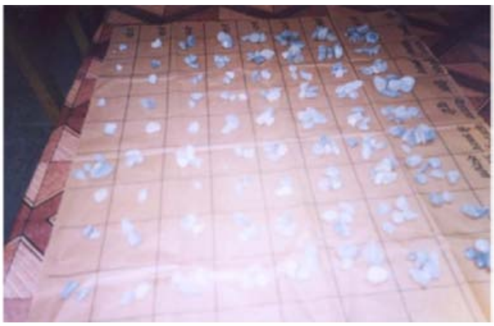

Plate 1: Locally available materials were used to facilitate participatory discussion.

The photo shows the use of smaller stones in a matrix scoring regarding perceived changes in wildlife population, hunting etc. Different locally available materials such as stones, grains were used to facilitate such tools. Information provided during PRA was cross-checked during interviews and questionnaire survey. Using wildlife photographs facilitated discussion regarding wildlife issues. For example, relevant photographs of wildlife species were used to discuss changes in wildlife population after ICDP approach intervention in the area.

Secondary Data

The secondary data and information for the study were gathered in Nepal, mostly during field work period from academic literatures, previous studies on ACA, studies on protected area management, and annual progress reports of ACAP, ACAP GIS studies, IUCN and reports of other related organizations (e.g., WWF, FAO, and UNDP). Internet research was conducted, whenever necessary.

(e) Participatory Rural Appraisal (PRA)

Participatory tools such as matrixes were used to obtain insights and discover change in wildlife populations.

Data Analysis

Analysis of data was divided in terms of quantitative and qualitative. Quantitative data were analyzed using Microsoft Excel application and simple arithmetic approaches. Qualitative information was generated mainly from PRA, focal group discussion and formal survey. The information generated from

PRA was validated during other surveys. The PRA information was analyzed and interpreted together with the participants. Elaboration of the information was immediately carried out. The quantitative data on some aspects were analyzed using Likert's Rating Scale. For this, first of all the data were coded. All the variables were coded in the same direction. The statements with agree and strongly agree were coded 4 and 5 respectively. Where as neutral, disagree and strongly disagree were coded 3, 2 and 1. Attitudes and perception data were examined using 5-point scale statements which respondents were asked to agree or disagree. To obtain an overall score for all respondents on some of the attitude scale, responses to each of the statements were added and average score was estimated.

Results

Changes in wildlife population, especially Snow Leopard, Musk Deer and Blue Sheep after ICDP intervention in the study areas were mainly analyzed through questionnaire survey, focus group interview, informal meeting and PRA. 81.38% of the total respondents knew that Snow Leopard, Blue Sheep and Musk Deer were found in their area, while 18.59 % did not know it. The survey reflected that the said wildlife in study area has increased. 89.23% of the respondents believed that Blue sheep population has increased, which is followed by 62.27% respondents, who believed that musk deer population hasincreased and 53.9% respondents believed that snow leopard population has increased after ACAP intervention. One of the reasons behind the increase in wildlife population can be attributed to the increasing level of awareness among the local community. This is evident because the survey found that almost 89.2% respondents indicated that wildlife was not problematic to the community.

Table 2. *Perceived Increase in Wildlife Population*

Statements	Responses (%)		
	Yes	No	As before
Increase in wildlife population	89.23	3.92	6.86
Increase in Snow leopard population	53.9	16.67	29.99
Increase in Musk Deer Population	62.27	22.54	14.74

This perceived increase in wildlife population in the study areas was supported by a participatory wildlife matrix scoring, which showed an increasing number of snow leopard, musk deer and blue sheep in study areas. The study was carried out separately for

Marpha and Jomsom VDCs based on 5-point scoring scale (1 to 5, 1 is very low and 5 is very high) for different time periods (from 1980 to 2005). The participants identified three species for scoring. The matrix scoring indicated that the said species have increased after ACAP initiatives

Table 3. *Perceived change in wildlife population in Marpha VDC based on the participatory wildlife matrix scoring.*

Wildlife Matrix Scoring from 1980-2005	Average Matrix Scoring[a]					
Year	1980	1985	1990	1995	2000	2005
Blue Sheep	3.85	3.85	3.73	3.95	3.98	4.20
Snow Leopard	2.15	2.16	2.14	2.16	2.55	2.70
Musk Deer	2.85	2.86	2.45	2.54	2.90	2.95

a . Note: Matrix Scoring 1 to 5, 1 is very low and 5 is very high

Table 4: Perceived change in wildlife population in Jomsom VDC based on the participatory wildlife matrix scoring

Wildlife Matrix Scoring from 1980-2005	Average Matrix Scoring[a]					
Year	1980	1985	1990	1995	2000	2005
Blue Sheep	3.50	3.56	3.30	3.60	3.92	4.30
Snow Leopard	2.20	2.16	2.18	2.40	2.60	2.85
Musk Deer	2.30	2.32	2.00	2.40	2.57	2.76

[a]*Note: Matrix Scoring 1 to 5, 1 is very low and 5 is very high*

ACA's records of legal actions after ICDP initiatives showed that there were only seven illegal hunting cases filed (KMTNC-ACAP, 2004). Compared to report cases from other army guarded National parks and wildlife reserves of Nepal, illegal hunting in ACA is comparatively very low. There have been criticisms that conservation areas don't protect wildlife and there have also been reports that incidences of wildlife poaching are far greater in conservation areas than in National parks or wildlife reserves (Bajracharya, 2004) but the present study indicated that these studies might be invalid at least for the study areas. The study is also supported by some studies in ACA – a study of Himalayan Tahr *(Hemitragus jemlahicus)* populations indicated that there is handy population of the animal in the area (Gurung, 1995). A recent study in the area reported that a 20% increase in the population of Tahr over a five-year period (Shrestha and Ale, 2001). A recent monitoring study of snow leopard and blue sheep in one of the areas of ACA reported that the area is a potential habitat for both snow leopard and blue sheep and sizable population of snow leopard and blue sheep inhabit there. The above-mentioned findings resulted from the study indicates that the said wildlife population is in increasing trend after ICDP approach intervention of ACAP in the study areas.

Table 5. *Perception of respondents towards wildlife conservation as indicated in questionnaire survey*

Perception statements	Responses[a] (n=1 02)				
	SA	A	N	D	SD
1) ICDP helped to conserve wildlife	47	25	10	18	0
2) Conservation Awareness helped	31	60	8	2	1
3) Wildlife hunting is minimal compared to 11 years ago	78	8	8	8	0
4) Protection of forest helped to increase wildlife	8	70	16	8	0
5) Wildlife was freely hunted before ACAP initiatives	39	31	8	24	0
6) Wildlife is freely encountered in forest	16	65	10	6	5
7) Frequency of wildlife damage of crops increased	0	24	8	39	31
8) Number of wildlife in the forest and pasture has increased	16	70	8	5	3

Notes: The responses are measured using a five point scale. Where, SA = Strongly Agree; A = Agree; N = Neutral; D = Disagree; SD = Strongly Disagree. Respondents are assigned a score of 5 for SA, 4 for A, 3 for N, 2 for D and 1 for SD

Perception towards prevailing effective wildlife conservation situation was different among different respondents. A Likert's Scaling test showed that 47 respondents strongly agreed and 25 respondents agreed that ICDP approach helped to conserve wildlife effectively, while 86 respondents either strongly agreed or agreed that wildlife was freely hunted before ICDP approach intervention in the study area, 31 respondents strongly agreed and 60 agreed that conservation awareness helped to effectively protect wild life species, while 39 respondents strongly agreed and 31 agreed that wildlife species were freely hunted before ICDP approaches.

Conclusion

The results of this study indicated success of ICDP approach in conserving wildlife in an efficient and effective way in comparison with the conventionalconservation approaches. Results indicated that ICDP has demonstrated improvements in wildlife conservation, thus increased studied wildlife population in the study areas. Evidences during the study reflect that wildlife poaching has decreased and wildlife population has increased in ACA after ICDP intervention. ICDP approach is undoubtedly delivering conservation benefits not only to the protected area but also to the local communities.

In Memory

The primary author of this article Ashok Prasad Ojha was a dedicated researcher and conservationist who died in 2010 while working in the Western Terai Landscape Complex Project with the United Nations Development Programme in Nepal. This article is written based on the field data collected by Ashok Prasad Ojha during his tenure with the UNDP, Nepal.

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Carbon Sequestration Potential of Dipterocarps at Chittagong University Plantations in Bangladesh

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Abstract

Organic carbon storage was measured in mature stands of Dipterocarpaceae in plantations of Chittagong University Campus of Bangladesh. The aim of the study was to count the organic carbon storage in three major Dipterocaraceae tree species viz. *Dipterocarpus turbinatus*, *Hopea odorata* and *Shorea robusta* in the study site. Study revealed that, different parts of *Dipterocarpus turbinatus, Hopea odorata* and *Shorea robusta* do not differ significantly in organic carbon percentage where organic carbon stock of leaf, primary branch, secondary branch and bole (stem) *Dipterocarpus turbinatus* were significantly different. Results depicted that organic carbon percentages were almost identical for *Dipterocarpus turbinatus* (58%), *Shorea robusta* (57%) and *Hopea odorata* (55%). In the plantation of the study area *Shorea robusta* has the highest mean organic carbon stock (185.03 kg/tree) followed by *Hopea odorata* (167.51 kg/tree) and *Dipterocarpus turbinatus* (142.64 kg/tree). From the study it was also found that, *Dipterocarpus turbinatus* has highest total organic carbon (121.25 t/ha) than *Shorea robusta* (109.17t/ha) and *Hopea odorata* (102.18 t/ha). In conclusion, it may be accomplished that Dipterocarpaceae species like *Dipterocarpus turbinatus*, *Hopea odorata* and *Shorea robusta* may be suitable for large scale plantations as they may sequester more than 40% organic carbon in its all stages of life. And it will assist to take part in carbon trading and to obtain economic benefit.

Key words: *Dipterocarpaceae, carbon sequestration potential, plant part, organic carbon flow.*

Introduction

Increasing carbon emission is one of today's foremost concerns, which was well addressed in Kyoto Protocol (Ravindranath, Somashekhar, & Gadgil, 1997). It is the main causal factor for global warming (Lal, 2001). Over the years, research has explored a broad range of factors that influence how tree species and forested ecosystems may assist in reducing emissions of carbon dioxide (CO_2). Therefore, efforts to lessen global warming by reducing emissions of CO_2 and other greenhouse gases or by increasing uptake of carbon by vegetation are of great interest to conservationists. The Kyoto Protocol, an international treaty under prolonged negotiation, offers countries the opportunity to obtain credits for reducing emissions or increasing sequestration of carbon (Noss, 2001).

Forestry has been considered to have potential in reducing the atmospheric concentration of carbon dioxide by sequestrating carbon in above-ground timber and below-ground roots and soil (Sedjo, & Sohngen, 2000). Forests sequester and store more carbon than any other terrestrial ecosystem and constitute an important natural defense against climate change (Matthews, Payne, Rohweder, & Murray, 2000). Therefore, the ability of forests, trees and vegetation as terrestrial carbon sinks to absorb CO_2 emission and mitigate climate change has attracted wide attention (Alamgir, & Al-Amin, 2007).

Carbon forestry is potentially attractive because the areas of planting are not constrained by harvesting, transport and processing needs. Carbon forestry includes new forests that are not harvested planted with the primary purpose of storing carbon. To be eligible under Kyoto requirements these forests need to be established on agricultural or rural land that had been cleared prior to 1990. The main factor in the uptake of forest carbon plantings will be the adoption of a sufficiently high carbon price under the Carbon Pollution Reduction Scheme (Stavins & Richards, 2005).

Bangladesh has a total land area of 14.757 million hectares (Bangladesh Bureau of Statistics, 2005). It has a total forest land of 2.53 million ha of which 1.11 million ha is under tree cover (Roy, 2004). With a huge pool of existing plantations and natural forests in Bangladesh, it can be assumed that Bangladesh is playing a major role in mitigating global warming. To realize the potential of the forestry sector in Bangladesh for full-scale emission mitigation, understanding carbon sequestration potential of different species in different types of plantations are important (Miah, Shin, & Koike, 2011). Chittagong University campus has a healthy forest plantation area where the campus belongs 1271 acres of land (Islam, Chowdhury, Hoque, & Malek, 1979). Therefore a need may exist to estimate the organic carbon content of different forest species in the proposed area. Present study was conducted in the plantations of Chittagong University campus to get a clear picture of organic carbon storage in these plantations. The present study will help to demonstrate the role of indigenous forest species in carbon sequestration process.

