Synergies of Remote Sensing with Social Science Tools for Participatory Management of Natural Resources

Dr. Md. Abu Syed[1], Prof. M. Al Amin[2] and Dr. Atiq Rahman[1], Dr. Dwijen Mallick[1]

[1] Bangladesh Centre for Advanced Studies (BCAS), House # 10, Road 16A, Gulshan 1, Dhaka 1212, E-mail: abu.syed@bcas.net and mabusyed@gmail.com
[2] Institute of Forestry and Environmental Sciences, University of Chittagong, Hathazari, Chittagong, Bangladesh

Abstract

Rising temperatures, increasing erratic rainfall, and more frequent and severe floods, cyclones and droughts all have significant negative impacts on ecosystems, society, economy and consequences for the lives and livelihood of people. To ensure sustainable ecosystem services, climate resilient Natural Resource Management (NRM) and climate change adaptation, it is necessary to understand who, how and where is vulnerable to the climate induced conditions in any ecosystem. Landscape level planning (LLP) is a concept in managing ecosystems. In accomplishing LLP it is crucial to understand ecosystem strengths and opportunities as well as the drivers of degradation in a holistic approach with their spatio-temporal dynamism. Remote sensing and GIS are the tools appreciated by scientific communities that facilitate a landscape level perspective with space and time dimensions. Syntheses of ecosystem coupled with socio-economic information in geospatial environment were done to discern potentials in the landscape and ecosystems towards eco-restoration of degraded ecosystems. Ecologically important landscape, the Himchari National Park (HNP) was selected for the study in Bangladesh. This research demonstrates potentials and importance of iterative and interactive use of geospatial and social science techniques and tools in synergistic approach for sustainable development and adaptation. The potential synergies and complementarities among GIS and social science methods and tools may be used to guide formulation of effective adaptation options. The research highlighted the need for a shift in policy approaches from a conventional ecosystem only or society only focus, which may result in unsustainable ecosystem services; to an integrated approach with policy coherence at national down to landscape level.

Key Words: Sustainable Eco-restoration, Landscape Level Planning (LLP), Protected Forest Areas, Remote Sensing & GIS, Participatory Climate Vulnerability Assessment (PCVA), community based adaptation to CC.

1. Challenges and opportunities in the Management of Forest Protected Areas

Rising temperatures, increasing erratic rainfall, and more frequent and severe floods, cyclones and droughts all have significant negative impacts on ecosystems, society and economy and bad consequences for the lives and livelihood of people. Tropical forests are vulnerable to a warmer, drier climate, which may exacerbate global warming through a positive feedback that decreases evaporative cooling, releases CO2, and initiates forest dieback. Moreover, according to the largest analysis to date of the rapidly shifting ranges of species in Europe, North America, Chile and Malaysia, the greater the warming in any given region, the farther its plants and animals have migrated (Allen et al. 2010 and Gadgil and Rupa, 2006). Attempts were made to understand the exposure of the ecosystems to the changing climate especially global warming and its impacts through changes in micro climate. Conceptual diagram (Figure 1) schematically represents the key assumption of the research how range of variability of climatic parameters for precipitation and temperature, with only a small portion of the climate ‘‘space’’ currently exceeding a species-specific tree mortality threshold. In the diagram ‘‘Future Climate’’ shows increases in extreme drought and temperature events associated with projected warming indicating heightened risks of die-off/ shifting of plant species to more suitable location where favorable climatic conditions prevail.

Climate has a major influence on rates of photosynthesis and respiration (Lewis, 2006; Lenoir, 2008; Stocker et al. 2013), and on other hand forest processes, acting through temperature, radiation, and moisture regimes over medium and long time periods. Climate and weather conditions also directly influence shorter-term processes in forests, such as frequency of storms and wildfires, herbivory and species migration (Jones et al. 2009). As the global climate changes, forest ecosystems will change because species’ physiological tolerances may be exceeded and the rates of biophysical forest processes will be altered (Olesen et al. 2007; Kellomaki et al. 2008 and Malhi et al. 2008).

