The Costs of Ecosystem Adaptation: Methodology and Estimates for Indian Forests

Elena Ojea, Ranjan Ghosh,

Bharat B. Agrawal and P. K. Joshi

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The Costs of Ecosystem Adaptation:

Methodology and Estimates for Indian Forests

Elena Ojea[1], Ranjan Ghosh[2], Bharat B. Agrawal[2] and P. K. Joshi[3]

This paper presents a detailed methodology for estimating the cost of adaptation to climate change impacts on ecosystems. Up to date estimates are built-up following national investments in measures such as protected areas, with inaccurate estimates of the adaptation level needed. Here we propose a new methodology which identifies vulnerable areas due to climate impacts and the specific adaptation options feasible for these regions. An illustration of the methodology for shifts in forest ecosystems in India is presented. Advantages and future requirements for this methodology are finally discussed.

Keywords: Climate change, adaptation costs, forest ecosystems, India

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[1] Basque Centre for Climate Change (BC3), Bilbao, Spain. +34 944014690. Corresponding author: elena.ojea@bc3research.org
[2] The Energy and Resources Institute (TERI), New Delhi 110 003 India.
[3] TERI University, New Delhi 110 070 India. pkjoshi@teri.res.in

1. Background

At the end of the 21st century, climate change impacts are expected to be the primary cause for biodiversity loss and changes in their services on a global scale (MEA, 2005; Pimm and Raven, 2000; Thomas *et al.*, 2004). Biodiversity is a key component of any ecosystem, influencing capacity of ecosystem to respond to external stresses such as climatic impacts. Maintaining and enhancing the resilience of natural ecosystems is the best and most cost-effective defense against climate change (Zaunberger, 2008). In general terms, resilience of ecosystems is being reduced as a consequence of climate change and other anthropocentric causes. The Intergovernmental Panel for Climate Change (IPCC) predicts that approximately from 20 to 30% of the plant and animal species known will suffer an increase in the risk of extinction if global temperature increases in a 1.5-2.5ºC range (Parry *et al.*, 2007). Fischlin *et al.* (2007) estimate that a 3°C warming would transform about one fifth the world's ecosystems. It is also likely that substantial impacts on marine ecosystems would occur from a 3° C warming (UNFCCC, 2007). When assessing the impacts of climate change on biodiversity and ecosystems, there are some key points that may be taken into account: *i)* The evidence on the physical and biological impacts of regional climate changes has been increasing over time, as reported by the fourth IPCC assessment report (Parry *et al.*, 2007); *ii)* Global losses of biodiversity are of key relevance since they usually are irreversible; iii) Climatic impacts on biodiversity and ecosystems are difficult to isolate from other anthropocentric causes such as land use change, pollution, overexploitation of resources, etc. and; *iv*) The capacity of the ecosystems to adapt to external stresses (resilience) is being decreased by climate change, as is their role in climate regulation. Mitigation policies are already taking place to reduce climate change impacts, but effects of mitigation policies on biophysical systems will not be globally noticeable until the middle 21st century (Parry *et al.*, 2007). Short-term impacts are thus expected even if strong mitigation efforts are made. Therefore, adaptation is the only way to deal with the unavoidable impacts of climate change (Stern, 2006; Parry et al, 2007).

Currently, countries lack estimates of the costs to be incurred to adapt to climate change impacts. This gap is even larger in the case of biodiversity and ecosystem impacts of climate change. This is mainly because there is not an agreed methodology to estimate adaptation costs. Demand for these types of studies has been increasing, especially in developing countries. Very few current estimates of the need of adaptation measures in developing countries and their costs exist. Up to date estimates of the cost of adaptation have focused on the additional costs of including adaptation in their investments with only general estimates and few information on the different adaptation options to be applied.

Our contribution in this paper is thus to propose the basis for a new methodology to estimate the cost of adaptation options specific to ecosystems, where adaptation costs are finally estimated for forests of India. With this aim, we conduct a review of the literature on the costs of ecosystem adaptation options and identify research needs to improve current estimates, especially in developing countries. Second, we propose a methodology to estimate adaptation costs for ecosystems, with an illustration for the forest ecosystems in India. The paper is structured as follows: first, section 2 summarizes the projected climate change impacts on ecosystems; section 3 discusses the adaptation options and how these measures have been valued in the literature; section 4 presents the methodology we propose with section 5 illustrating the application to forest adaptation in India. Finally, section 6 closes with some concluding remarks.

2. Climate Change Impacts on Ecosystems

According to the IPCC 4th Assessment Report, there is strong evidence of climate impacts already affecting biodiversity and ecosystems on the Northern Hemisphere (Parry *et al.*, 2007). Biodiversity is revealing consistent responses to climate change with changes in the timing of growth stages for vegetation, marine species shifting habitats polewards, and changes in migration, distribution, abundance and productivity and in community composition and phenology in fresh water species. In the marine environment the impacts are also relevant, with a decrease on the resilience of marine ecosystems due to the globalisation of fisheries, where exploitation of several sea species in the past three decades have been shown to make reefs more vulnerable to extreme events such as hurricanes and to coral bleaching and mortality due to increased sea surface temperatures. Terrestrial ecosystems will suffer from a decrease on their resilience capacity due to an unprecedented combination of climate change, associated disturbances and other global change sources of pressure (Parry *et al.*, 2007). The climate change impacts observed on biodiversity and ecosystems in the Northern Hemisphere compiled by the IPCC are summarized in Table 1.