Method

Study site

The study area was the Diptercarpaceae plantation sites of Chittagong University, Chittagong, Bangladesh. It lies between about 22º 27´30´´and 22º 29´0´´ North latitudes and 91º 46´30´´ and 91º47´45´´ East longitudes (Islam et al., 1979).

The original vegetation is highly eroded due to biotic interaction .Then is converted to secondary forest with weedy environment such as thickest with a few scattered trees, thatching grasses and some bamboos. A total of 665 species under 404 genera and 126 families are present in Chittagong University campus (Alam & Pasha, 1999). Almost all the tree species are planted as a part of afforestation programme.

Sampling procedure

The study was conducted using collected field data through physical measurement, field observation and laboratory analysis. Reconnaissance survey was conducted to collect general information about the plantation sites and make familiar with the studied area. The plot was determined through Gareth's method (Gareth, 1991). For sampling tree species 10m × 10m plot were determined. Complete Randomized Block Design (CRBD) was followed to design the experiment.

Materials and Procedure

Estimation of Biomass of Tree

It was not possible to cut all trees and to estimate biomass of trees. Consulting models developed by FAO, (1997); Luckman, Baker, Mora, Corina-da-Costa, & Frery, (1997); Negi, Sharma, & Sharma, (1988) and Brown, Gillespie, & Lugo, (1989); models of Brown et al. (1989) was used to estimate above ground biomass because literature showed this method was one of the most suitable methods for tropical forest (Alves et al., 1997; Brown, 1997; FAO, 1997; Schroeder, Brown, Birdsey, Cieszewski, 1997). The model is as follows:

Y= exp. {- 2.4090+ 0.9522 ln (D^2HS)}

Where, exp. = [……] means "raised to the power of […….]", Y is above ground biomass in kg, H the height of the trees in meter, D the diameter at breast height (1.3 m) in cm, and S the wood density in units of tonne per m^3. Below ground biomass was calculated considering 15% of the above ground biomass (Michelle, & Francis, 1997; Macdicken, 1997).

Estimation of Biomass of Tree Parts

To estimate the biomass of different tree parts the whole visible portion of the tree was divided into two parts: the bole part and the crown part. To determine the biomass of bole at first the form factor of *Dipterocarpus turbinatus, Hopea odorata* and *Shorea robusta* was calculated. To calculate the form factor, the total height, bole height, Diameter at Breast Height (DBH), sectional diameter were measured by using Spiegel Relaskope. Then the form factor was calculated (shown in Table 1, Table 2 and Table 3). After that, form factor, bole height and DBH were multiplied to get the total volume of bole. Then biomass of bole was calculated by multiplying total volume of bole and wood density.

After that with Spiegel Relaskope crown height and width were measured. From the equation of the volume of cone ($1/3\pi r^2 h$), crown volume was calculated (Figure 1). Then taking a fresh branch of about 1/2m×1/2m×1/2m, volume of primary branch, secondary branch and number of leaves were calculated. Comparing with crown volume, the total volume of primary branch, secondary branch and number of leaves of the crown were calculated. Fresh weight and dry weight of these different tree parts were also measured using electric balance.

Estimation of Organic Carbon Stock in Trees and Tree Parts

After taking fresh weight by electric balance samples were dried in electric oven at about 110ºC for about 48 hours to evaporate all the moisture contents present in different parts. Then oven dried weight were determined. After taking the dried weight, samples were grind into fine powder using grinder. Then porcelain crucibles were washed with 6N HCL and distilled water and dried in an oven at 110°C for 1 hour. Oven dried grind samples are taken in pre-weighted crucibles. The crucibles are placed in the furnace. Then the furnace was adjusted at 550ºC, heating was increased slowly and after reaching at 550ºC, ignition was continued for 1 hour. The crucibles were cooled slowly keeping them inside the furnace. After cooling, the crucibles with ash were weighted and percentage of organic carbon was calculated as Allen, Grimshaw, & Rowlad, (1986).

The formula and symbolic calculations are given below:

Ash % = (W3-W1)/ (W2-W1) ×100 C % = (100 - % Ash) × 0.58 (considering 58%carbon in ash free timber material) (Allen, et al., 1986).

Where, C = Organic carbon; W1 =

Weight of crucibles; W2 = Weight of sample + Crucibles; W3 = Weight of ash + Crucibles.

Percentage of organic carbon with the above procedure was estimated for each sample. Then amount of organic carbon in the both above and below ground biomass of each tree was calculated separately and added to get total amount of organic carbon in the trees. Mean organic carbon stock (kg/tree) and total organic carbon content (t/ha) for each species was calculated. Organic carbon percentage of different tree parts of *Dipterocarpus turbinatus, Hopea odorata* and *Shorea robusta* were also measured. From carbon percentage, the amounts of organic carbon of different tree parts were calculated. All the recorded data attributes were analyzed statistically by using statistical software Minitab 2002 version 13.2.

Results

Organic Carbon Percentage

Organic carbon percentages in trees are shown in Figure 2. Among the tree parts, leaf (52%) of *Dipterocarpus turbinatus*, secondary branch (50%) of *Hopea odorata* and bole (stem) (49%) of *Shorea robusta* has captured the highest organic carbon percentage (Figure 2). Among the three Dipterocarpaceae species, *Dipterocarpus turbinatus* has the highest organic carbon percentage (58%) than that of *Hopea odorata* (55%) and *Shorea robusta* (57%). This may be due to higher wood density of *Dipterocarpus turbinatus.*

Organic Carbon Storage

Figure 3 illustrates the flow of the organic carbon stock of *Dipterocarpus turbinatus, Hopea odorata* and *Shorea robusta*. Among the different tree parts, bole has the highest mean value in organic carbon stock followed by secondary branch and primary branch. It may be due to higher weight of bole. Mean organic carbon stock of bole of *Dipterocarpus turbinatus* and *Shorea robusta* were almost equivalent 70.65 kg/tree and 70.89 kg/tree respectively, while for *Hopea odorata*, it was 60.90 kg/tree.

From the study it was depicted that, mean organic carbon (kg/tree) was highest for *Shorea robusta* (185.03 kg/tree) and for this species average height and diameter at breast height was 16.6 m and 20.4 cm respectively. While for *Hopea odorata* and *Dipterocarpus turbinatus* it was 167.51 kg/tree and 142.64 kg/tree respectively. Average height and diameter at breast height of *Dipterocarpus turbinatus* and *Hopea odorata* were found 16.58 m and 14.03 cm; 14.48 m and 22.53 cm respectively. The study revealed that, total organic carbon (t/ha) of *Dipterocarpus turbinatus* was highest (121.25 t/ha) than *Shorea robusta* (109.17t/ha) and *Hopea odorata* (102.18 t/ha).

Organic carbon stock of leaf, primary branch, secondary branch and bole (stem) *Dipterocarpus turbinatus* were significantly different shown in Table 4. There was no significant difference among different tree parts of *Hopea odorata* and *Shorea robusta.*

Discussion

As outlined previously, there were no significant difference of percentage of organic carbon storage among the tree parts of *Dipterocarpus turbinatus, Hopea odorata* and *Shorea robusta*. Study conducted by Hossain (2007), found no significant difference in the organic carbon of shoot, root and leaf of *Terminalia belerica (*Arjun). Present study supports the findings.

Ahmed (2007) indicated that in *Shorea robusta* seedling, leaf carbon was 57%, shoot carbon was 55% and root carbon was 55.98%. Another study conducted by Swamy & Puri (2005) found that in Gamar (*Gmelina arborea*) carbon concentration in shoot and branches was nearly 45 %, in leaves 41 %. Study conducted by Alamgir & Al-Amin (2007) in Chittagong (South) forest division, Bangladesh found that mean organic carbon percentage of *Shorea robusta* was 57.28% followed by *Hopea odorata* (56.4%), *Dipterocarpus turbinatus* (56.16%), *Dipterocarpus costatus* (55.76%) , *Dipterocarpus alatus* (55.64%). Alamgir & Al-Amin (2007) also found that mean organic carbon (t/tree) was the highest in *Dipterocarpus turbinatus* (1.82 t/tree) followed by *Dipterocarpus costatus* (1.31 t/tree), *Shorea robusta* (1.31 t/tree), *Hopea odorata* (0.83 t/tree) and *Dipterocarpus alatus* (0.11 t/tree). In Chittagong (South) forest division total organic carbon (t/hm^2) was highest in *Dipterocarpus turbinatus* (9.086 t/hm^2) (Alamgir & Al-Amin, 2007). In Chittagong Hilly region of Bangladesh gross organic carbon stocks in the stand of *Dipterocarpus turbinatus* was found 175.56 t/ha (Shin, Miah, & Lee, 2007). Another study conducted by Uddin (2002) in the Chittagong University Campus, Bangladesh found that total organic carbon content in the *Dipterocarpus turbinatus* plantation was 147t/hm^2. Comparing to the above research findings it can be assumed that, the species belongs to Dipterocarpaceae family may be promising for large scale plantations as they are able to sequester organic carbon from the very beginning of their life.

The study concludes by estimating organic carbon stock of three indigenous Dipterocarpaceae: *Dipterocarpus turbinatus, Hopea odorata* and *Shorea robusta*. The study may be helpful to estimate the organic carbon stock of other tree species by using non-destructive method. It will facilitate to get a more complete understanding of the organic carbon sequestration potential of different types of forests and plantations of Bangladesh. The study revealed that, *Dipterocarpus turbinatus, Hopea odorata* and *Shorea robusta* can store a significant amount of atmospheric organic carbon throughout their life span if adequate protection is provided and reforestation in the bared areas through sustainable forest management is implemented. It may offer the country to receive credits for reducing carbon emission through the carbon trading as well as help to reduce global atmospheric carbon and global warming.

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Ethno medicinal studies of mangrove forests of Sundarban Tiger Reserve, West Bengal, India

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Abstract

36 mangroves and its associate plant species were identified from Sundarban Tiger Reserve, West Bengal, India. Those plant species belong to 20 families and 27 genera. Among 20 families Rhizophoraceae contain maximum number of plants (7 species) followed by Avicenniaceae and Sonneratiaceae (3 species). These 3 families represent altogether 65% of the total species. The fringe people depend on the mangrove forests for their daily needs like fuelwood, fodder, timber, tannin, honey production, medicine and other traditional products. The article provides field information on traditional products and medicinal uses of 36 plant species of mangrove forests recorded through interviews and cross interviews of JFMC members, forest staff, local traditional healers, user group of the Tiger Reserve areas. Species are arranged alphabetically providing local name, scientific name, family, habit, plant parts used, ethno medicinal uses, other uses and status.

Key words: *Mangrove Forests, ethno medicinal Plants, Traditional Knowledge, Sundarban Tiger Reserve, West Bengal, India*

Introduction

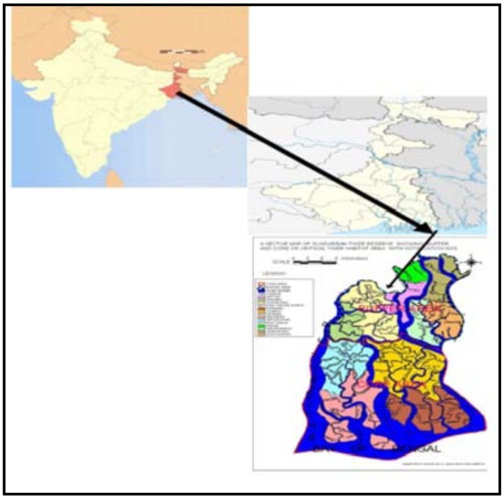
Traditional people throughout the world possess unique knowledge of plant resources on which they depend for their food, medicine, and general uses including tremendous botanical expertise (Martin, 1995). Traditional knowledge based herbal medicine has played a key role in the health care of many countries. Ethno medicinal plants as a group comprise approximately 8000 species and account for about 50% of all the higher plant (flowering species) in India (Gour and Tiwari, 1987). It is estimated that about 60% of the world's population and 80% of developing countries population rely on traditional knowledge based medicine which are mostly plant drugs for their primary health care needs (Gadgil and Rao, 1998).