Tropical forests ecosystems are complex, self-organizing systems with multiple natural processes that respond autonomously to internal and external drivers (Lenoir, 2008). If available water becomes limiting, the height and density of the tree canopies are reduced because of basic ecophysiological relationships those regulating plant growth (Bonan 2008 and Allen et al. 2010). If climate change results in a significant reduction in water availability, then the forest system will naturally change species composition (Kelly and Goulden, 2008). The vegetation will reach a threshold beyond which the vegetation structure is not sufficiently tall and dense to comprise a forest, along with the concomitant changes in the dominant taxonomic composition of the plant community (Lewis, 2006). Hence, maintaining forest resilience can be an important mechanism to mitigate and adapt to climate change (Allen et al. 2010). Societal responses, particularly adaptations, will influence near-term outcomes

1.1 Climate change and tropical forest ecosystems

The resilience of tropical forests is seen under pressure from climate change as well as local stressors such as deforestation, illegal logging, and forest fire (Malhi et al., 2008). The pattern and behaviour of climate, including variability and extreme events, play a significant role in ecosystem performance, water availability; and hence its growth regime and its productivity; in the function of natural ecosystems and biodiversity; in influencing human health; and in influencing the livelihood of the people dependent on the natural resource base. In addition, forest cover regulates regional precipitation signifying that loss of forest contributes to overall rainfall reduction increasing the risk of happening forest fire (Malhi et al., 2008 and Brando et al., 2014). Climatic and landscape features set the ultimate limits to the geographic distribution of species and determine the seasonal conditions for establishment, recruitment, growth and survival (Rejmánek and Richardson 1996; Thuiller et. al., 2006). It is well established and understood fact that climate is an overall regulator of vegetation, that species distributions in the past have varied as climate changed, and that we can expect plant species to continue to shift to in range and abundance as the climate continues to change (see, for example; Woodward 1987). Studies have shown that: (a) species generally shifted northward (Delcourt and Delcourt 1988); (b) species did not shift in unison—that is, the rates and direction of migration differed among taxa, and species assemblages did not remain the same (Davis 1981; Webb 1992); and (c) variations in competition and dispersal mechanisms seemed to have little influence on vegetation migration patterns or rates—that is, historical data show little distinction in past migration patterns between trees with wind dispersed propagules and trees with animal-dispersed propagules (Malanson 1992). During the Holocene, species tended to remain in equilibrium with the climate even though it was changing, as migrations were occurring over thousands of years and over a relatively uninterrupted landscape. The climate will change at a faster rate; moreover, natural migrations will be inhibited in today's fragmented and human-dominated landscapes (Iverson and others 1999). Thus, it is difficult to assess what the future may hold for forest species and communities.

The observed climatic data from 1978 to 2012 indicate that the average temperature in Bangladesh is increasing for all the four seasons. In pre-monsoon (March-May) average maximum and minimum temperature was found to be increasing at a rate of 0.016°C and 0.015°C per year respectively. Similarly, the rate of increase in average maximum and minimum were found 0.034°C and 0.014°C for monsoon (June- August), 0.018°C and 0.010°C for post- monsoon (September-November) and 0.015°C and 0.009°C for winter (December- February). With rising temperatures, Bangladesh is also experiencing a higher occurrence of drought. During 1960 to 1991, there were 19 droughts year, which covered as much as 47% of the country's area and 53% of the current population.

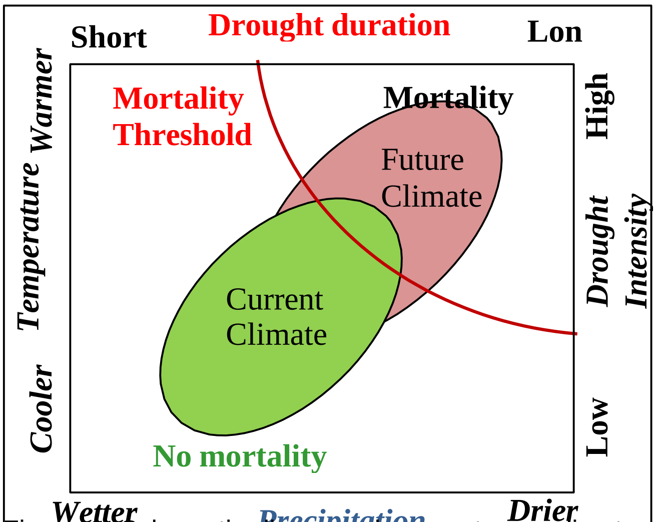

Figure 1. Schematic diagram shows extreme climate, conditions and ecosystem responses (Adopted from Allen et. al. 2010)

The natural ecosystems both the terrestrial and coastal within geographical boundary of Bangladesh would be under serious threat due to rises in surface water temperature. If the temperature increases over 32°C as predicted, this would certainly impact ecosystems in various ways and induce shift in plant species communities in the tropical ecosystems of Bangladesh. Further rises would facilitate invasion of alien species that might seriously affect the ecosystem products and services.

The impacts of global warming on the climate, however, will vary in different regions of the world. According to estimates by a World Bank assessment of climate change impacts in Bangladesh, a small change in peak discharge may result in about 20% increase in the area flooded. Similarly, riverbank erosion is exponentially related to maximum flood levels. In addition to rise in temperature these extreme events would affect various ecosystems.