Current impacts due to climate change manifest the importance of global change and serve as a basis for studying and predicting the future expected impacts. The IPCC has projected a series of impacts on biodiversity and ecosystems for expected changes in physical conditions and extreme events. They are summarized in Table 2. Impacts are presented in relation to the main change in the climate conditions and differentiating between impacts in biodiversity and ecosystems.

Table 1. Main observed impacts of climate change on biodiversity and ecosystems in the Northern Hemisphere (from IPCC)

Impacts affecting	Type	Impacts already observed
Ecosystems	**Lakes and river ecosystems**	Abundance and productivity effects on freshwater species (Eutrophication)
		Effects in community composition of freshwater species
		Effects on migration and distribution of freshwater species
	Forestry	Significant lengthening/shortening of the growing season (Phenological variations)
		Increase in forest productivity in some regions
		Drought reducing forest productivity
		Increase of forest fires
		Migration and distribution of the species
Biodiversity	**Terrestrial species**	Earlier onset of spring events
		Increased net primary production linked to longer growing season
		Migration and lengthening of the growing season
		Changes in abundance of certain species
		Changes in community composition
	Marine and Freshwater species	Polewards shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans

Source: Adapted from Parry *et al*. (2007).

Table 2. Main projected impacts on biodiversity and ecosystems (from IPCC)

Change in conditions	Impacts on ecosystems	Impacts on biodiversity
Changes in structure and functioning of terrestrial and marine ecosystems with a global warming of 2 to 3°C	Increase of 2º: 15% ecosystems affected Increase of 3.5º: 40% ecosystems affected Disturbance regimes: wildfire and insects Major biome changes/shifts, including emergence of novel biomes Amazon forests, China's taiga, and much of the Siberian and Canadian tundra are very likely to show major changes with global mean temperatures exceeding 3°C While forest expansions are projected in North America and Eurasia with <2°C warming, tropical forests are likely to experience severe impacts, including biodiversity losses	Increasing high risk of extinction for roughly 20 to 30% (of species assessed so far varying among regional biotas from 1% to 80%) Changes in species' ecological interactions, with predominantly negative consequences for goods and services Shifts in species distribution.
Ecosystems are very likely to be exposed to atmospheric CO_2 levels much higher than in the past 650,000 years	Accelerated release of carbon from vulnerable carbon stocks (peatlands, tundra frozen loess, permafrost soils, and soils of boreal and tropical forests) Projected increase in carbon sequestration by poleward taiga expansion Carbon emission increase from albedo changes, wildfire, forest declines at taiga's equatorial limit and methane losses from tundra will be likely greater than the increase in carbon sequestration by taiga Tropical forest sequestration by 2100 is likely to be dominated by climate-change impacts, especially in drier regions	
The resilience of many ecosystems is likely to be exceeded by 2100	Key ecosystem properties (e.g., biodiversity) or regulating services (e.g., carbon sequestration) are very likely to be impaired	Extractive use from and fragmentation of wild habitats are very likely to impair species' adaptation Disruption of species' ecological interactions
By 2100, ocean pH is very likely to be lower than during the last 20 million years (ocean acidification)	Expected negative impacts on marine shell-forming organisms (e.g., corals, crabs, squids, marine snails, clams and oysters) and their dependent species	Likely to impair aragonite-based shell formation in a wide range of planktonic and shallow benthic marine organisms

Table 2. Main projected impacts on biodiversity and ecosystems (cont.)

Change in conditions	Impacts on ecosystems	Impacts on biodiversity
Impacts on the Oceans for global mean temperature increases of about 1.5 to 3°C	Shift in the productivity of the oceans: The low-productivity zones in sub-tropical oceans are likely to expand by about 5% (Northern) and about 10% (Southern Hemisphere) The productive polar sea-ice biomes are very likely to contract by about 40% (Northern) and about 20% (Southern Hemisphere) Loss of corals due to bleaching (especially for the Great Barrier Reef). Climate change and direct anthropogenic impacts (such as pollution and harvesting) are expected to cause annual bleaching (around 2030 to 2050) followed by mass mortality Slow down of the Meridional Overturning Circulation, with potentially serious consequences for fisheries	Polar species, including predators such as penguins, seals and polar bears, are very likely to experience habitat degradation and losses as sea-ice biomes shrink Likely regional changes in the distribution and productivity of particular fish species Local extinctions of particular fish species are expected at edges of ranges
Forestry production will be affected by the projected changes in the frequency and severity of extreme climate events	Food and forestry trade is projected to increase in response to climate change, with increased food-import dependence of most developing countries Increment of wildfires Production increase will shift from low-latitude regions in the short term, to high-latitude regions in the long term.	
Greater rainfall variability	Likely to compromise inland and coastal wetland species through shifts in the timing, duration and depth of water levels	

Source: Adapted from Parry *et al.* (2007) and Easterling *et al.* (2007). Global mean annual temperature changes are relative to 1880-1999 (ºC).