Mangrove forest is a special type of vegetation community consisting of a variety of salt resistant species having same characteristics and adaptations growing in the intertidal areas and estuary mouths between land and sea. Mangrove forests are one of the most productive and dynamic ecosystems on the earth (Alongi, 1966). It can provide habitat of diverse marine flora and fauna and out of them some are endangered. This unique type of ecosystem is threatened in the world. Traditionally local communities in mangrove ecosystem collect fuel wood, fodder, timber, tannin, honey, medicinal plants, fishes, prawns and other products as per their needs (Bandarnayake, 2000; Dahdouh – Guebas *etal*, 2000). Studies have been done on ethno medicinal uses of mangrove ecosystem in different part of India like Ravichandran *etal*, 2005 in Pichavaram mangroves of east coast; Pattanaik *etal*, 2008; Banerjee, 1984; Banerjee and Rao,1990 in coastal area of Orissa; Chowdhury and Das, 2009 in coastal area of Digha- Junput of West Bengal; Dagar and Dagar, 1986 in Andaman and Nicobar Island but no such study has been done on ethno medicinal uses of mangrove plants in Sundarban Tiger Reserve (Indian part of Sundarban). So present authors have made an attempt to identify some of the plants on mangrove ecosystem of Sundarban Tiger Reserve (STR) which are traditionally used for curing different diseases as well as used for other purposes by fringe people for their livelihood.

Study area

Sundarban (between 21^0 31' & $22^0$31' north latitude and $88^0$10' and $89^0$51' east longitude) is located in the southernmost part of the state West Bengal under civil district of North and South 24 Parganas (Fig-1).

Fig-1: Location map of study area



Fringe villages are situated on the northern side, Bangladesh on the eastern side, Forests of South 24 Pargana division on the west and Bay of Bengal on the southern side. Total area of the Tiger Reserve is 2585 sq km which constitute total 60 percent areas of Indian part of Sundarban. Out of which 362.40 sq km area has been declared as a Sajnekhali Wildlife Sanctuary vide Government notification number 5396-For, dated 24.06.1976 and 1330.10 sq km area declared as Sundarban National Park vide Government notification number 2867-For, dated 04.05.1984. Critical Tiger Habitat with an area 1699.62 sq km was declared vide Government notification number 6028-For, dated 18.12.2007. Rest 892.43 sq km forests area was declared as Buffer area as per Government notification number 615-For/11m-28/07 dated 17.02.2009 which is Reserved Forest. It is one of the first nine Tiger Reserves declared under Project Tiger Scheme in the year 1973 by the Government of India. National Park area of the reserve was honoured as a World Heritage Property by UNESCO during the year 1985. Entire Indian part of Sundarban was declared as a Biosphere reserve in the year 1989. Sundarban Tiger Reserve (STR) consists of 15 forests blocks, 71 compartments, 4 territorial ranges, 14 beats / camps (land based) and 10 floating camps.

Head quarters of the Tiger reserve is at Canning town, situated 45 km away from Kolkata which is well connected by Air by different National and International cities and by rail with all important cities of India.

There are 140 plant species belonging to 59 families and 101 genera that have been reported from entire Sundarban Biosphere Reserve region (Naskar, 2007) comprising true mangroves and its associated species including all type of habit like grasses, climbers, herbs, shrubs, trees, epiphytes, and parasites. Some true mangrove species which are found in STR are *Rhizophora mucronata, R. apiculata, Excoecaria agallocha, Avicennia alba, Avicennia marina, Avicennia officinalis, Ceriops decandra, , Bruguiera gymmorhiza, B. parviflora, B. sexangula, Xylocarpus mekongensis , X. granatum, Kandelia candel, Aegiceros corniculatum,* etc.

Mangrove vegetation has developed some specialised adaptation system like viviparous germination, prop root, pneumatophores, lateral root formation and thick waxy leaves etc.

The reserve is the home to large number endangered and globally threatened species like tiger (*Panthera tigris tigris*), fishing cat (*Felis viverrina*), estuarine crocodile (*Crocodilus porosus*), gangetic dolphin (*Platanista gangetica*), irrawady dolphin (*Oracella brevirostris*), king cobra (*Ophiophagus hannah*), water monitor lizard (*Varanus salvador*) , river terrapin (*Batagur baska*), olive ridley turtle (*Lepidochelys olivacea*), green sea turtle (*Chelonia mydas*), hawks bill turtle (*Eretmochelys imbricata*), goliath heron (*Ardea goliath*), horse shoe crab *(Tachypleus gigas* and C*arcinoscropius rotundicaudata*) etc. It is considered as a kingfishers' paradise as it harbours 8 species out of 12 species found in India. These kingfishers' species are lesser pied kingfisher (*Ceryle rudis*), white throated kingfisher (*Halycon smyrnensis*), stork billed kingfisher (*H. capensis*), ruddy kingfisher (*H. coromanda*), black capped kingfisher (*H. pileata*), brown winged kingfisher (*H. amauroptera*), collard kingfisher (*Todiramphus chloris*), common kingfisher (*Alcedo atthis*)

The average annual rainfall for the area is 1920.30 mm and average relative humidity is over 80 percent. A close net work of rivers, channels and creeks intersect the whole area which has resulted in formation of huge number of islands. There are total 102 island found in the entire Indian Sundarban area and out of them human inhabitation is found in 50 percent of the islands.

The main rivers flowing in an around the reserve are Matla, Raimangal, Harinbhanga, Kapura, jhila, Gomdi, Gosaba, Gona, Bidya and Kalindi. In the Sundarban high tides and ebb tides occur twice daily and the current changes its direction every six hours. On eastern side of the reserve Harinbhanga, Raimangal and Kalindi Rivers share border with Bangladesh Sundarban. The maximum and minimum tides recorded at sager island (western part of Sundarbans) 5.68 m and 0.96 m respectively.

Management problems of STR include killing of prey species, illegal fishing, illegal collection of honey, collection of crab and tiger prawn seeds, difficult terrain, unstable nature of land, frequent natural calamities and man animal conflicts

The population of the district south 24 Paraganas as per 2001 census figures is 69.07 l*akhs* (1lakh=100,000) having population density 693 per sq km. As compared to the state average of 25.61%, nearly 36.5% of the population belongs to Scheduled Castes and Scheduled Tribes category. Nearly 73.5% of the population is engaged on agricultural activities out of which 26.45% are cultivator and 47.08% agricultural labourers (Anon, 2006).

The fringe villages have a high percentage socially backward group like Scheduled Castes (32%) and Scheduled Tribes (12%). The literacy level and per capita income are much less in Sundarban than rest part of the state. Main occupations of the people are cultivation, agricultural labourers, house hold workers, fishing, honey and crab collection etc. Most of the farmers do small and marginal rainfed monocropping with very low production. There is no electricity in fringe villages and in entire STR. Medical facilities are poor and mostly dependent on traditional method of treatment. Basic facilities like good drinking water, schools, health care, road net works, markets are almost absent in majority of the villages. Other Infrastructures in the villages are extremely inadequate. Overall there is high level of natural resource based dependency among the people for their fodder, fuel wood, medicine, timber etc.

Tiger project authority had introduced joint forest management system with the fringe people by forming Joint Forest Management Committees (JFMCs). Till date 25 such JFMCs have been formed by involving 855 families of 32 villages who are protecting 25000 ha of forests. Moreover, more than 200 Self Help Groups (SHG's) are also formed by involving woman folk in these 32 villages.

Methodology

During the last one year (2010 – 2011) in the course of study the area was frequently surveyed. Several attempts were made to collect materials in different seasons. Unknown species were collected, processed, preserved and mounted over herbarium sheets following standard herbarium techniques (Jain and Rao, 1977). Herbarium sheets were identified by local experienced people, JFMC members, forest staff, traditional healers and others. Different floras, monographs and other works were also consulted. During the field survey as many number of plant species as possible were identified that are used in different purposes. Ethno medicinal and other information were collected from local experienced people, user groups, local traditional healers, Vaidyas, Ojhas, JFMC members and staff of forest department; they were consulted repeatedly. The collected information was cross checked by interviewing and cross interviewing again and again by other knowledgeable persons of the locality and by consulting relevant literature, such as Chopra *et al* (1956); Banerjee *et al* , (1989); Chopra *et al* (1969); Anon (2010) and Jain

(1983,1987) . The parts used to treat diseases, having medicinal values and economic importances of plants were recorded during field survey.

Results and discussion

In the present study as many as 36 plant species (Table – 1) have been identified which were locally used by local inhabitants of nearby villages, who are dependent mostly on mangrove forest for their livelihood. Those plants species are mangrove species and their associates, mostly used for medicinal and other economical purposes. 36 identified plant species which were collected during survey and field investigation belong to 20 families and 27 genera. According to habit class tree has the highest diversity (24 species) followed by shrubs (4 species), climbers (3 species), herbs and palms (2 species each). Family wise maximum plants were available in Rhizophoraceae (7 species) followed by Avicenniaceae and Sonneratiaceae (3 species each), Caesalpineaceae, Papillionaceae, Malvaceae, Combretaceae, Arecaceae, Meliaceae (2 species each); Acanthaceae, Myrsiniaceae, Euphorbiaceae, Convolvulaceae, Sterculiaceae, Poaceae, Tamaricaceae, Cactaceae, Aselepiadaceae, Plumbaginaceae and Aizoaceae (1 species each). The families Rhizophoraceae, Sonneratiaceae and Avicenniaceae altogether represent 65% of the total species and which are all Mangrove species. It has been found that local rural people largely are dependent on mangrove and its associates species of STR for medicine, fuel wood, fodder, roof thatching, mat making, tannins, timber, boat making, food, oil, honey production, gum, fish poison, soil binder and fencing. Out of 36 plants only 3 species like *Pontiac dillenii, Pongamia pinnata, and Thespepsia populnea* were found in villages but rest 33 species were strictly available in the mangrove forests. Photographs of some ethno medicinal mangrove and its associate plants of STR are given in Fig-2.