A recent study in Sitakunda Eco-Park in Chittagong revealed that over a three year period, 63 native tree species sprouted from root suckers, stump coppices and in-situ seed sources, and these trees had attained height 1-2 meters (Misbahuzzaman and Alam, 2006). The later studies demonstrate the ability of native forest ecosystems to recover in denuded areas; even when seed-bearing “mother trees” are almost absent. The density of natural regeneration that has been recorded is species 3502.5 per ha, which is greater than the density usually be found in plantations planted at 2 m by 2 m spacing yielding 2500 seedlings per ha (Misbahuzzaman and Alam, 2006). Another study of a natural regeneration in degraded hill forest at Faitong, Bandarban Hill District, revealed that after 25 years, 58 native tree species were present with a stocking rate of 2,457 stems per ha (BFRI, 2009).

These few examples of natural regeneration and restoration of forest ecosystems in hill forests suggest creating a safe operating space involving surrounding dependent people in managing and regulating resources extraction from the protected area may be one of the management options for degraded forest ecosystems.

2. Approach and methods: Synergy of physical and social science methods

Landscape Level Planning (LLP) acknowledges the role of human actions in the environment while committing to a goal of sustaining biodiversity, agricultural production, and rural and urban settlements and industrial activities. Moreover, LLP examines and seeks solutions to multidisciplinary issues that affect sustainability within a natural landscape boundary. Furthermore sustainable landscape level management requires consideration of a variety of social, environmental, economic and political issues, making LLP both challenging and complex as well as sufficient and appropriate technical skills to address the issues encountered and communication forums that promote dialogue and consensus among relevant stakeholders. A key element of this kind of participatory planning and management is accurate and detailed geo-spatial data and maps that facilitate informed decision making. This includes mapped information showing the size, shape and interconnections among PAs, its elements, current land use patterns, the location, size and names of settlements and urban centers, the location and names of water courses and water bodies and relevant infrastructure such as roads, rail lines, business centers, government and non-government offices, *etc*.

Synergies of remote sensing, GIS and Participatory Climate Vulnerability Assessment (PCVA) tools helps us to understand the impacts and multiple risks of climate change on forest, biodiversity, lives and livelihoods of the people. GIS tools were used in conjunction with PCVA tools to map the challenges ecosystems face from climate and society. Assumption here is that climate change impacts are additional pressure to the existing socioeconomic ones. When considering the ecological health and integrity of Protected Area (PA) it is important to note that areas such as Himchari National Park (HNP) a PA considered being one of Bangladesh’s important biodiversity and eco-tourism sites, is in fact logged over secondary forest that developed over the past 50 to 60 years in areas where long and short rotation mono-culture plantations were established. Himchari National Park (HNP) is located between 91°58”5’ east to 92°22”5’ east and 21°20”45’ north to 21°26”30’ north Bangladesh government has declared it as a national park in 1980 under Wildlife act 1974. Notable among the major stressors of PAs are:

- illegal exploitation of forest resources for domestic firewood, collection for firewood for sale in urban areas,
- timber exploitation for local construction needs, commercial sawmills and brick fields;

- agriculture and grazing activities within PAs; and
- encroachment of settlements within PAs;

Rapid Eye imagery of November 12, 2013 and February 10, 2013 were used to classify the park. This is winter season and this is to lessen the atmospheric disturbance usually occurs in the satellite images. To classify the image we applied segmentation based approach in the ecognition i.e multi- resolution segmentation then we also applied region grow algorithm to clump similar or same object into a larger one. Again we applied brightness based filtering to sort out the intended classes. After all we generated a classification.

Finally geospatial analyses incorporating socio-economic data were carried out to come up with landscape level restoration plan. This research utilized a tested methodology for participatory mapping process and a decision support system at landscape level. However, landscape level planning is the prime objective of this mapping study with inputs from PA dependent communities. Hence, on screen digitizing of polygons was done on the images depicting some specific classes which are important for landscape level planning for sustainable forest resources management. To do so a list of land use classes for each landscape was developed in a common understanding with stakeholders. These agreed land use classes were demarcated on 1:10,000 scale map print of Rapid Eye bands 432 in RGB false color composite through extensive field survey. Here again people living around the protected area could help in locating and identifying important features or the ecosystem. Finally draft land use maps, climate hange risk and threats maps and adaptation maps were taken to the PA dependent communities again. So that they can evaluate maps if these really reflect real world conditions and their (people) inputs.