3. Literature on Adaptation Costs

3.1 The need for adaptation

In the previous section we have reviewed the imminent impacts of climate change on biodiversity and ecosystems. Adaptation becomes necessary since climate change impacts cannot be avoided in the next decades by any mitigation strategy, although mitigation is of course still necessary in order to reduce future costs of adaptation measures (Parry *et al.*, 2007). When defining the adaptation strategies concerning ecosystems and biodiversity, the main actions proposed by the IPCC are those related to the reduction of other threats, such as habitat degradation, pollution or introduction of alien species. There are currently many international Multilateral Environmental Agreements (MEAs) signed by numerous countries that are already working against these kinds of threats, such as the Convention on Biological Diversity (CBC), the Ramsar convention, the Millennium Ecosystem Assessment, among others. Adaptation measures for Biodiversity should be integrated and synergistic responses in adherence to and compliance with the terms and conditions of MEAs and improve environmental quality (Parry *et al.*, 2007). When designing adaptation measures, it is important to bear in mind the promotion of win-win strategies and the avoidance of maladaptation or unsustainable adaptation. There are adaptation measures that can be beneficial to one sector but causing important damages to other sectors. For a review on adaptation and mitigation options in relation to the potential impacts on biodiversity see Paterson *et al.* (2006). On contrast, other adaptation measures can have co-benefits in terms of climate resilience.

In the Stern review it is stated that climate change will require nature conservation efforts that extend the current approach of fixed protected areas (Stern, 2006). They purpose that conservation efforts will be required to operate at the landscape level, with larger areas managed to better accommodate species movement. But ecosystem adaptation options should not only focus on protected areas. Heller and Zavaleta (2009) review in a recent work the literature addressing biodiversity management and adaptation in the face of climate change. From 113 papers, they identify 524 recommendations that they rank depending on the frequency of appearance. General conclusions from the analysis are that 33% of the recommendations address biodiversity conservation in conjunction with ecosystem services. Among the three first measures ranked are: the increase in habitat connectivity, the integration of climate change into planning exercises and the mitigation of other threats to ecosystems (Heller and Zavaleta, 2009).

From the literature we identify the main adaptation options proposed per impact both for biodiversity and forest ecosystems (Tables 3 and 4). Forest ecosystems were chosen as more information on impacts and adaptation is available than for other ecosystems. Furthermore, in the present paper an illustration of the proposed methodology for estimating costs is presented for Indian forests.

Table 3. Adaptation options for Biodiversity

Impact	Adaptation Activity	Specific policies
Increase on the species extinction rate	**Establishment of protected areas**	Improve management of actual protected areas Increase the area of existing reserves Establish new protected areas
	Integrated landscape-scale management	Development of institutions for coordination in planning and management along watersheds and ecosystems Programs to improve regional, national and international coordination in preservation strategies
	Increase landscape permeability	Schemes to increase migration corridors around protected areas Schemes to increase buffer zones around current reserve areas that include different altitudes and ecosystems
	Reduction of other pressures on biodiversity	Avoid habitat conversion Control over-harvesting Reduce pollution Control of alien species invasions
	Agricultural biodiversity	Management of agricultural biodiversity
	Restoration of damaged ecosystems	Conservation strategies and re-introduction of species
	Ex-situ conservation	Creation of gene and seeds banks, nurseries, gardens and zoos
Disruption of species ecological interactions	**Increase habitat heterogeneity within reserves**	Gradients of latitude and altitude Soil moisture and different succession states
	Maintain ecosystem structure and function to ensure healthy and genetically diverse populations	Schemes to implement a graded system of management, with innermost areas receiving greater protection and outer buffer zones where users are allowed
	Introduction of species with essential functions on pollination	
	Natural forest regeneration, sustainable forest management / and avoided deforestation	Practice of low-intensity forestry
Shifts in species distribution	**Establishment both vertical and horizontal corridors**	Programs to develop corridors around reserve areas to allow animals to migrate as climate changes
	Introduction of cultivated plant varieties tolerant to higher temperatures	

Table 3. Adaptation options for Biodiversity (cont.)

Impact	Adaptation Activity	Specific policies
Increase in frequency and intensity of forest fires and pest outbreaks	**Fire prevention**	Forest fires prevention programs
	Introduction of pest-resistant varieties	
Ocean acidification and pressure to marine resources	**Reduction of other sources of pollution and pressures**	Control in the exploitation of wild fisheries
	Establishment of marine protected areas	Improve management of actual marine protected areas
		Increase existing marine protected areas
		Establish new marine protected areas

Source: adapted from the CBD, 2008, UNFCCC, 2007; FAO, 2008b

Table 4. Adaptation measures for Forest ecosystems

Impact	Adaptation Activity	Specific policies
Changes in forests productivity	**Modification of the rotation times**	Flexibility regarding silvicultural management
	Replanting	Replanting with different species
		Replanting with populations from other parts of the distributional range (e.g. from lower elevations or latitudes).
		Schemes to establish fuel wood orchards. Establishment of forest plantations will reduce impacts on forest ecosystems due to increased fuel wood demand.
	Alternation of thinning procedures	Flexible policies for salvage harvests so as to allow adjustments as climatic conditions change
Increase of wildfires and pests outbreaks	**The reduction or prevention of fires**	Flexible policies for fire control
	Responsible use of herbicides, pesticides and fertilizers to avoid insect outbreaks and diseases	
	Breeding of pest-resistant lines	

Table 4. Adaptation measures for Forest ecosystems (cont.)