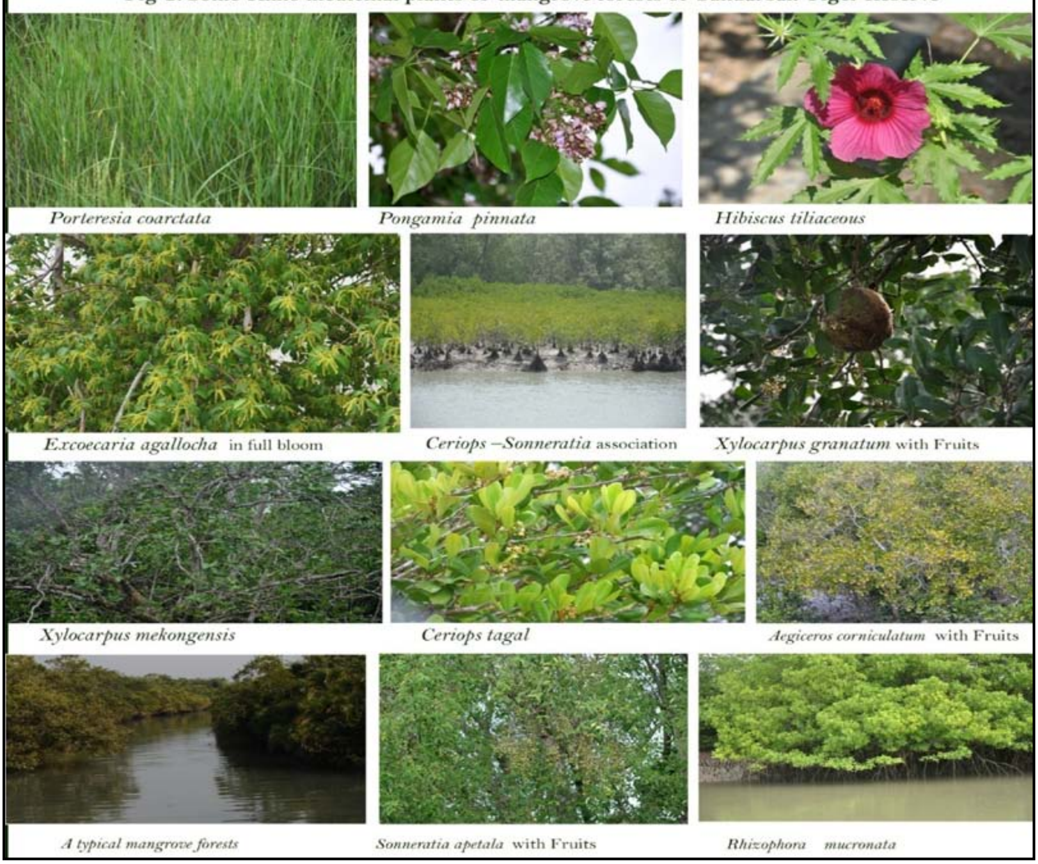
The study reveals that the fringe people are dependent on timber of mangrove species for house and boat construction, furniture, fences, poles, and paddles. Stem of *Bruguiera cylindrica, Ceriops decandra, C. tagal, Heritiera fomes, Xylocarpus granatum, X. mekongensis are* used for construction purposes. Wood of *Heritiera fomes, Xylocarpus granatum, Bruguiera gymnorrhiza* are used for making boats. Species like *Avicennia alba, A. marina, A. officinalis, Bruguiera cylindrica, Ceriops decandra, C. tagal, kandelia candel, Rhizophora apiculata, Thespepsia populnea. Sonneratia alba, Xylocarpus granatum and X. mekongensis* are used as fuel wood. Mangrove plants are not generally used directly as food source, probably due to the high levels of tannins and other distasteful chemicals. However, some plant species were used as food like fruits of *Nypa fruticans*, seed oil of *Pongamia pinnata* (non mangrove) fruit of *Sonneratia apetala*, *Terminalia catappa (non mangrove)*, and *Phoenix palludosa*, Some species are used as fodder like *Avicennia sp, Kandelia candel, Pongamia prinnata, Sonneratia sp, Thespepsia populnea.* Leaves of *Nypa fruticans* and *Phoenix palludosa* are used for thatching roof and making mat. Parts of some mangrove species are used by wild animals like fruit of *Sonneratia sp* are favoured by spotted deer and rhesus macaque. Fruits of *Avicennia sp* are eaten by *Batagur baska*. Succulent tips of *Porteresia coarctata,* growing on newly colonised mud flat have also been seen to attract spotted deer groups. *Avicennia sp* and *Excoecaria sp* are also browsed quite often by the herbivores. Fresh shoots of *Phoenix palludosa* is browsed by spotted deer and fruits are preferred by birds and rhesus macaque. Fruits of *Excoecaria agallocha* are favoured by dove and other birds.

Rock bees (*Apis dorsata*) are attracted by nectar of flowers of mangrove species as most of the mangrove flowers are highly nectar bearing. Flowering start with the blooming of *Aegiceros corniculatum* at the end of March followed by flowering of *Acanthus ilicifolius, Avicennia species, Sonneratia apetala* and *Rhizophora spp* and it continues up to May of every year. The quality of honey collected from Khalsi (*Aegiceros corniculatum*) is considered to be the best. Besides above cited species other mangrove species like *Excoecaria spp, Ceriops spp* also produce good quality of honey. It was found from records that an average 20 tonnes honey annually collected officially by honey collectors on getting permit from Tiger Project Authority.

The fringe people who are mainly concentrated on the northern side of the reserve mostly depend on mangrove plants having medicinal value to treat / cure different diseases. It has been found during study that out of 36 species identified 29 species have both medicinal and other uses but 7 species have purely medicinal use. Plant parts used to prepare medicine are leaf (6 species), bark (2 species), latex (1 species), fruit (3 species) and seeds (1 species). Whole plant of 4 species is utilised to prepare herbal medicine. Single plant part is used for 17 species but multiple parts are utilised for rest of the 19 species. During the course of study, it was found that medicines are used in crude forms, extracts, tablets, decoction, paste and juice. Dosage administered by local herbal healers varies from twice to thrice daily and continues up to 3 to 21 days according to the gravity of the disease or until it is cured. Diseases found to be treated / cured are paralysis, dyspepsia, asthma, diabetes, rheumatism, snake bite, ulcers, dermatological problems, boils, small pox, hepatitis, jaundice, scabies, malaria, carbuncle, tooth ache, leprosy, hemorrhage, diarrhea, blood pressure, gonorrhea, dysentery, leucorrhoea, menorrhagia, inflammation, flatulency, urinary problem, nausea, stomach disorders, sore throat, eczema, sprain, burn, cholera, colic pain, abdominal fever, cough, etc. Moreover, the plants are also utilised as birth controller, astringent, tonic, purgative, stimulant, antispasmodic, poultice, toxic substances, emetic, aphrodisiac, hypoglycaemic, laxative, anti-viral and to remove excess salt etc purposes.

Traditional knowledge of ethno medicine is not written anywhere by local communities; rather it is transferred from one generation to another orally. It is interesting that this traditional practice is capable to cure several diseases in the study area even in the present era of modern medicine. Although modern healthcare medicines are believed to cure almost all human diseases, however, such facilities could not be reached to each and every corner in this region in proper form. Moreover, such medicines are very costly and not readily available in the remote pockets.

Fig-2: Some ethno medicinal plants of mangrove forests of Sundarban Tiger Reserve




Terminalia catappa


Bruguiera cylindrica


Heritiera fomes with fruits


Phoenix palludosa


Ceriops decandra


Bark of *Ceriops spp*


Heritiera fomes with flower


Avicennia alba with fruits


Avicennia officinalis with fruits


Acanthus ilicifolius


Excoecaria - Phoenix association


Nypa fruticans

Table-1: Traditional use of Mangrove and other plants in mangrove habitat of Sundarban Tiger Reserve

S. No	Local Name	Scientific Name	Family	Habit	Parts Used	Medicinal Uses	Other Uses	Status
01.	Hargoja	*Acanthus ilicifolius* L	Acanthaceae	Shrubs	Fruit, Plant extract, root, leaf	Whole plats used in paralysis & dyspepsia; root is used to cure asthma; leaf used in diabetes, rheumatism, snake bites & fish poison	Honey production	Common, mangrove associates
02.	Khalsi	*Agiceros corniculatum* (L.)	Myrsiniaceae	Tree	Leaf	Leaf is used in diabetes, asthma	Leaves are used in fish poison, flower produce best quality honey	Common, mangrove
03.	Tora	*Aegialities rotundifolia* Roxb.	Plumbaginaceae	Tree	Wood, flower		Timber, honey production	Mangrove
04.	Kalo baen	*Avicennia alba* Bl	Avicenniaceae	Tree	Root,wood, fruit, resin	Root is aphrodisiac. Resin is used as anti fertility. Fruit is used to cure ulcers & skin diseases. Bark is astringent & wood is used for tonics.	Timber, honey production, fodder, fuel wood. Fruit is a good food of *Batagur baska*	Common, mangrove

05.	Peyara baen	*Avicennia marina* Forsk	-do-	Tree	Whole plant, fruit, bark	Whole Plants juice is used to promote abortion; unripe fruit paste is used to treat boils, and bark is used as astringent.	Fodder, fuel wood. fruit is a good food of *Batagur baska*,, honey production	Common, mangrove
06.	Jat baen	*A officinalis* L.	-do-	Tree	Root,bark, resin, fruit & seed	Root is used as aphrodisiac; resin is used as anti fertility; bark is used as astringent. Fruit and seeds are used to cure small pox & paste of green fruit is used to treat ulcer.	Fodder, fuel wood. Fruit is a good food of *Batagur baska*,, honey production	Common, mangrove
07.	Bakul Kankra	*Bruguiera cylindrica* (L) Roxb	Rhizophoraceae	Tree	Leaf	Leaf is used to cure hepatitis	Fuel wood, timber	Mangrove
08.	Kankra	*Bruguiera gymnorrhiza* (L.) Lamk	Rhizophoraceae	Tree	Bark, leaf, flower	Bark is used against diabetes and diarrhoea; leaves & flowers are used to reduce blood pressure.	Boat making,	Mangrove

09.	Nata	*Caesalpinea bondac* (L) Roxb	Caesalpineaceae		Leaf	Leaf is used to cure jaundice, rheumatism & paste used against scabies.	Tannin	Mangrove
10.	Shingri lata	*Caesalpinea cristata* L.	Caesalpineaceae	Climber	Leaf	Leaf paste used against scabies.	Tannin	Mangrove associates
11.	Jhamti goran	*Ceriops decandra* (Griff) Ding Hou	Rhizophoraceae	Tree	Fruit, bark	Fruit Paste is used against ulcers and malaria. Bark extract is anti haemorrhagic	Fuel wood, timber, fencing material	Common, mangrove
12.	Math goran	*Ceriops tagal* (Perr.)Robins	Rhizophoraceae	Tree	Fruit, shoot	Fruit is purgative, stop haemorrhages; shoot decoction is against malaria & skin infection.	Fuel wood, timber, fencing	Common, mangrove
13.	Pan lata	*Derris trifoliata* Lour.	Papillionaceae	Climber	Whole plants	Whole plant extract is used as anti spasmodic & stimulant.		Common, mangrove associates

14.	Genwa	*Excoecaria agallocha* L	Euphorbiaceae	Tree	Latex	Latex is used against carbuncle, leprosy, and toothache; wood is used as purgative.	Toy making, fruit is edible to birds	Mangrove
15.	Chhaga lkhuri	*Ipomoea pescarpae* Sweet	Convolvulaceae	Climber	Whole plants, root, leaf	Plant extract is used to cure diarrhoea, skin diseases; leaf paste is applied on boils & carbuncles; root decoction is used to treat rheumatism, gonorrhoea.	Good soil binder	Mangrove associates
16.	Sun dari	*Heritiera fomes* Buch. Ham.	Sterculiaceae	Tree	Whole plant , seed	Plant extract & seed is used to treat diarrhoea & diabetes, also used as hypogly caemic.	Timber, boat making	Common, mangrove associates.
17.	Bhola	*Hibiscus tiliaceous* L.	Malvaceae	Shrubs	Leaf, root, seed	Leaf decoction is used to cure dysentery & laxative, Root paste is act against rheumatism & seed is used as emetic.		Common, mangrove associates.
18.	Garia	*Kandelia candel* (L.) Druce	Rhizophoraceae	Tree	Bark	Bark is used to cure diabetes.	Fuel wood, fodder	Endangered mangrove

19.	Kripa	*Lumnitzera racemosa* willd.	Combretaceae	Tree	Fruit, stem, bark	Fruit is used in skin diseases; stem juice is used in herpes, & itches; bark tannin has antiviral properties.		Critically endangered mangrove
20.	Golpata	*Nypa fruticans* Wurmb	Arecaceae	Palm	Root, leaf, fruit	Root & leaf ash is used in tooth ache. Fruit pulp is used is to cure herpes & skin diseases.	Fruit is edible. Leaf is used as thatching material	Vulnerable, mangrove
21.	Phani mansa	*Opuntia dillenii* Haw	Cactaceae	shrub	Whole plants	Used as expectorant, also used in boils, ulcers, fever, leucorrhoea menorrhagia.		Non mangrove
22.	Hental	*Phoenix palludosa* Roxb.	Cactaceae	Palm	Fruit	Fruit is used as cooling and to treat inflammation & flatulence.	Fruit is edible. Leaf is used as thatching material and making mat.	Common, mangrove associates
23.	Karanj	*Pongamia pinnata* (L.) Pierre	Papillionaceae	Tree	Fruit, seed	Fruit is used in piles & ulcers; seed oil is used to treat skin diseases.	Fodder, oil is edible	Non mangrove

24.	Dhani ghas	*Porteresia coarctata* (Roxb.)	Poaceae	Herb	Whole plants	Plant extract is used to treat stomach ailments.	Fodder	Common, mangrove associates
25.	Garjan	*Rhizophora apiculata*, Bl.	Rhizophoraceae	Tree	Leaf	Diarrhoea, skin disease, nausea.	Fodder, fuel wood, tannin, honey.	Common, mangrove
26.	Garjan	*R. mucronata* Lamk.	Rhizophoraceae	Tree	Bark	Bark is used as astringent; also used to treat diabetes, stop blood discharge through vomit & urine or spitting.	Tannin, honey	Common, mangrove
27.	Cowphal	*Sarcolobus globosus* wall	Asclepiadaceae	Shrubs	Seeds	Seeds are toxic to mammals.		Mangrove associates
28.	Gadabani	*Sensuvium portulacastrum* L	Aizoaceae	Herb	Whole Plants	Plant extract is used to remove excess salt from body.		Mangrove
29.	Keora	*Sonneratia apetala* Buch. Ham.	Sonneratiaceae	Tree	Fruit		Honey, fodder, fruit is edible.	Common mangrove