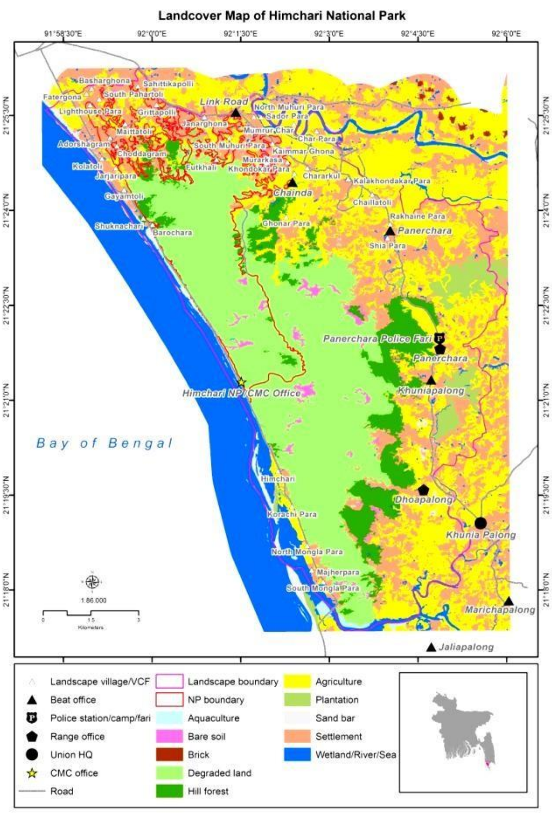

Figure 2. Land use map of HNP landscape

3.1 Climate Vulnerability and threat map

Climate change vulnerability and risk maps

Field exploratory surveys showed significant number of degraded forest patches in HNP which can also be visualized on land use map (Figure 2). Hence there are enormous opportunities for assisted natural regeneration enrichment planting, habitat restoration and agroforestry in HNP (Figure 3). Enhanced livelihoods will reduce local population's dependence on natural resources within the NP contributing to greater protection and integrity of natural habitats supporting native biodiversity.

Degraded sites present huge opportunities to enhance the productivity of natural ecosystems which in turn can augment the income of local populations and lessen their reliance on the remaining natural resources that have been designated for protection through ecological restoration (assisted natural regeneration/ enrichment planting). Vegetative cover is an important way to lessen soil erosion on degraded slopes. The maps vulnerability illustrate prospective management options suggested in the area for restoration of the ecosystem and hence ensuring sustainable conservation and management of the landscapes. This type of broad based recommendation maps needs further field level endorsement and validation by the communities in the landscape particularly those who are going to be involved in participatory management of the ecosystem. Considering all these communities came up with Climate change vulnerability and risk maps with assistance from research team. A whole set of detailed PCVA tools were sued in engaging communities and taking in their inputs. All detailed PCVA tools and steps are not present here for brevity reason only.

The land use/cover statistics for the area that are inside the national park are as below:

Land use/cover class	Area(hectares)
Aquaculture	0.85
Bare soil	24.86
Degraded land	1379.05
Hill forest	130.70
Irrigated agriculture	117.87
non-native plantation	13.22
Sand bar	3.19
Settlement	309.63
Wetland	4.83
Total	1984.19