Impact	Adaptation Activity	Specific policies
Loss of forest resilience	**Connectivity, heterogeneity and diversity at the landscape level facilitating forest resilience**	Forestry schemes with high planting densities
		Schemes to plant tree species drawn from warmer climate zones
		Policies to include a mix of planting practices
		Planting of trees that have greater resistance to heat and drought on the southern range of managed forest boundaries if trees can survive in the current climate
		Schemes to plant tree species and adjust management practices considering future climate scenarios
		Schemes for forest rehabilitation through agroforestry
		A mix of different timber harvesting strategies to promote forest diversity
	Conservation of forest diversity	Schemes to increase forest seed banks
		Enhance forest seed banks aimed at conservation of original genetic diversity of forests, to rebreeding
Shifts in forest distribution	**Assist or enable ongoing natural adaptive processes**	Help species dispersal and migration
		Enable population mortality and colonization
		Allow changes in community composition or species dominance and changing disturbance regimes
	Reduction of habitat fragmentation	Incentive policies and programs for multiple-use management that balances preservation and use within a single parcel
		Negotiation of conservation easements that protect geographically important land parcels from development
	Development of migration corridors	

Source: FAO, 2008; National Adaptation Plan India (Government of India, 2008), Heller and Zavaleta (2009)

3.2 The cost of adaptation

In the previous sections we have detailed a broad range of adaptation options both for biodiversity and forest ecosystems. Although specific actions are needed to adapt to climate impacts, current estimates of adaptation costs are often based on one single adaptation measure such as increasing protected areas (James *et al.*, 2001; Blamford *et al.*, 2002).

The IPCC states that adaptation strategies can often be implemented at low cost, however, comprehensive estimates of adaptation costs and benefits are currently lacking (Parry *et al.*, 2007). The literature on adaptation costs and benefits is limited and fragmented and is not focused on biodiversity or ecosystems (Parry *et al.*, 2007; Stern, 2006). Moreover, there is an emphasis on the USA and other OECD countries, with only a few studies for developing countries. Improving the knowledge of the costs of climate change adaptation will allow policy-makers to consider optimal strategies for implementing adaptation policies (Parry *et al.*, 2007). Estimates of the costs of adaptation for ecosystems are scarce and very recent. Two types of approaches have been developed to estimate adaptation costs: financial flows on conservation and costs of specific adaptation measures.

a) Financial flows

The UNFCCC conducted an overview of current investment and financial flows by source of financing. They obtain that between 1991 and 2000, the GEF provided about $1.1 billion in grants and leveraged an additional $2.5 billion in co-financing biodiversity-related projects. Most of these grants were used to support protected areas covering 226 Mha in 86 countries (UNFCCC, 2007). James *et al.* (2001) report that in the mid-1990s an average of $6.8 billion per year was spent on global protected areas, with about 89% of that amount spent in developed countries. The James *et al.* study is an attempt to estimate the investment and financial flows needed to protect natural ecosystems from current threats. To do this the authors follow IUCN recommendations of how much additional land needs to be set aside as biodiversity protection areas, not specifying the additional protection needs that climate change might require. As a result they estimate that this improved protection will be achieved with an annual increase in expenditures of $12 – 22 billion (James *et al.*, 2001). More recently, Berry (2007) differentiates between two different approaches for assessing the costs of adaptation: the costs of maintaining natural ecosystems and their services in the face of climate change and the additional costs for the planned/additional adaptation actions. They provide a guide to the costs of adaptation in natural ecosystems adopting the following methodology: 1) estimating current global expenditures on conservation; 2) estimating the shortfall in current conservation expenditure; 3) estimating levels of additional expenditure needed for climate change adaptation. Finally, by adapting James *et al.* (2001) estimates, Berry (2007) estimate the additional conservation costs for an increase in 10% of global protected area, for two scenarios: all protected areas and highly protected areas. Assuming that expenses in protected areas are one third of total biodiversity expenses, they also provide the total expenses on biodiversity conservation, which amount to $64.5 billion per year under the scenario with mitigation and $36 billion per year in the scenario with adaptation.

Table 5 summarizes the studies done to date with global financial investment on adaptation for biodiversity conservation. We include information about the adaptation measure, the scope of the study, the methodology they use and the costs they estimate. These costs have been calculated on a range going from $12 billion/year to $28 billion/year when only considering the expansion of protected areas as the adaptation measure, and between $65-83.5 billion/year when considering protected areas expansion as one third of total adaptation measures required.

Table 5. Financial flows in conservation

Study	Adaptation measure	Area covered	Methodology	Costs
James *et al.*, 2001	Increase on protected areas	Global	Costs of a 10% increase in all protected areas globally as recommended by the IUCN	$12.0 billion year
James *et al.*, 2001	Increase on highly protected areas	Global	Costs of a 10% increase only in highly protected areas	$21.5 billion year
Blamford *et al.*, 2002	Increase on protected areas	Global	Cost of expanding PA to cover 15% of the area on each terrestrial region	$20-28 billion year
Blamford *et al.*, 2002	Increase on marine protected areas	Global	Cost of expanding PA to cover 30% of marine areas	$23 billion year
Berry, 2007	Adaptation needed for Biodiversity conservation in terrestrial ecosystems	Global	Employs James *et al.* (2001) scenarios and estimated costs of a 10% increase in PA and assumes that expenses in protected areas are one third of total biodiversity expenses	$83.5 billion year
Berry, 2007	Adaptation needed for Biodiversity conservation in marine ecosystems	Global	Employs James *et al.* (2001) scenarios and estimated costs of a 10% increase in PA and assumes that expenses in protected areas are one third of total biodiversity expenses	$64.5 billion year

Table 5. Financial flows in conservation (cont.)