30.	Ora	*S. caseolaris* (L.) Engler.	Sonneratiaceae	Tree	Fruit	Fruit is used to treat cough, urinary problems, stomach disorders & swelling intestinal worms	Tannin, ripe fruit is edible	Endangered mangrove
31.	Keora	*Sonneratia alba* J. Smith	Sonneratiaceae	Tree	Fruits	Fruit is used in skin diseases, cough and poultices of cut.	Fuel wood , fodder	Mangrove
32.	Laljhau	*Tamarix dioica* Roxb.	Tamaricaceae	Tree	Whole plants	Whole plant is used in dysentery, diarrhoea, ulcer & sore throat.	Green fruit favoured by ungulates	Mangrove associates
33.	Kath badam	*Terminalia catappa* L	Combretaceae	Tree	Leaf	Leaf is used to treat cutaneous diseases, scabies, & rheumatism.	Edible fruit, gum.	Common, mangrove associates
34.	Paras pipul	*Thespepsia populnea* (L.) Soland ex. Correa.	Malvaceae	Tree	Root , bark, fruit, leaf	Leaf paste is used in scabies, eczema, & painful joints; fruit juice is used to treat sprain, burn, insect bites, skin diseases; bark & root is used in skin diseases, diarrhoea, cholera etc.	Fodder, Fuel wood.	Common, mangrove associates
35.	Dhundul	*Xylocarpus granatum* koeing	Meliaceae	Tree	Bark, seed	Bark is used as astringent; seed oil is used to treat cholera, diarrhoea, colic pain, dysentery & abdominal fever.	Timber, fuel wood, boat making, tannin, furniture making.	Vulnerable mangrove

36.	Passur	*X. mekongensis* Pierre.	Meliaceae	Tree	Bark, leaf, flower	Bark is used in diarrhoea & diabetes; flower & leaf is used to reduce blood pressure.	Timber, fuel wood, boat making, furniture making	Mangrove

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Carbon Balance Assessment in Indian Himalayan Managed Forests: Analysis of Anthropogenic Extractions for Domestic Combustion vis-a-vis Accretions of Forest Biomass

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Abstract

Biomass burning, a major source of atmospheric trace gases, contributes to global environmental change. Large proportion of population of developing countries is dependent on biomass burning for cooking food. Fuelwood burning in kitchens generally leads to incomplete combustion, and hence emit polluting gases into atmosphere. Quantitative dynamics of carbon lost in emissions due to burning in kitchen of fuelwood extracted from forests, and carbon added due to annual accretion in managed forests is unclear due to lack of scientific data. Present study is a scientific attempt to addresses the issue by considering and analysing the data collected in a random survey of 102 households in rural Jaunsar area of Himalayas in Uttarakhand State of India for estimation of carbon lost in emissions due to fuelwood burning. The carbon dioxide concentrations and other polluting gases emitted during fuelwood combustion were measured by portable instruments at the mouth of stoves. The annual emissions due to fuelwood burning and annual removals in shape of forest biomass addition in the managed forests of the region were estimated based on Intergovernmental Panel on Climate Change (IPCC) 2004 approach.

Average fuelwood consumption rate was 8.5 kg/day per household with mean CO_2 normalized emission ratio of 8.0, 0.17 and 0.23 percent for CO, SO_x and NO_x, respectively. This leads to total annual carbon emission of 0.018 Mt and 1.06 Mt due to fuelwood burning by all households of Jaunsar region and Uttarakhand State, respectively. As against this, the annual increment in biomass carbon stock in the forest, based on average decadal addition was estimated to be 0.13 Mt and 6.6 Mt CO_2eq in Jaunsar and Uttarakhand, respectively. This on comparison reveals that the fuelwood generated carbon emissions from fuelwood burning is approximately 16% of the sequestration potential of the regional forests. The present carbon balance may get disturbed with the high demand for fuelwood in future due to growing population, and may turn forests into a net source of emissions. Therefore, it will be advisable for policy planners to develop and implement a strategy for providing of alternate source of cooking fuel. This will help in forest conservation and enhancement of forest carbon stocks, thus maintaining the status of forests as carbon sinks. This finding has implication and relevance in the context of adoption of a national strategy implementation of REDD-plus.

Key words: *Carbon storage, Emission factor, Incomplete combustion, REDD-plus*

Introduction

Biomass burning includes the burning of the world's forests (tropical, temperate, and boreal); savannas; agricultural lands after the harvest; production of charcoal and use of wood for cooking, heating and other household needs. Biomass burning was identified as a significant global source of trace atmosphere gases (Crutzen, 1979) and an important contributor to increase in tropospheric concentrations of CO_2, CO, CH_4, non-methane hydrocarbons and ozone (Levine, 1990).

In general, biomass material contains about 50% carbon (IPCC, 2004). However, nitrogen and sulphur may account for 0.3 – 3.8% and 0.1 - 0.9% respectively of the biomass content, depending on the composition (Bowen, 1979). The nature and quantity of combustion materials present in the biomass and fire characteristics govern the generation of combustion products (Levine, 1994).

Burning biomass such as fuelwood, charcoal and non-woody biofuels for various household purposes is used by about half of the world's population (Ludwig *et al.,* 2003). Emissions associated with the biomass burning influence indoor air quality, health and surrounding environment (Bruce *et al.,* 2000; WHO 2002, 2003). Studies focusing on analysis of the regional effects of the biomass burning on the environment are lacking for most part of the world except for a few studies in Africa by Ludwig and colleagues (Levine, 2003). It is imperative that spatial distribution of biofuel use should be assessed for evaluation of trace gases' budget for developing possible mitigation options for climate change (Yevich and Logan, 2003).

In India, rural population depends on traditional biomass fuels for meeting their household energy needs, wherein the contribution of fuelwood is substantial. Smith *et al*. (2000a) reported that most bio-fuels used by rural communities of India emit polluting gases and particulate matter. Supporting this, Pandey and Tyagi (2011) reported that poor combustion characteristics of bio-fuels can potentially lead to higher global warming impacts than caused by consumption of common fossil fuels. The energy use pattern in rural India is changing although slowly, with preference for clean energy. All the same, traditional fuels still remain the main source of household cooking energy due to inadequate and unreliable supply of clean energy (Balakrishnan *et al*. 2004). High cost of clean energy, vis-a-vis, the traditional fuels is another impediment to quick switchover to the clean fuels in rural areas. Continued dependence on use of bio-fuels mainly fuelwood is relevant in the context of internal policies relating to status of emissions in the country. It may be mentioned that the assessment of the current and projected trends of green house gases (GHG) emissions from India indicate that annual emissions grew at the rate of 4% during the period from 1990 to 2000, and that the projected growth was driven by the necessity of meeting the national developmental needs (Sharma *et al*., 2006).

Collection of fuelwood, and the emissions resulting from domestic combustion of fuelwood impact the local environment and generally the information in this regard is not available at local or regional scale. This constrains the policy planners from prescribing suitable and locally implementable mitigation actions aimed at avoiding the ill effects of the emissions on human health and also on the local environment. The estimation of GHG emissions from biomass burning requires information on two parameters: i) quantity of biomass fuels consumed, and ii) quantity of associated emissions of various gases and particulates. Since biomass extracted for cooking energy from forests is reduction of forest carbon stocks, the estimation of emissions due to combustion of fuelwood for cooking will facilitate a comparison between the carbon stocks removed as fuelwood, and the carbon stocks added through process of carbon sequestration in the forests. The net emissions measured as a proportion of the net accretion of forest carbon stocks during the same period may reflect the resilience and sustainability of the forest resource under continued anthropogenic extractions.

Present study has been undertaken to assess the quantum of emissions, and the level of pollution caused by the polluting gases released due to burning of fuelwood in the households of Himalayas in India. We also attempted a quantitative assessment of the mitigation role of managed forests in terms of carbon sequestration under the hypothesis that the biomass extraction for fuelwood is balanced by the annual addition of biomass in the regional forests managed by the forest department. The aim of this research is to provide an empirical analysis of the dynamics of carbon balance in a managed forest resulting from interplay of extraction of fuelwood from, and the accretion of biomass in that forest. This is important as limited research has been published about the carbon balance analysis relating to mitigation service rendered by forestry sector in developing nations.

Conceptualising dynamics of forest biomass carbon stocks change due to anthropogenic extractions and additions

The change in biomass carbon stocks in forests can be ascertained by devising a common unit for both the factors, which influence the emissions. The forests of a region can be measured in terms of carbon mass in units of tons of carbon contained in its oven dry biomass stocks (Houghton, 2003). In this context, the forest biomass stocks cover all the biomass in managed forests, and in trees outside forests in the region, termed as forest and tree cover. Forest and tree cover in this paper, henceforth is referred to as 'forests' only.

It is considered that whole of the fuelwood being consumed for household cooking energy originates from the regional forests, which are repository of accumulated carbon assimilated by the trees. This is corroborated by the fact that no market activity relating to fuelwood trading exists in the region. Therefore, fuelwood extraction can be seen as a flow of carbon that, if not extracted, would have added to the existing forest carbon stocks. Within a large area or a region, fuelwood extraction will cause a reduction in the quantity of carbon stocks in the forests, and in cases where extractions exceed biomass increment; a depletion of carbon stocks will be effected. Also burning of fuelwood will add to emissions in the atmosphere.

However, to be able to arrive at meaningful results, a number of simplifications and assumptions are necessary for embarking on such an assessment. Most importantly, we adopt and apply average value for conversion and expansion factors across the country to estimate the forest biomass carbon stocks, which although may not reflect the accurate picture for specific locations, but all the same application of such averages will give fairly good and acceptable estimates at the State, regional or national level. Another assumption made is that all fuelwood is derived from the regional forests, and that uniform utilisation pattern prevails across the region throughout the year.

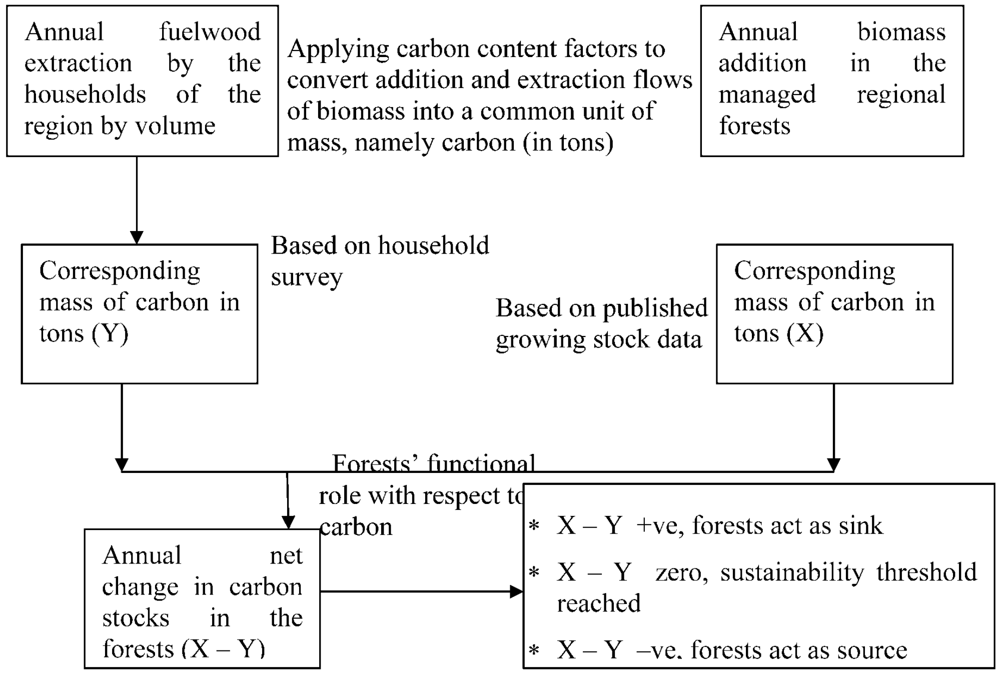

***Figure 1**: Calculation flow chart for assessment of the impact of fuelwood burning on forest carbon stocks change*

Systematic relationship of interplay between the emissions due to burning of extracted fuelwood from forests, and change in carbon stocks of regional forests can be established by answering the following questions: how much fuelwood is being extracted from the forests for burning in the households in a fixed timeframe, and how much biomass is being added in the forests of the region during the same time period. For the analysis, we use the quantity of carbon corresponding to i) addition of biomass in forests, and ii) extraction of biomass for fuelwood. Empirically, we establish the relationship between fuelwood extraction and change in forest carbon stocks as follows:

Starting point was estimation of annual increment in a managed regional forest based on the change in stocks during the period from 1995 to 2005. The data of quantity of biomass for the two periods was obtained from the secondary sources. For assessment of fuelwood extraction, we conducted household survey to estimate general consumption of fuelwood on annual basis by the households of the region. Based on the information obtained by using the above approach, the annual carbon (in tonnes) added in the managed regional forests was estimated and compared with the annual carbon (in tons) extracted in shape of fuelwood from these forests by the households of the region. The net change in forest carbon stocks, i.e., the differences between addition and extraction of biomass is a measure of the status of the mitigation service by the forests (Figure 1). The inference from this analysis will lead to any of the following three situations:

- ❖ If net change in the forest carbon stocks is positive, the forests are acting as a sink under the prevailing anthropogenic pressure.
- ❖ If there is no change in forest carbon stocks, the forests have reached the threshold level, and any additional extraction beyond this, will make forests as net source of emission. .
- ❖ It net change in the stocks is negative, the forests are already acting as a source under the prevailing anthropogenic pressure.

Study region

The present work is based on a random survey conducted in the rural hilly tribal areas known as Jaunsar in Dehradun district in Uttarakhand State of India. It lies between latitudes of 30^0 31' and 31^0 03'30" N, and longitudes of 77^0 45' and 78^0 07'20" E with spread of 1,002.07 square km at the altitude varying between 1,100 – 1,800 m. The total number of households using fuelwood in whole of Uttarakhand State and in Jaunsar was 865,411 and 14,399 households, respectively (Census of India, 2001). Individual households were approached and information pertaining to the relevant parameters of fuelwood burning was collected from 102 randomly selected households distributed in different villages of Jaunsar during the year 2008-09. The information pertaining to various characteristics of utilization of fuelwood in households including its collection and burning was obtained through pretested questionnaire.

Data and calculations

Estimate of polluting gases

The gaseous emissions from fuelwood burning were measured by placing calibrated portable instruments at the mouth of chulha (stove) in the kitchen of each household before and during burning of fuelwood. The Gas Alert Micro 5-IR was used to measure concentration of CO_2 and CO, and the Q-ARE Plus Multi-Gas Analyzer was used for measurement of NO_x and SO_x. Multiple measurements of the concentration of gases at 10, 30 and 60 minute time intervals were recorded after igniting of chulha, besides the initial status of concentration of these gases, i.e., before igniting of chulha. These measurements are considered as the indices of exposure.

The emission ratio and emission factor were estimated for generalisation of gaseous emission. Emission ratios are used to predict the excess quantity of a particular gas or pollutant getting added to atmosphere from the combustion of a certain amount of biomass. Emission ratio (ER) of a greenhouse gas is the excess gas production (above background) normalized with respect to the excess CO_2 production (above background). The ER is usually normalized with respect to CO_2 due to high production of this gas during fuelwood combustion, and also the relative ease of its estimation. On the basis of before and after combustion measurements of CO_2 concentrations, emission ratio was estimated for each of the observed gases, as defined below.

$$ER = \frac{\Delta X}{\Delta CO_2}$$

Where $\Delta X = X^* - X$ is the concentration of the gas produced by fuelwood combustion, X^* is the measured concentration in the smoke produced due to biomass burning, and X is the background concentration (initial) of the gas ; and $\Delta CO_2 = CO_2^* - CO_2$, where CO_2^* is the measured concentration in the smoke, and CO_2 is the background atmospheric concentration (initial) of CO_2 (Levine, 1994). The emission factor (EF) is the quantity of polluting gases emitted per unit of activity such as per unit of biomass burning in the present case. The emission factors of trace gases from biomass combustion are influenced by several factors including the actual amount of carbon in the pre-burnt dry matter, the size, shape and moisture content of the sample, and the flaming versus smouldering pattern of the burning process (Ward *et al.,* 1996).

Estimates of annual incremental carbon in managed regional forests

The emission due to fuelwood burning was compared with the actual quantity of carbon sequestered in the forests of Jaunsar and Uttarakhand State. The carbon sequestration was estimated by calculating increase in the growing stock in forest and tree cover. This estimate was based on secondary data of growing stock as per methodology of Brown and Lugo (1984), Dadhwal and Nayak (1993), and more precisely of Kishwan *et al.* (2009). The data were obtained from FSI (1997); Manhas *et al.,* (2006); and FSI (2008) and used for estimating the biomass carbon in forest and tree cover of Jaunsar and Uttarakhand. The growing stock for forest and tree cover for the years 2003 and 2005 is respectively available in State of Forest Report 2003 (FSI, 2005) and State of Forest Report 2005 (FSI, 2008), inter alia, for Uttarakhand, and based on the figures for the whole State, the growing stock was calculated on proportionate geographical area basis for Jaunsar. However, for 1995, growing stock only for forest cover is available and, therefore, growing stock for the tree cover was estimated based on the mean of the ratio between growing stock of tree cover and that of forest cover for the available data for the years 2003 and 2005 with the assumption that during the period of about a decade between 1993, and 2003-2005, the increment in growing stock of the tree cover followed a uniform pattern.

Suitable biomass expansion and conversion factors and the ratio of below and above ground biomass as reported in different studies covering a range of forest types of the region were used in the present study in absence of particular data, by averaging relevant published data (Chhabra *et al.,* 2002; Kaul *et al.,* 2009). The biomass of forest floor, i.e. understory, was estimated based on the average ratio of total tree biomass to the total forest floor biomass as per published records for different vegetation types and different localities (Negi, 1984; Singh and Singh, 1985; Rawat and Singh, 1988; Roy and Ravan, 1996). The biomass is estimated by taking into account the total growing stock of the forest including the above and below ground volume of all vegetation in the forest and multiplying it with a 'volume to mass' conversion factor. The average conversion factor is estimated based on the findings of Brown *et al.,* (1991); Rajput *et al.,* (1996) and Kaul *et al.,* (2009).

Biomass contains about 50% carbon by weight (IPCC, 2004). Mathematically, the biomass carbon can be estimated as follows:

$C_{Biomass}$ = Biomass x Proportion of Carbon Content

Based on the carbon estimates for the year 2005 and 1995, the mean annual addition of carbon in the managed regional forests was estimated.

Results and discussions

In Jaunsar, cooking practices are generally conventional. The fires for cooking are arranged inside the small sized kitchen. The fire device is made locally consisting of a raised structure on the floor of the kitchen in the house made of mud mixed with some locally available material. The device is usually either L shaped or in single line having one to five burners. The kitchen in general is not spacious, and may be classified into four types based on the location of chulha in the house. Twenty seven percent kitchens were indoor, separated from other habitable space in the house with a partition, and 25% were again indoor but without partition. Another 27% kitchens were located outside, but attached to the house, and the remaining 21% were entirely separate kitchens located outside the house. The entry to the house , i.e., the door duplicates as a ventilator in absence of a proper chimney or flue in these houses.

Table 1: Descriptive statistics of kitchen and cooking parameters of a household

Parameter	Mean ± SE	Min.	Max.
Chulha burning in morning (Hours)	1.82 ± 0.16	1	5
Chulha burning in evening (Hours)	2.37 ± 0.14	1	7
Chulha burning in midday (Hours)	0.79 ± 0.15	0	3
Chulha burning in one day (Hours)	5.65 ± 0.24	2	12
Time for smoke emission morning (Minutes)	12.02 ± 0.98	3	30
Time for smoke emission evening (Minutes)	11.91 ± 0.91	3	30
Time for smoke emission mid day (Minutes)	4.46 ± 1.00	0	25
Cooking frequency per day (Number of Meals per day)	2.22 ± 0.04	2	3
Fuelwood required per day (Kg)	8.51 ± 0.35	3	20

SE – Standard Error, Min. – Minimum; Max. – Maximum

In general, the cooking process started early in the morning between 4.30 am to 5.30 am in morning session, and between 4.00 to 5.00 pm in evening session depending on the requirements of the households with the initial load of 1 to 2 kg fuelwood followed by stacking of two to three reloads combined with fanning or blowing. The average time of chullha burning was 5.6 hours a day which accounts for the combustion of nearly 8.51 kg of fuelwood per day. The fuelwood collected was generally by way of cutting small twigs and branches of live trees. However, in a few cases, woody debris and dead trees picked from the floor of the forests were also used as fuelwood. Based on the per household estimated fuelwood consumption rate of 8.51 kg per day, the total annual fuelwood consumption was found to be 2,688,096,378 kg (8.51 x 365 x 865411) for the total 8,65,411 rural hilly households of Uttarakhand, and 44,725,453.85 kg for 14,399 households of Jaunsar.

Fuelwood was usually staked up in a linear pile in the chulha, and ignited with the help of a small amount of inflammable material like kerosene, paper, dry leaves, etc. Depending on the desired effect or need of intensity of heat required, the fire was being controlled by reloading additional fuelwood or by removing some of the burning fuelwood, and fanning or blowing. Exhaust gases were released in the kitchen, and finally found their way into the atmosphere. During the initial phase, concentrated smoke was released, which turned into flames in due course of time. The amount of smoke emitted during combustion depended upon the quantity of fuelwood burnt and the time span of combustion as observed and reported by the households.

GHG emissions due to fuelwood burning in kitchen

Table 2 reports the temporal behaviour of the concentration of gases of CO_2, CO, SO_x and NO_x measured during cooking inside the kitchens in Jaunsar. The background value of CO_2 before the combustion was below 600 ppm except in one case, where it was as high as 1,050 ppm. Probably, higher concentration of CO_2 was due to continuous burning of fuelwood in kitchen without ventilation.

Initiation of burning requires good quantity of fuelwood to obtain the required flaming for cooking. Therefore, the concentration of green house gases increases exponentially in the first 10-15 minutes of ignition, and after that it becomes steady as the fire stabilises (Table 2). These gases disseminate into the environment either from ventilators or from doors or from both depending upon the existence of ventilating devices. The average concentration of CO_2 and CO in kitchen after 10 minutes of burning was 1,089 ppm and 53.04 ppm, respectively, and the figure for NO_2 and SO_2 was 2.22 ppm and 1.61 ppm, respectively. After half an hour of burning, the average concentration was excessively high in the kitchen with the value of 1,329.22 ppm, 67.18 ppm, 2.13 ppm and 1.63 ppm for CO_2, CO, NO_2, and SO_2, respectively. The variation in concentration of emissions of these gases corresponded with different phases of combustion ranging from flaming to smouldering, and even vice versa.

Carbon mass balance is used to derive the emission factor for CO_2, and the same used to calculate the emission ratio of other gases relative to CO_2. The ash contains 11% carbon content (Brocard *et al.,* 1996; Brocard and Lacaux 1998), and bears an average proportion of 6.6 ±2.8% to the total quantity of fuelwood burnt (Ludwig *et al.,* 2003). Therefore, ash of one kg burnt fuelwood contains 6 g of carbon and remaining carbon is released in the atmosphere as a result of combustion. Carbon emissions from fuelwood burning predominantly comprise CO_2, and therefore, approximation based on CO_2 emissions only from fuelwood burning will not introduce significant error as also supported by Brocard and Lacaux (1998). However, based on the periodic measurements in the kitchens, the mean CO_2 normalized ERs for CO, SO_2 and NO_2 was 8.0, 0.17 and 0.23, respectively.