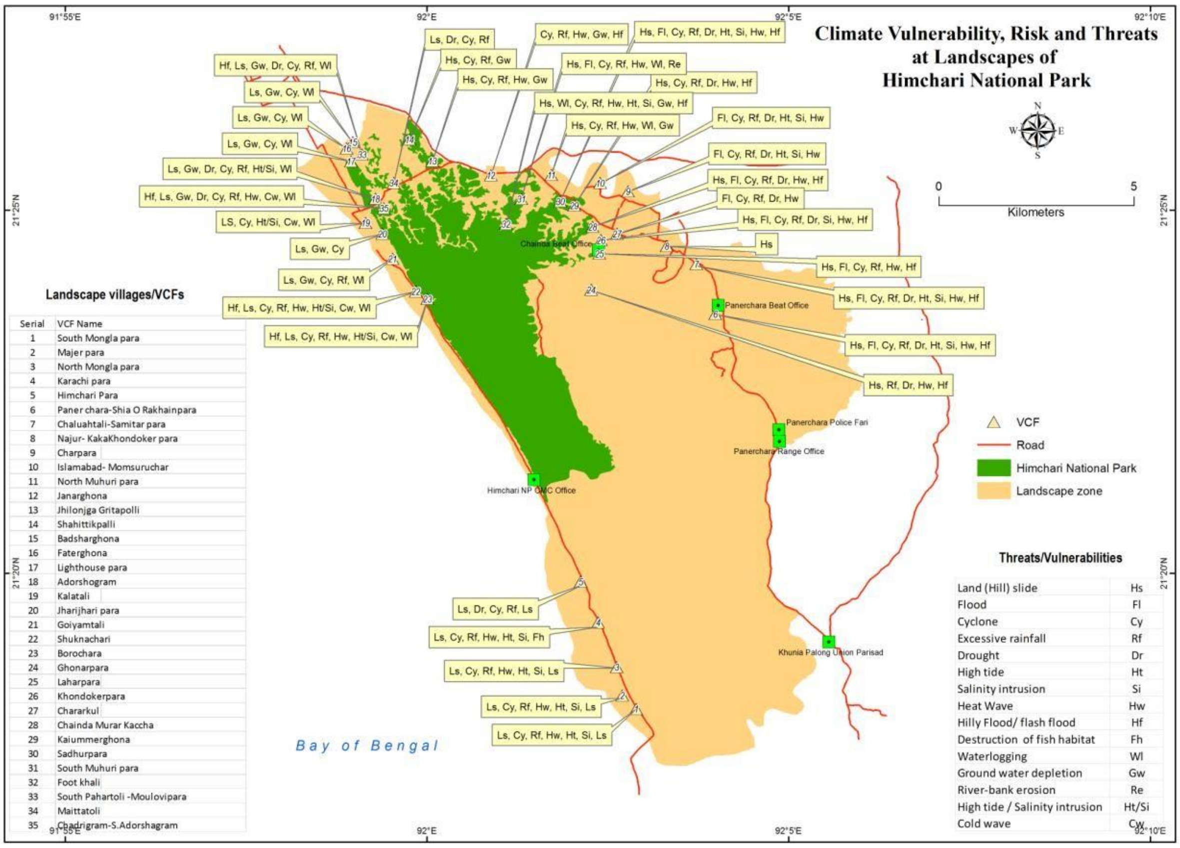

Figure 3. Climate change vulnerability and risk maps produced through participatory GIS exercise engaging PA dependent communities.

3.2 Community suggested adaptation options at Himchari National Park landscape

The final step of the PCVA would be to share the findings and engage the VCF (Village Conservation forum), CMC (Co-Management Council) members, local actors and stakeholder to improve the local NRM plan with adaptation, mitigation and DRR (Disaster Risk Reduction) options. The community level workshop, consultations enabled sharing the findings of PCVA and facilitate exchange and reflection on risk, vulnerability, adaptation and mitigation strategies and options. The appropriate adaptation and mitigation options may be integrated into the existing PA/ Co-management plan. While adaptation, DRR options were taken into the planning process, also taken into mapping process were the ecosystem management options suggested by experts which were shared with communities. Finally with their inputs Finally