Study	Adaptation measure	Area covered	Methodology	Costs
Berry, 2007	Adaptation needed for Biodiversity conservation in terrestrial ecosystems	Global	Employs James *et al.* (2001) scenarios and estimated costs of a 10% increase in highly protected areas and assumes that expenses in protected areas are one third of total biodiversity expenses	$65 billion year
Berry, 2007	Adaptation needed for Biodiversity conservation in marine ecosystems	Global	Employs James *et al.* (2001) scenarios and estimated costs of a 10% increase in highly protected areas and assumes that expenses in protected areas are one third of total biodiversity expenses	$36 billion year

Source: Berry (2007)

b) Costs of specific adaptation measures

There are however other regional studies calculating the cost of specific adaptation measures, such as migration corridors in Kenya (Ferraro and Kiss, 2002), coastal reforestation in Croatia (Pagiola *et al.*, 2004) or conservation of tropical forests in Costa Rica (Ferraro and Kiss, 2000). From a literature review, there is evidence on the need of a methodology for costing ecosystems' adaptation that takes into account more details, such as: Identifying where adaptation actions are needed (vulnerable regions); Identification of the positive or negative direction of the impacts on each area; Linking adaptation options to specific impacts; Valuing the costs of these specific and feasible adaptation requirements. The aim of this paper is thus on proposing a methodology to fill these gaps.

As far as we are concerned, none of these studies attempts to estimate total adaptation costs on a developing country level, taking into account different adaptation measures and their likeability to be implemented. Moreover, positive adaptation measures such as allowing ecological changes in some cases have not yet been considered in the literature. The contribution of the present work is on presenting the requirements and steps to be followed for reaching such a detailed approach, and testing this methodology for forest shifts in India due to climate change.

4. Estimating Ecosystem Adaptation Costs

In this section the proposed methodology is described. Based on the literature review and on the identified gaps in knowledge, we propose a methodological guide to estimate the costs of adaptation for ecosystems on a country level, and illustrate our approach for Indian forests.

4.1 Methodology for estimating adaptation costs in ecosystems

The approach is split in five steps: *first* the identification of the climatic impact; *second* and based on the impacts, the identification of the vulnerable areas; *third* the identification and election of the adaptation options; *fourth* the unitary costs of the adaptation measures and finally; *fifth*, the total cost of the adaptation measure. Each step is described below, while next sub-section presents the specific steps to be followed for forest adaptation in India.

1. Quantification of climate change direct impacts: First step is to identify and quantify the relevant impacts of climate change on the country's ecosystems. Impacts should be quantified based on the available scientific knowledge where geographically disaggregated data will be preferred.

2. Identification of the vulnerable areas (VA): Climate change is not affecting all regions in the same way. It can be the case of a net global impact being neutral at the state level, while the same impact can be extremely negative for a given region. In order to avoid this problem, we need to identify the regions in which an impact has significant effects; positive or negative. These areas will be selected for each specific impact identified in the previous step.

3. Identification of adaptation options: Third step consists on the identification of the relevant adaptation options per impact and vulnerable area. Adaptation measures should be selected based on the following criteria:

   Relevance: the adaptation option should be relevant for the impact. This step can be based on the existing literature on adaptation policies and on the countries specific existing policies.

   Effectiveness: this is a measure of the success of the adaptation measure on avoiding the impact. How much adaptation measure units are required to avoid the impact to happen or reduce it to the minimum. With the magnitude of the impact identified, we need a rule that gives us the magnitude of the adaptation option to be implemented. If the adaptation option recovers the system to the status quo scenario (with no impact) then, the efficiency of the adaptation measure will be 1. This measure of efficiency will be employed only where relevant information is available or some imputation can be made reasonably.

Scale of action: magnitude of the adaptation option. We must have an estimate of the magnitude of the impact to be avoided by the adaptation option, in order to be able to calculate the magnitude of the adaptation measure needed, following the effectiveness criteria.

Feasibility: real possibility of applying the adaptation option. This is a crucial criteria where both the adequacy to implement the adaptation measures in the vulnerable areas and the feasibility itself of the adaptation measure must be examined.

Imagine we have a situation where there are impacts (I_i) affecting ecosystems in vulnerable areas. Our baseline scenario is the current situation (current impact) that we identify as I_0. In a medium timeframe and with no adaptation, climate change is projected to change the magnitude of the impact to I_1. The magnitude of an impact will be the difference between the projected impact (I_1) and the baseline scenario (I_0) for all the vulnerable areas (*va*). Thus an impact *i* can be quantified as:

$$I_i = \Sigma_{va}\left(I_{1va} - I_{0va}\right)$$

Now for each impact (*i*) we have identified several adaptation measures (*a*). Each adaptation measure has a different effectiveness, in reducing the impact, leading to a reduction in the magnitude of the impact. Thus, with the help of an adaptation option, the expected impact will change from I_1 to I_2, where $I_1 > I_2$.

The effectiveness of a given adaptation option (E_a) is the part of the expected impact with climate change (I_1) that can be avoided by the adaptation option $I_1 - I_2$:

$$E_a = \frac{\left(I_{1va} - I_{2va}\right)}{I_1}$$

When the adaptation option completely avoids the impact of climate change (I_1), the effectiveness is equal to 1 and the expected impact with adaptation is equal to zero:

$$\frac{\left(I_{1va} - I_{2va}\right)}{I_1} = 1; I_{2va} = 0$$

For each impact, we should select the set of adaptation measures that minimize the expected impact with climate change. However, the effectiveness of adaptation options is not always known, and in the example presented forward in this paper, we will deal with this situation.