The average moisture content of 20% mcdb (moisture content on dry basis) was considered to be conservative for estimation of biomass carbon on dry wood basis, as suggested by Leach and Gowen (1987); Hall *et al.* (1994). Therefore, one kg of fuelwood releases 394 g (emission factor of CO_2) of carbon presuming a carbon content of 50% in dry wood, and 6 g in ash. The emission factor for CO, NO_2 and SO_2 is 32 (80 x 394/1000), 0.90, and 0.67, respectively. Moreover, these emission factors are in accordance with Zhang *et al.* (2000) and Smith *et al.* (2000b).

Table 2: Temporal behaviour of concentration (in ppm) of various gases in Kitchens of Jaunsar before and after fuelwood combustion

Gas	Mean ± SE			
	Before Combustion	After Combustion		
		10 Minutes	30 Minutes	60 Minutes
CO_2	264.22 ± 174.11	1089.71 ± 711.41	1329.22 ± 814.71	1246.38 ± 814.71
CO	2.42 ± 3.35	53.04 ± 29.71	67.18 ± 29.84	66.15 ± 31.88
SO_2	0.13 ± 0.15	1.61 ± 1.77	1.63 ± 1.47	1.88 ± 1.88
NO_2	0.25 ± 0.20	2.22 ± 2.22	2.13 ± 1.05	2.11 ± 1.12

Total annual carbon emitted due to fuelwood burning in kitchens of all households is 2,688,096,378 x 0.394 = 1,059,109,973 kg (1.06 Mt) in Uttarakhand and 0.018 Mt in Jaunsar. The total NO_2, CO and SO_2 content in emissions due to fuelwood burning in kitchens of all households are 2,419,286.74 kg, 86,019,084.1 kg and 1,801,024.573 kg, respectively for Uttarakhand. The volume of these gases is relatively very low, and therefore, has not been considered further for analysis of emissions.

Incremental forest carbon in regional managed forests

The total growing stock in forests (natural forests and trees outside forest) was estimated to be 401 million cubic meters (M m^3) and 425 M m^3 in Uttarakhand, and 7.51 and 7.97 million cubic meters (Mm^3) in Jaunsar during 1995 and 2005 respectively as per the published records (Manhas *et al.,* 2006; FSI 2008;). Therefore, as per our methodology, the carbon stored in the forests was computed at 297 Mt and 315 Mt with mean annual increment of 1.8 Mt carbon, i.e., 6.6 Mt CO_2eq in Uttarakhand, and 5.56 Mt and 5.91 Mt with mean annual increment of 0.035 Mt, i.e., 0.13 Mt CO_2 eq in Jaunsar in 1995 and 2005, respectively (Table 3).

Table 3: Carbon estimation in Jaunsar and Uttarakhand forests for year 1995 and 2005

BEF, RBA, Ratio are averages based on Brown *et al.,* 1991; Rao and Ravan, 1996; Kaul *et al.,* 2009

Average MD is based on Rajput *et al.,* 1996

Item	Factor	Jaunsar		Uttarakhand	
		1995	2005	1995	2005
Growing Stock in Mm^3 (GS)		7.51	7.97	401	425
Mean Biomass Expansion Factor (BEF)	1.578				
Mean Density (MD)	0.727				
Above Ground Biomass Weight AGB = GS X BEFX MD		8.62	9.15	460	488
Ratio (Below to Above Ground Biomass) (RBA)	0.27				
Below Ground Biomass Weight BGB = AGB X RBA		2.32	2.48	124	132

Biomass Weight in Mt = AGB + BGB		10.94	11.63	584	620
Ratio (Other Forest Floor Biomass except Tree Biomass)	0.015				
Total Forest Biomass in Mt (Trees + Shrubs + Herbs) - TFB		11.11	11.81	593	629
Carbon in Mt (50 % of DW)		5.56	5.91	297	315
Difference between 2005 and 1995 in Mt (Mean decadal sequestration)		0.35		18	

Comparison between anthropogenic extraction and natural addition of biomass in managed forests

Comparatively, the emissions of carbon in form of CO_2 due to the burning of extracted fuelwood is equivalent to only 16% of the quantum of the annual addition of forest biomass carbon in the regional forests. Therefore, it can be deduced that the annual accretion of biomass carbon in forests of Uttarakhand far exceeded the emissions resulting from fuelwood burning in the rural households of the State during the same time period. Hence it may be concluded that the regional forests are acting as a carbon sink in the present social and natural resources management regimes.

Conclusions

The present study reports a preliminary empirical analysis of emissions generated from fuelwood burning for producing cooking energy in mountainous region of Jaunsar in Uttarakhand State. The study also analyses the carbon balance at regional level taking into account the i) amount of biomass carbon extracted from managed forests anthropogenically for domestic burning to produce cooking energy, and ii) amount of biomass carbon added in the managed forests during the same time period,i.e., annually. The study concludes that at present, forests are acting as net carbon sink at regional scale in so far as use of fuelwood as cooking fuel is concerned. However, use of fuelwood exposes the poor household members daily to pollutants including GHGs, and thus increase the risk of affliction with diseases like, pneumonia, chronic respiratory disease and lung cancer, accounting for a substantial proportion of the global burden of disease and ill health in developing countries (Schirnding *et al.*, 2002), besides adding to the burden of GHG emissions responsible for global warming.

The results show that the overall

carbon content of forests in the regional managed forests gets reduced due to extraction of fuelwood, thereby reducing the emissions removal capability of the forests. The release of additional carbon content due to fuelwood burning adversely impacts the global environment by affecting local, regional and global air quality and by disturbing rainfall patterns (Garivait, *et al*., 2004). This calls for the need to develop a policy framework that encompasses initiatives, which support direct or indirect enhancement of the forest capability with respect to carbon sequestration. These forest-based climate change mitigation strategies include: reducing CO_2 emissions produced by deforestation; improving forest management practices to reduce emissions from forest degradation by improving quality and productivity of degraded forests; and increasing forest and tree cover through afforestation and reforestation aiming at increased carbon sequestration. The strategy may also include reduction in anthropogenic forest biomass extraction for household and other purposes including commercial.

Saghir (2005) observed that high reliance on biomass energy has major implications for economic development, livelihoods, social dignity and environmental sustainability. Therefore, reduction of emissions caused due to burning of fuelwood is possible by switching over to the use of cleaner or processed fuel (Kandpal *et al*., 1995; Gustafsson *et al*., 2009), which also provide many other benefits including safer health conditions (Pandey, 2011). Reduced use of fuelwood could be achieved by embarking on a programme for large-scale dissemination of liquefied petroleum gases (LPG) at affordable prices in the mountainous areas where fuelwood use is widespread for producing cooking energy. The means of solving these issues are location-specific because these issues depend not only on the quality and quantity of fuelwood, but also on the household's economic status (Pachauri and Jiang, 2008). However, practically, at present it is difficult to conceive a scenario of providing clean fuel to the huge rural poor mountainous population in view of the large public investment needs for the purpose. The economic issue of the poor households can be addressed to some extent by mobilizing surplus unproductive labour in income-generating activities.

Another option which can be explored is the selection of fuelwood species with low emission potential, and use of fuelwood saving devices based on modern technological innovations. Awareness is considered an essential tool focusing on rural populations and educating them about the environmental and other associated benefits of changing their cooking habits. Ultimately, by better understanding of the climate effects of fuelwood emissions, path can be paved for contemplating and implementing the most cost-effective mitigation measures such as conserving and enhancing the forest carbon stocks. Therefore, providing incentives to the rural poor at the local level for their contribution towards reducing their emissions could be one of the workable policy options. Strong commitment and determination on part of the federal and state governments will be necessary to realize the dissemination of clean and efficient energy for adoption by the rural poor. Efficient dissemination would require improvement in the distribution infrastructure for taking clean and affordable energy to rural areas in addition to providing the rural people with suitable options for greater income earning opportunities.

The results of the study can also have a bearing on the national REDD–plus strategy as these corroborate the role and potential of the actions that on one hand can reduce the emissions from fuelwood burning, and on the other can facilitate conservation of forests and enhancement of forest carbon stocks. The study can also provide some inputs for the mechanism for safeguarding the health and socio-economic interests of the local people.

Limitations

The estimation is based on use of average values available for some prominent species and forest types in respect of expansion and conversion factors; and ratios for calculating forest carbon content. The carbon mass balance approach is not based on local experimentation to assess the annual increment in forest biomass carbon, and thus may introduce error in the estimates of addition of biomass carbon in the regional managed forests. The second limitation is non-inclusion of all actual extractions of biomass from forests for anthropogenic use. Hence, conclusion about the quantitative role of regional managed forests as a sink may need revision based on other identified anthropogenic extractions of forest biomass.

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Sustainable Wood Energy Management in the SAARC Region: Scenario and Future Options

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Wood energy remains and will continue to remain in the foreseeable future, the most preferred form of energy for majority of population in the SAARC Countries for meeting its domestic energy needs; due to its almost cash free availability, accessibility due to proximity; and unavailability of alternatives. It is estimated that as high as 94% Sri Lankan rural households are dependent on wood energy for cooking while over three fourths in Bhutan and Nepal, two thirds in Bangladesh and India and one third in Pakistan use wood energy as prime source to meet their energy needs. (Country Outlook Study Reports). People living in the rural areas who predominantly constitute the low socio-economic strata of society have to go for it.

Natural forests are the main supply sources in the Region. However, but for Bhutan where firewood production potential is not a major problem due to its 72% area being under natural forests, all other SAARC countries face formidable challenge of sustainable production, extraction and supply of fuel wood from forests. Over the years, the demand supply gap has been, however, widening due to increase in population on one side and rapid depletion of the resources on the other. The task of developing WE resources to balance supply-demand equation sustainably has become a major challenge.

Country wise Scenario (Current as well as Future)

Afghanistan

There is little data available on the demand supply position either current or in future for the country. It is estimated that during 1996-1998 a quantity of 6210 000 cubic meters fuelwood was used. The country being predominantly agrarian and rural with limited other resources of energy it is much dependent on the fuelwood for meeting its energy needs.

Bangladesh

Fuelwood is the major wood product required today, Bangladesh needs over 8.0 million cubic meter fuelwood every year. Domestic cooking uses an estimated 63%, which is 5.1 million cubic meter annually. Industrial and commercial use is also significant, which is 2.9 million cubic meter annually. According to Forestry Master Plan, village household supply about 75% of the fuelwood in the country The remaining 25% comes from government forestry program. Due to limited alternative sources of energy the rural people are mainly dependant on fuelwood for cooking and other household activities. Rural population uses fuelwood and other minor forest products practically free of cost.

Bhutan

Wood is easily available in most parts of the country. The other sources of energy like LPG, kerosene are more expensive because of the heavy cost of transportation. On the other hand electricity has not reached all rural areas, therefore wood is the cheapest source of energy. Firewood is supplied free of cost for people living in rural areas. Detailed analysis of energy consumption during 2005 showed that 58.96 percent of the total energy consumed was firewood followed by electricity which constituted 13.81 percent and diesel constituting 11.76 percent. Fuelwood is being used by many sectors in the country. The most prominent are (i) Agriculture, (ii) Residential (both rural and urban areas), (iii) Institutional (including hotels and restaurants), (iv) industrial and finally a small quantity is consumed for cremation. People in the rural areas depend on wood as a source of energy for cooking, space heating and also for cooking fodder for their animals. People living in the colder region use more wood per capita as an energy source than people living in the warmer climate.

Firewood is obtained from the natural forest. In the foreseeable future of about 12 to 15 years, the main source of energy will still be fuelwood obtained from natural forest Supply of huge volumes of wood as firewood is impacting negatively on the forest resources of the country. Presently most fuelwood is produced from government-reserved forest and partly from community and private forests. However if bio-fuel production picks up greatly then there could be heavy pressure on government-reserved forest. Large tracts of forest area could be converted to other land use. The implication is reduction in forest areas Further, the demand for firewood is also increasing steadily. At the national level firewood production potential and extraction is not a major problem. However, at the local level, extraction of firewood and sustainable management of forest for firewood supply is a critical forest management problem because of the concentration of human settlement in the valley and other favourable locations. This situation also poses extra stress on forests near the settlements leading to forest fragmentation and degradation.