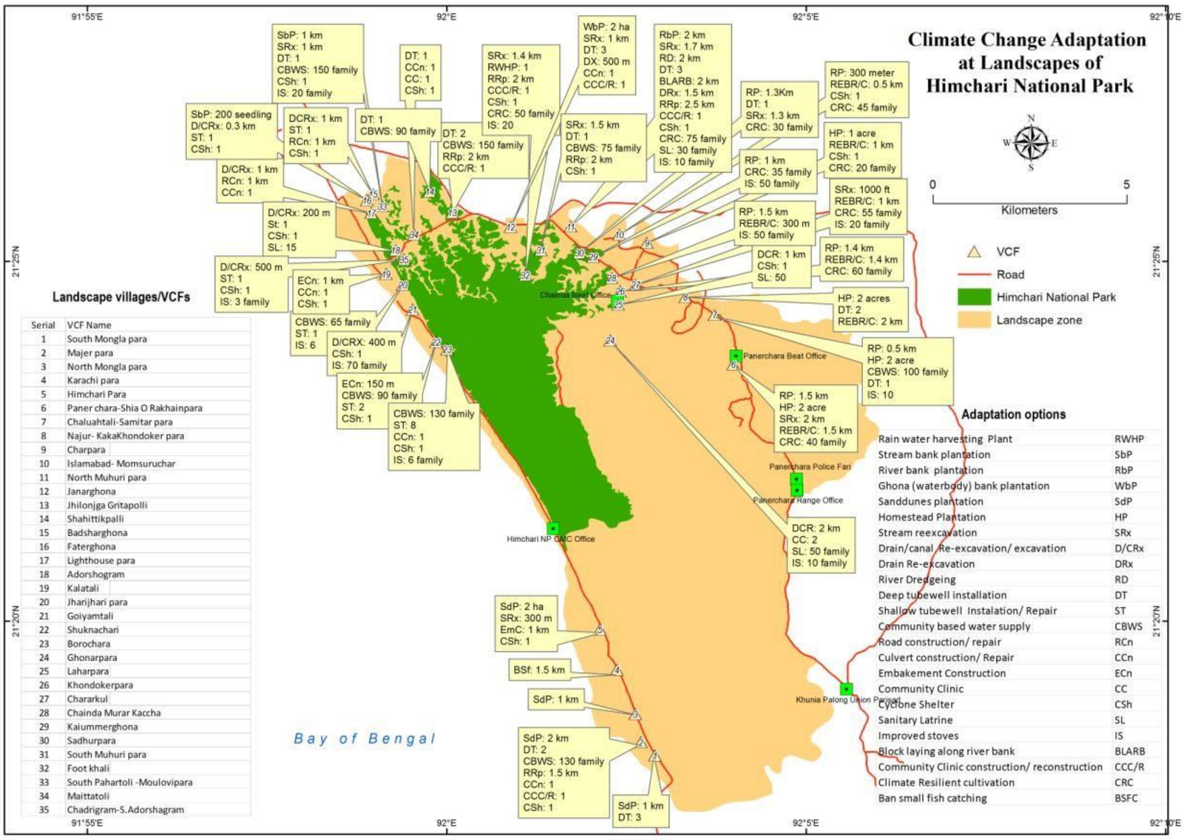

Figure g. 3: Map showing proposed adaptation options at Himachari National Park landscape options

3.3 Plantation Forestry–An option for landscape level management of PAs

Plantations also may play an important role in providing an alternative source of wood resources that might otherwise be derived from forests of the core protection zone or other forested areas within the HNP and Himchari landscape. Plantation forests are also important in the context of their contribution to Alternative Income Generation (AIG) activities that may be linked to the types of trees or other plants grown. Enrichment plantation, natural regeneration management, buffer plantation, and strip plantation in the marginal land may be the establishment methods for successful plantation. Silvicultural requirements for medium or long term maintenance of a plantation in the target landscapes may be weeding, thinning and final harvest. However, the success of plantation management relies on regular monitoring by a team formed for such purpose. The CMC working with the FD may form the monitoring team. Infrastructure required to support this type of plantation includes nursery shed, nursery implements, water supply facilities, and nursery fencing. Moreover, FD field staffs and participating community members will require training on nursery raising and plantation establishment techniques. Office and residential facilities may also need to be provided. In this case, buffer plantations and strip plantations may be raised by community members based on a Participatory Conservation Benefit Sharing Agreement (PCBSA). Forest products obtained from cleaning, pruning and thinning can be distributed among the members through the CMC. In case of buffer plantations, the distribution may be as follows: 45% to the participants; 45% to Forest Department; 10% as TFF (Tree Farming Fund). In case of Strip plantations, it may be 55% to the participants; 20% to the Land owner; 10% to Forest Department; 5% to Union Parishad and 10% as TFF.

3.4 Habitat Restoration and Assisted Natural Regeneration, Enrichment Planting for Management of the PAs

Restoration activities that increase plant cover on severely degraded or otherwise disturbed lands have a high potential to increase carbon sequestration and enhance biodiversity. Thus restoration as a critical component of sustainable environmental management will aid in reducing deforestation and degradation and is linked with climate change mitigation strategies and REDD projects. Degraded secondary forests are characterized by high potential biomass production with the potential to make important contributions to carbon sequestration projects by using different approaches of eco-restoration aimed at harnessing large amounts of atmospheric carbon while also contributing to improved long term protection of biodiversity. Carbon projects using restoration ecology can also provide high levels of social, cultural, and ecological services by planting native tree species of traditional importance to local communities and preserving and enhancing many of the secondary forest's ecological services. Therefore, ecological restoration which promotes enrichment tree planting in degraded forests could be considered as a way to promote synergies between two UN Conventions: climate change and biodiversity. Bio-geographical settings and physical conditions are not similar at Himachari. So, site assessment for each area may differ and one should be flexible in selecting sites considering the unique situation present within specific sites. The following site conditions should be considered but not be limited: Degraded land with no tree cover, Forest land with scattered trees and bamboos, Lands covered with scrubs, Plantations covered with Acacia auriculiformis, Degraded plantations and mini water catchments. In selecting sites the presence of native trees or older plantation tree patches and areas with natural vegetation along watercourses should be taken into consideration. Furthermore, edaphic and climatic factors are two major criteria for selecting of species for particular sites. Restoration of an ecosystem is a human initiated intervention intended to aid in the recovery of an ecosystem. Accordingly the restoration process may involve assisting different stages in the succession of plant community development. The level of degradation, canopy cover, presence and trend of existing natural regeneration processes are all important factors to consider in the selection of species to be used in the restoration process. In selecting species for restoration program knowledge of local flora, vegetation communities, past history of vegetation, and vegetation dynamics are important. In the recovery process at the early stages of succession are characterized by pioneer species, followed by the second storey species and ultimately the climax or top canopy species. In addition, framework species for rapid regeneration of a forest and indigenous species to bring back a forest in its resilient state may be planted in the target landscapes (HNP). However, the success of an ecological restoration project depends largely on its approaches. Generally an experimental approach should be taken that relies on multiple approaches to ensure success. The most commonly used strategy for accelerating forest succession is planting seedlings of a few native tree species that are fast-growing, drought resistant and able to grow in low-nutrient soils. In some cases direct seeding may be a viable option, but weed invasion and predation rates are often sufficiently high to preclude this option. There are, in fact, a number of promising possibilities. No single alternative can be prescribed because each landscape has a different ecological and social situation. This means that the final outcome in any landscape will probably contain a number of alternative approaches to overcoming degradation including monocultures of exotic species as well as various versions of forest rehabilitation using some of the approaches outlined above and, in some particular situations, ecologically restored forests. The task for forest managers will then be to ensure that these options are combined in such a way as to maximize the overall ecosystem integrity across the landscape while also maximizing an improvement in human well-being. Likewise, management depends on type of establishment approach adopted and the nature of species planted. Management requirements for restoration approaches are outlined below:

i) Silvicultural management of natural succession to protect native tree growth from a variety of biotic interferences; ii) Frame work species plantings; iii) Assisted Natural Regeneration; iv) Enrichment planting; v) Mini-watershed Management (half moon trenches; contour furrows; staggered trenches; mulching; hedgerows; small check dams; impounding pits; small tanks; soil barriers and traps; and diversions ditches) and vi) Fire prevention. Traditional systems for monitoring the results through recording of survival rates after planting has to be replaced with more appropriate methods for monitoring and evaluation of restoration ecology programs. Capacity building is of prime importance in implementing a program like ecosystem restoration which includes institution development, human skills, infrastructure development and technical capacity and action research. Expected benefits from ecosystem restoration include direct benefits and indirect benefits such as: Wood products and thinning produces obtained during silvicultural operations; Non Timber Forest Products (NTFPs); Ecosystem services such as erosion control, and sustained base flow in streams; and Habitat restored for threatened, endangered and extirpated species of plants and animals.

References

Akhtaruzzaman, A.F.M., (2004), Stocktaking of Agroforestry Research in Bangladesh (Forestry Part), Consultancy Report, Sustainable Access to Agroforestry Knowledge, Technology and Information, Inter Cooperation, Dhaka, Bangladesh

Allen, C. D. Macalady, Alison K. Chenchouni, H. Bachelet, D. McDowell, N. Vennetier, M. Kitzberger, T. Rigling, A. Breshears, D.D. Hogg, E.H. (Ted). Gonzalez, P. Fensham, R. Zhang, Z. Castro, J. Demidova, N. Lim, J.H. Allard, G. Running, S.W. Semerci, A. and Cobb, N. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests, Elsevier B.V. Forest Ecology and Management 259 (2010) Pp. 660–684.

Akhtaruzzaman, A.F.M., (2010), National and Medium Term Priority Framework (NMTPF) 2010-2015 for Bangladesh: Sector Paper- Forestry, Draft Report, FAO, Dhaka

Bangladesh Forest Research Institute (BFRI) 2009. Annual Research Progress Report: Forest Inventory Division. Bangladesh Forest Research Institute, Chittagong.

Bonan, Gordon B. 2008. Forests and climate change: Forcings, feedbacks, and the climate benefits of forests; Science, 320, June 2008, DOI: 10.1126/science.320, pp. 1444–1449

Brando PM, Balch , epstad , orton , ut F , Coe T, ilv rio , Macedo M et al. (2014) Abrupt increases in Amazonian tree mortality due to drought-fire interactions; Proceedings of the National Academy of Sciences doi: 10.1073/ pnas.1305499111

Delcourt, Hazel R. and Delcourt, Paul A. (1988), Quaternary landscape ecology: Relevant scales in space and time, Landscape Ecology vol. 2 no. 1 pp 23-44 (1988) SPB Academic Publishing, The Hague

Forest Department (FD). (2006). Management Plans for Himchari National Park. Forest Department, Ministry of Environment and Forests, Government of eople's Republic of Bangladesh.