4. Identification of per unit cost of the adaptation measure: Based on the existing literature and national expenses on conservation, afforestation, etc., per unit costs must be identified for each adaptation measure. Per unit costs must be in the form of cost per magnitude per year, where the magnitude should be in the same units as on the adaptation option. Naidoo *et al.* (2006) differentiate several conservation costs that can be identified when measuring adaptation, these are: acquisition costs (costs of acquiring property rights of a land area); management costs (costs associated with the conservation programs developed in a protected area; damage costs (associated with damages to economic activities arising from conservation programs); transaction costs (costs of transfer property rights; opportunity costs (costs of foregone opportunities). Per unit costs of the adaptation measure should optimally account for acquisition and management costs.

5. Total costs: final step consists on the aggregation of the costs of adaptation measures for all the vulnerable areas and adaptation measures passing the criteria. For this we can follow these steps: *first* the cost of each adaptation measure can be calculated using the unitary cost of the adaptation measure and the magnitude of adaptation measure required; *second*, we can aggregate the adaptation costs per impact, and finally, *third*, to aggregate the cost of all the impacts to obtain the total cost of adaptation for a given ecosystem. Cost estimates should ideally be provided in form of intervals: lower and upper bounds should be presented as a result of including different interest rates (Arrow, 1995) and climate scenarios (IPCC).

4.2 Estimating forest adaptation costs in India

Forests cover 19.4% of India's surface. Forests have a crucial importance in energy supply providing almost 40% of the country energy needs, reaching 80% in rural areas (Government of India, 2008). From a review of the literature we have identified four *major* climate change impacts on forest ecosystems in India that are summarized in Table 6. The potential adaptation measures that can be implemented in order to adapt to these impacts are also presented in Table 6. Note that adaptation measures can be directed to allow the changes or to avoid them (adaptation to positive or negative impacts).

Table 6. Impacts on forests: adaptation to positive and negative impacts

Impacts	Adaptation to Positive impacts	Adaptation to Negative impacts
Shifts in forest distribution	Enable population mortality and colonization	Create migration corridors
		Adapt the PA system to protect most threatened forest ecosystems: Expand protected areas and link them whenever possible to promote migration
	Allow species dispersal and assist natural adaptation processes	Avoid habitat fragmentation with plantation of heat and drought tolerant tree species
Change in forest productivity	Flexibility regarding silvicultural management	Negotiation of conservation easements protecting important parcels from development
	Modification of the rotation times	Community instruments to avoid forest dependency: Revitalizing and up scaling community based initiatives
	Schemes to establish fuel wood orchards in climate appropriate areas: establishment of forest plantations will reduce the impacts on forest ecosystems due to increased fuel wood demand	Replanting with heat and drought tolerant productive tree species
Increment of pest outbreaks and invasive species		Plantation of pest-tolerant species
		Responsible use of pesticides, herbicides and fertilizers
Increase in wildfires		Fire prevention programs
		Fire control programs

Source: National Adaptation Plan India (Government of India, 2008): Ravindranah *et al.*, 2006; Ministry of Environment and Forests India.

We will detail for this sector the steps to follow in the application of the methodology for estimating costs of adaptation proposed in the previous section. To do this we will specifically focus on one impact: shifts in species distribution.

1) Quantification of climate change direct impacts

The main climatic impact affecting forest ecosystems in India is the shift between forest types (Joshi *et al*., 2006; Ravindranath *et al*., 2006). This shift will affect forests in terms of their productivity and dominant species, as well as the biodiversity and human livelihoods dependent on each forest type. Ravindranath *et al.* (2006) identify what forest types are more vulnerable to decrease under the A2 and B2 climate scenarios. Following the study of Ravindranath et al (2006), we identify the forest areas that will be impacted the most by climate change in terms of change in forest type (see annex) for B2 scenario and year 2085. Based on the grid size and data used in the BIOME4 model it is very difficult to calculate the exact areas for each of the vegetation types. We cannot assume that a certain vegetation type will cover the total area of a grid, a part of which may be located inside. So as a proxy measure we have divided the total forest land in India, 64 Mha (Ravindranath et al, 2006), proportionately based on the number of grid points into the various vegetation types. From there we have estimated the size of the areas which will shift in either direction based on Ravindranath *et al.* (2006) projections of forest shifts in India. Table 7 presents the magnitude of the change and the projected area of future biomes. Like this we can see how, for example, Tropical xerophytic shrubland (TPXS) forests are currently expanded in 26.06 Mha and in 2085 under B2 scenario are projected to be spread in only 1.56 Mha.