India

Wood Energy accounts for about 67% of the total fuel consumption in rural India (FSI, 2002). It is the mainstay of India's rural population for cooking food and for other household and non-agricultural works such as rural crafts. The annual consumption can be taken to be ranging between 250-300 million. cubic metres. Of this, only about 17 million cubic metres. of fuelwood is recorded to come from India's forest, leaving a staggering gap of more than 90% of the total consumption. Part of the gap is absorbed by production from forest and trees outside the forests but much of it is collected in an unorganized way from the forests. This is an important factor impacting the growing stock and ecological imbalances. Based on per capita fuelwood consumption, Forest Survey of India, Dehradun has estimated the annual consumption of fuelwood in rural areas in the vicinity of forests and non-forest areas at 78 million tons and 74 million tons respectively. The average per capita consumption was 424 kg and 144 kg respectively.

The fuelwood collection ("head loading") from forests is traditionally uncontrolled and unmonitored. About 75% of all forest production is said to be fuelwood, mostly collected from natural forests. Although most of the 225 million cubic metres of fuelwood is consumed domestically by the forest dependent poor including tribals. The sale of fuelwood is also a major source of income. About 30 million cubic metres of fuelwood is used for industrial purposes, including as charcoal.

The fuelwood consumption is projected to go up to 400 million cubic meters in 2020. This is quite reasonable to assume when FAO (1997) has projected fuelwood consumption of

262.782 million cubic metres in 1993 and 302.387 million cubic meter in 2010. Fuelwood is likely to continue to be the most important fuel for cooking and heating particularly in rural areas in the vicinity of forests. However, the proportion of fuelwood from forest and non forest sources is likely to remain at 50:50. Presuming the current trend of decadal population growth there is no likelihood of any perceptible change in the present amount of household fuelwood consumption. This optimism is based on the projected trend for use of LPG for heating water and cooking among rural middle (20%,) rural high (20%), urban low (10%) and urban 57 middle (60%) classes. Gradually LPG supply is reaching the slums and rural areas in the vicinity of medium and small towns as well.

Maldives

Brush wood is used for cooking; it is collected by the islanders with the permission of the island chief. The island authorities permit the locals to collect fire wood on a stipulated day. Although firewood consumption is declining, wood can be seen piled up in houses for domestic use. Wood consumption seems to be higher during the *Ramazan.* Considerable amounts of wood materials are harvested on the inhabited Island and are used. Harvested volumes and the sustainability of harvesting regimes are however not known. The cumulative effects of this exploitation combined with the amount of wooded areas cleared for house construction and agriculture will be a problem in future. Firewood is slowly being replaced by kerosene and gas in domestic cooking. However, in rural areas a considerable percentage of households still cook their food with firewood.

Another important use of firewood is in fish smoking. Traditionally smoking of fish was the main way to preserve perishable products for distant markets. However fishermen now sell their catches directly to the ships provided by industrial processing companies. Accordingly, the need for firewood for fish smoking is also declining.

Nepal

Fuelwood is consumed in households as well as industries. Per capita consumption in household varies from one physiographic zone to another, because of climatic, economic and other differences It is estimated that household fuel consumption in the Middle Mountains and Siwaliks will continue to increase. However, consumption in the High Mountains and High Himalayas will decline, as the population in these areas decreases because of migration to lower zones. The Terai has the biggest projected increase in consumption as a result of the big population increase that is expected, mainly from migration. It is estimated that 80% of fuelwood is obtained from forests, and private trees are the source of the remaining 20% fuelwood demand. A decrease is predicted in fuelwood use by industries after 2000, as industries switch over to alternative fuels possibly electricity.

Overall fuelwood surpluses will not be attained in the country under the current trends assumptions even when its projected plantations, managed natural forests and private tree farms are in full production.

Pakistan

The share of wood energy in rural energy consumption is 37.52%.The consumption of fuelwood is higher in rural areas, and Punjab followed by NWFP and Sindh. The consumption of fuelwood is more for domestic purpose, mostly in rural areas, followed by the industrial sector. The consumption of fuelwood was estimated at 26 million m3 in 1992 and this increased to 31.52 million m3 in 2003. Firewood, dung and agricultural residues are the main cooking and heating fuels used by 90% of the rural and 60% of the urban households (FSMP, 1992). Thus, 32% of the total energy requirements in the country are met through biomass. Only 10% of people's firewood requirements are met by state forests and plantations. Mangroves provide fuelwood to about 12,000 people. The remaining 90% of the total requirement is met from farm trees. Fuelwood consumption per capita is highest in NAs, FATA and Balochistan in descending order

According to the projections, domestic use of fuelwood and industrial use of wood will increase significantly but the use of industrial fuelwood will remain static. However, the envisaged increase in the projections, especially for fuelwood appears to be on the higher side considering the reduced population growth rate per annum and the use of alternatives for fuelwood. Use of wood, as fuel, will no longer be a cheaper option in the wake of inflated rates of forest labour and transportation charges of fuelwood According to linear trends, fuelwood demand would increase from 31.523 million m^3 in 2003 to 42.051 million m^3 by 2018 on existing per capita consumption of 0.205 m^3 and population growth rate of 1.94%. The future scenario regarding wood energy is that the demand for wood would increase in the short and medium term but would stabilize in the long term with import of natural gas and LPG, and development of small, medium and mega hydropower, biogas, solar and wind energy and Thar coal reserves as well cost effective technology for use of the new sources of energy.

The key challenge, however, is high demand of wood for fuel. Currently, the management approach focuses on extraction of resources with almost no management input and investment in production.

Sri Lanka

Fuelwood is used mainly in the domestic sector for cooking, to a small extent for keeping houses warm in the montane region and in some industries for drying and heating purposes. Ninety four per cent of Sri Lankan households use fuelwood for cooking. Electricity is used mainly for lighting and in industries.

Numerous fuelwood planting programmes have been started in the country in the recent years. Fuelwood is also produced from thinnings and branches from forest plantations. The agro-based plantation fuelwood and extensive non-forest fuelwood planting programmes are mainly meant to supply fuelwood for industries. In addition to the Forest Department, agencies that have undertaken fuelwood planting programmes of their own include tea industry, Sri Lanka's State Plantation Corporation, Janatha Estate Development Board, Ceylon Tobacco Company, Ceramic Corporation, Brick and Tile Industries and Mahaweli Development Authority. The FD, with the forestry extension division has provided technical assistance to most of these institutions in raising fuelwood plantations.

Future Strategies and Approach

There are three workable strategies either independent or in combination of bridging the demand supply gap sustainably:

(i) Demand management

(ii) Supply enhancement through improved distribution systems and increased production management of natural forest, new reforestation and afforestation, private tree planting etc.

(iii) Development of alternatives.

The first approach calls for tackling social and economic factors while the third approach may result in a limited gain as all the SAARC countries are developing economies with limited investment capabilities for providing alternative sources of energy such as electricity or fossil fuels at affordable prices to their poor people. The second approach is therefore, better suited to the Region compared to the other two.

Supply Enhancement

Where woodfuel is yet not a traded item, it will be difficult without its integration into local farming and forestry management practices to enhance the supply. Where woodfuel is collected mostly free of charge for subsistence, no prospect exists for its commercial production in the short-run. In such a case, local people's participation in the sustainable production and utilisation of woodfuel from locally available resources (mostly from existing natural forest and shrub/scrub and waste lands will be appropriate strategy. Tree planning in community wastelands could contribute to the development of new supply sources in the form of village or community woodlots. Therefore continuation of the prevailing programme of social/ community forestry, which primarily aims to promote participatory forestry development schemes, may be the most feasible low-cost strategy to meet the basic subsistence energy needs of the poor and small farming communities in rural areas.

Woodfuel production and consequently supply can be enhanced by (i) increasing production area (ii) increasing productivity, (iii) adopting improved agronomical & silvicultural practices and (iv) Juxtaposing i. ii. iii. It may be decided to adopt the methodology as per the local conditions and factors prevailing there, yet on the national level and as a general approach the reallocation of wasteland to the fuelwood producing area appears to be the most logical. Current scenario in Land Management in the SAARC Region in general (exception rugged mountainous part where land is limited) depicts a picture of sub-optimal use of the prime resource i.e. land. According to the land use statistics available from these countries, a sizeable percentage of land which is non arable is still non operational eg. culturable waste, or permanent fallow lands. Cultivable wastelands inter alia include gullied or ravines lands, upland hilly areas, waterlogged areas, salt affected land, shifting cultivation areas, strip lands, sandy and mining areas. These areas can be targeted, possibilities for energy tree plantation explored and areas can be selected which would ensure an yield of 5 tonnes per hectare per year on an average.

The first step towards achieving sustainability is to gather extensively the updated information at the local(micro) level: land use pattern, fuelwood requirement, demand supply position. The deficiency – surplus position can then be taken care of by adopting suitable extra measures keeping affordability and accessibility angles in mind. The issues are localized and solved. Since land use map, resource map, energy use pattern, vegetative map, demographic and other data are available for almost all districts in all the countries they can be processed using computers and other aids to obtain district wise fuelwood resource mapping. A uniform strategy for the Region as a whole is however will neither be prudent nor appropriate as the fuelwood parameters and factors vary considerably from area to area. Similarly the extent of wasteland and categories of wasteland differ considerably from area to area or even from one district to another. Thus, the task of reallocating the wasteland for its optimal use of fuelwood production should be taken considering district/division as a unit.

The implementation can be done at two levels micro e.g. a district/division level and macro e.g. national level. At the district level implementation programme for five years can be chalked out which would include resource mapping and analysis of data in the first year and actual work for the next four years. The resources – human, institutional, financial should be geared up for implementation. Social forestry wing of the forest department may be assigned the task of greening the wastelands whereas the forest department can take up the responsibility to rehabilitate the degraded forest land.

At the national level an apex coordination body may be established to coordinate among the various ministries, departments, state governments and other agencies so as to avoid fragmented approach and non utilization of funds in many cases. A national action plan of fuelwood resource development may be prepared in which and all activities in all targeted areas with all financial institutional and human resource details be included in the stated time frame.

Supply of Traded Woodfuel

The demand for market traded woodfuel is also not expected to be met (at least in the short term) by the development of new supply sources in the form of large-scale woodfuel plantations. Public supply sources, particularly government-managed forests, may still continue to be major suppliers as far as woodfuel used by institutions and traditional industries are concerned. Hence, the sustainable management of existing natural forest and plantations is necessary to at least partially meet the market demand for woodfuel. Public supply sources should even be managed from the point of view of price maintenance in the short run in order to supply the urban poor with woodfuel. Large scale plantations for commercial purpose by private entrepreneurs are also economically not viable due to low sale price of the fuelwood in the market. It can be grown by a particular industry to meet its own requirement. However, the land allocation may not be subsidized. Land may be made available only at its market price.

Trees outside Forests (TOF) have immense potential for sustainable wood energy development in the Region (except in high forested Bhutan) . Farmers, particularly small and marginal farmers should be encouraged to grow, on marginal/ degraded lands available to them, wood species required for trade.These may also be grown on community lands not required for pasture purposes, and by Forest department/corporation on degraded forests not earmarked for natural regeneration Land could be under the ownership of forest Department, revenue department. Military or it could be community land owned by local bodies as in case of India they are Panchayats Plants and technical know how could be provided by the forest department, wages under any rural development schemes meant for employment generation and protection responsibilities be given to the local bodies. Other costs and expenses could be borne by a private entrepreneur. The benefits accrued (grasses, minor produces, fuelwood) would accordingly be divided among the villagers and industrial timber to the entrepreneur. There would be tri-partite agreement between the industrial house, local body and the local forest department. The rights of local people if any, over the forest land would not be affected by the agreement in any case. In another model, the wages also could be provided by the private entrepreneurs who then could be entitled for final harvesting of industrial timber. Nevertheless, in any case, there will be much enhancement in wood fuel supply to the villagers and at the same time disburdening of the natural forests.

Conclusion

SAARC Region with great land and water resources has every potential to attain the goal of sustainable wood energy development through proper forest and other culturable land management and optimizing there land use pattern. Money is also not an important constraints. Public- private partnership models will take care of monetary requirements. The need of the hour is to adopt focussed strategies in policy implementation and prioritizing wood energy issues in the national agenda. A little persistent effort can overcome the threats and can change the overall scenario of wood energy in the countries and make the system sustainable and effective. The need of the hour is to give a deeper insight.

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