Frost, P., B. Campbell, G. Medina, and L. Usongo. (2006) Landscape-scale approaches for integrated natural resource management in tropical forest landscapes. Ecology and Society 11(2): 30. URL:.ecologyandsociety.org/vol11/iss2/art30/

Gadgil, S, and Rupa Kumar K 2006. The Asian monsoon, agriculture and economy. In: Wang B (ed) The Asian monsoon. Springer, Berlin, Pp. 651–683

Iverson LR, Prasad AM (1998) Predicting abundance of 80 tree species following climate change in the eastern United States. Ecological Monographs, 68, 465-485.

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324

Kellomaki, S., H. Peltola, T. Nuutinen, K.T. Korhonen and H. Strandman. 2008. Sensitivity of managed boreal forests in Finland to climate change, with implications for adaptive management. Phil. Trans. Roy. Soc. B: 363: 2341-2351.

Kelly A. E. and Goulden, M. L. 2008. Rapid shifts in plant distribution with recent climate change. Proceedings of the National Academy of Sciences, 105, 11823–11826.

Lenoir, J, Gegout JC, Marquet PA, De Ruffray P, Brisse H 2008. A significant upward shift in plant species optimum elevation during the 20th century. Science, 320, 1768–1771

Lewis, S.L., 2006. Tropical forests and the changing earth system. Philosophical Transactions of the Royal Society B-Biological Sciences 361, 195–210 doi:10.1098/ rstb.2005.1711.

Misbahuzzaman, K. and Alam, M.J. (2006). Ecological Restoration of Rainforest Through Aided Natural Regeneration in the Denuded Hills of Sitakunda, Chittagong, Bangladesh.

Ministry of Environment and Forests, Government of the eople’s Republic of Bangladesh (MOEF) (2004). National Biodiversity Strategy and Action Plan for Bangladesh, Dhaka, Bangladesh

Olesen, J.E., T.R. Carter, C.H. Az-Ambrona, S. Fronzek, T. Heidmann, T. Hickler, T. Holt, M. Quemeda, M. Ruiz-Ramos, G.H. Rubeak, F. Sau, B. Smith and M.T. Sykes. 2007. Uncertainties in projected impacts of climate change on European agriculture and terrestrial ecosystems. Climatic Change 81: 123-143.

Rejmánek, M. & Richardson, D.M. 1996. What attributes make some plant species more invasive? Ecology 77, 1655–1661

.

Woodward, F.I. 1987. Climate and Plant Distribution. New York: Cambridge University 174 p. Malanson 1992 Disturbance Intensity and spatial pattern and scale in the fragmented natural landscape, Ekistics

Reeve, M.S. Syed, M.A. Spengler, T. and Spinney, J. 2014. Complementing Scientific Monsoon Definitions with Social perceptions in Bangladesh, Bulletin of the American Meteorological Society (BAMS), June 2, 2014, http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-13-00144.1

Syed, M.A. 2015. Regional analysis, import-export and related issues on food security, Chapter 7 in Food Security and Risk Reduction in Bangladesh, Eds. Umma Habiba, Md. Anwarul Abedin, Abu Wali Raghib Hassan, Rajib Shaw, Springer Japan KK, Tokyo, March 19, 2015 ISBN-13: 978- 4431554103 ISBN-10: 4431554106 Edition: 2015

Stocker, T.F., D. Qin, G.-K.Plattner, L.V. Alexander, S.K. Allen, N.L. Bindoff, F.-M.Bréon, J.A. Church, U. Cubasch, S. Emori, P. Forster, P. Friedlingstein, N. Gillett, J.M. Gregory, D.L. Hartmann, E. Jansen, B. Kirtman, R. Knutti, K. Krishna Kumar, P. Lemke, J. Marotzke, V. Masson-Delmotte, G.A. Meehl, I.I. Mokhov, S. Piao, V. Ramaswamy, D.Randall, M. Rhein, M. Rojas, C. Sabine, D. Shindell, L.D. Talley, D.G. Vaughan and S.-P. Xie, 2013: Technical Summary. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Thuiller, W., Richardson, . ., Rouget, ., rocheş, Ş. and Wilson, .R.U. (2006) Interactions between environment, species traits, and human uses describe patterns of plant invasions. Ecology. 87, 1755-1769

Acknowledgements:

MAS is supported by a Himalayan Adaptation, Water and Resilience (HI-AWARE) under Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) program of International Development Research Council. Research works carried out in two consecutive projects of Bangladesh Centre for Advanced Studies (BCAS) with support from USAID. We are greatly indebted to Mr. Shariful Islam and Mr. Sunbeam Rahman of BCAS for their continuous help in GIS analysis and mapping exercises