Table 7. Shifts in forest distribution in Mha (Million hectares)

Current scenario		**B2 scenario (2085)**										
TPXS	26.062	1.564	15.376	-	-	8.340	-	-	-	-	-	-
TPD/WL	17.281	-	9.331	-	0.173	1.382	6.048	-	-	-	-	-
WM	8.748	-	1.400	5.074	0.612	-	0.787	0.700	-	-	-	-
TPSD	5.135	-	0.051	-	0.359	-	4.673	-	-	-	-	-
TPS	2.851	-	0.827	-	-	1.882	0.114	-	-	-	-	-
TPEG	1.771	-	-	-	-	-	1.771	-	-	-	-	-
TMC	0.504	-	0.040	0.187	0.030	-	0.207	0.025	-	-	-	-
TMSW	0.475	-	0.005	0.408	-	-	-	-	0.052	-	-	-
CC	0.431	-	-	0.405	-	-	-	-	0.009	0.009	-	-
ET/M	0.407	-	-	0.098	-	-	-	0.004	-	0.106	0.077	0.057
CLDMX	0.337	-	-	0.266	-	-	-	-	0.020	-	-	-
FUTURE AREA		1.564	27.031	6.437	1.175	11.604	13.600	0.729	0.081	0.114	0.077	0.057

Source. Adapted from Ravindranath *et al*., 2006. See Annex I for forest types.

With one example we will illustrate how the above table has to be read. Warm Mixed (WM) forests are spread across India covering roughly 8.75 Mha of land. 0.61 Million ha of these will shift to Tropical Semi Deciduous forest (TPSD). 0.79 Million ha will shift to Tropical Evergreen forest (TPEG). These two forests are higher productivity forests (based on NPP) and hence it is considered a positive shift with the lower and upper bound simply showing the range. On contrast, tropical evergreen forests are expected to increase from 1.77 to 13.60 Mha.

2) Identification of the vulnerable areas

Once the magnitude of the impact is quantified, it becomes crucial to determine whether such shifts in forest distribution are positive or negative. We thus need a criterion for selecting the vulnerable areas and continue our analysis focussing only on them. There might be changes in forest types which can benefit biodiversity or human livelihoods but, on the other hand, some changes might be negative such as loss of Net Primary Productivity. In the current analysis, we have adopted one criterion to identify the vulnerable areas: the Net Primary Productivity (NPP). Forest Biomes can be ranked in terms of NPP, depending on the annual growth of biomass. Ravindranath *et al*. (2006) provide in their study information about the NPP for the BIOME4 forests.

Based on the information in Table 7 and on the productivity of each forest types depicted by Ravindranath *et al.* (2006), we summarize in Table 8 the current and predicted area of each forest type, indicating whether is a positive shift (expected increase in productivity) or a negative shift (expected decrease in productivity). This is the direction of the impact and is shown in the last column of Table 8. As a result, we can identify the vulnerable areas where the impact of climate change is negative in terms of productivity. We will base our next calculations on these areas. However, we acknowledge that other criteria such as biodiversity richness or the impact on human livelihoods should also be taken into account when identifying the direction of the impacts. However, we present this approach as a first approximation to illustrate the methodology.

Table 8. Impact directions and vulnerable areas

Forest type	Current Hectares (Mha)	Shift to	% shift	Hectares 2085 (Mha)	Impact Direction* (NPP)
TPXS	26.06	TPD/WL	59	15.37	+
		TPS	32	8.34	+
TPD/WL	17.28	TPSD	1	0.17	+
		TPS	8	1.38	-
		TPEG	35	6.05	+
WM	8.75	TPD/WL	14	1.40	-
		TPSD	7	0.61	+
		TPEG	9	0.79	+
		TMC	8	0.70	+
TPSD	5.43	TPD/WL	1	0.05	-
		TPEG	91	4.67	+
TPS	2.85	TPD/WL	29	0.83	+
		TPEG	4	0.11	+
TMC	0.50	TPD/WL	8	0.04	-
		WM	37	0.19	-
		TPSD	6	0.03	-
		TPEG	41	0.21	+
TMSW	0.47	TPD/WL	1	0.01	+
		WM	86	0.41	+
CC	0.43	WM	94	0.41	+
		TMSW	2	0.01	-
ET/M	0.41	WM	24	0.09	+
		TMC	1	0.01	+
		CC	26	0.11	+
		CLDMX	14	0.06	+
CLDMX	0.34	WM	79	0.27	+
		TMSW	6	0.02	-

*NPP: net primary productivity of forests. Adapted from Ravingranah (2006)

3) Identification of adaptation options

Given the set of adaptation measures identified from the literature review and summarized in Table 6, we apply the set of criteria described in the methodology in order to determine which adaptation options can be applied in the field. We could not obtain data on the effectiveness of these measures, so we will simplify our approach considering that different adaptations will be implemented on the vulnerable areas. Finally, the feasibility of the adaptation options has been evaluated by means of forest expert opinion, depending on the type of shift expected. Based on this, two scenarios for adaptation option choices have been identified: “Adaptation Scenario 1”, where according to the negative direction of the shift, the most necessary measures to address these impacts are chosen, based on expert opinion. And second choice is “Adaptation Scenario 2” scenario, where based on the negative direction of the shifts all the possible options available from Table 9 are chosen. These scenarios in a way reflect the minimum action and the desired action option sets, respectively. In Table 9 the relevant adaptation options for forests in India based on the literature review are presented, while Table 10 presents the adaptation options considered for each scenario. As an example, the area under tropical deciduous forests/woodlands (TPD/WL) that is expected to shift towards tropical savannah (TPS) will require adaptation options A3, A7 and A10 as the minimum desirable options (Adaptation Scenario 1). Including all desirable options, Adaptation Scenario 2 for TPD/WL will be implementing A1, A3, A4, A5, A6, A7, A8, A9 and A10 to all 1.38 Mha of this forest type that have been identified as vulnerable.

Table 9. Potential adaptation options for shifts in forest biomes in India

	Adaptation options
A1	fauna and flora migration/biological corridors
A2	adaptation of the Protected Area system
A3	plantation of drought tolerant/multi species to avoid fragmentation
A4	allow natural adaptation: species dispersal (management)
A5	enable population mortality and colonization
A6	negotiation of conservation easements as protection from development
A7	community instruments to reduce forest dependency
A8	flexibility in sylvicultural management
A9	modification of rotation times
A10	plantation of productive species

Source: adapted from National Adaptation Plan India (Government of India, 2008), Heller and Zavaleta (2009)

Table 10. Adaptation scenarios for shifts in forest distribution in the vulnerable areas

Forest type	Shift to	Impact (Mha)	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
TPD/WL	TPS	13.82	X		O	X	X	X	O	X	X	O
WM	TPD/WL	14	X	X	O	X		X	O	X	X	O
TPSD	TPD/WL	0.51	X		O	X	X		O	X	X	O
TMC	TPD/WL	0.40			O	O	O	X	X	X	X	O
TMC	WM	1.87				O	O	X	X	X	X	O
TMC	TPSD	0.30				O	O	X	X	X	X	X
CC	TMSW	0.09	X	X	X	X	X	X	X	X	X	X
CLDMX	TMSW	0.20	X	X	O	X	X	X	X	X	X	X

O = Adaptation Scenario1: Most desirable adaptation options and; O+X = Adaptation Scenario 2: Taking all desirable adaptation options.

4) Identification of unitary costs of the adaptation measures

In order to obtain unitary costs for the adaptation measures and evaluate their feasibility in the country we start by doing a profound review on the Indian National Programs on forest management. From this, we identify those measures whose objectives match with the list of potential adaptation measures we have identified. From these range of sources we select the costs from the National Forestry Action Programme (NFAP), in order to maintain consistency among the costs for different adaptation options. Like this, we have enough information for the analysis and monetary costs are on a baseline of year 2001.

From the available programs in the NFAP, and with the information on the forest hectares and on the timeframe of the programs, we calculate the annual cost per hectare for each measure and link it to the potential adaptation options. We do this in two steps: first, forestry programs are synthesized according to the region, forest types and costs of policies. Second, we select those policies that clearly match the adaptation options we have for shifts in forest distribution and present the relevant information together with the unitary costs (see Table II in the Annex). The unitary costs for the feasible adaptation options are presented in Table 11.

Table 11. Costs of the adaptation options

	Adaptation option	Costs ($/ha.yr)
A3	Plantation of drought tolerant species to avoid fragmentation	$30.00
A4	Allow natural adaptation: species dispersal (management)	$10.80
A5	Enable population mortality and colonization	$0.80
A6	Negotiation of conservation easements as protection from development	$388.84
A7	Community instruments to reduce forest dependency	$19.50
A10	Plantation of productive species	$30.00

Source: adapted from National Forestry Action Programme (NFAP) India.

Table 12. Annual cost estimates of adapting to expected forest shifts in India (2085, B2 scenario)

2009 Forest type	2085 Shift to	Hectares shifted (Mha)	Adaptation Scenario 1 (M$/year)	Adaptation Scenario 2 (M$/year)
TPD/WL	TPS	1.382	109.87	677.13
WM	TPD/WL	1.400	111.30	670.81
TPSD	TPD/WL	0.051	4.05	5.16
TMC	TPD/WL	0.040	3.26	19.60
TMC	WM	0.187	9.65	86.01
TMC	TPSD	0.030	0.65	13.80
TMSW	TMSW	0.009	-	4.41
CLDMX	TMSW	0.020	0.99	9.80
TOTAL COSTS ADAPTATION			**M$239.78**	**M$1486.72**

- not expert judgment was available for the best preferred adaptation options at this particular shift.

5) Total costs of adaptation to forest shifts in distribution in India

Finally, the last step is to calculate the total costs for the impact on forest distribution. Given that we lack information on the effectiveness of the adaptation options, we will apply our two adaptation scenarios (described earlier) for the selection of adaptation measures. Finally, total costs are calculated by adding the adaptation costs for each vulnerable area. Table 12 presents the calculations. The estimated costs for adaptation to changes in forest distributions in India are in the range of $M 239.78 -1486.72 per year depending on the adaptation scenario.

5. Concluding Remarks

The present paper provides a guideline to estimate adaptation costs for ecosystems in a country level basis. Based on the scarce literature about adaptation costs, especially for biodiversity and ecosystems, we identify the main gaps and propose a new methodology for forest ecosystems in India. This methodology adds detail to the estimation of adaptation costs that should be linked to the vulnerable areas associated with climate change and to the specific adaptation options that can be implemented. The main contribution of this framework is on the selection of vulnerable areas and on the criteria needed to evaluate a given adaptation option. Also, this is an important contribution to the scarce literature on adaptation costs for ecosystems. We identify a set of desirable adaptation options based on the shifts in forest types. Finally, an illustration is presented for forests in India, which are expected to shift in distribution as a consequence of climate change. As a result we obtain that, depending on the set of adaptation options selected, adaptation costs for forest ecosystems in India based on a decrease on Net Primary Productivity are in the range of $239.78-1486.72 Million.

Further improvements of the present work will deal with the implementation timeline of the adaptation options as well as with the criteria for identifying vulnerable zones. This study is however a first step needed to move forward the debate on assessing the costs of adapting to climate change, especially relevant in developing countries. Given the lack of a consensus on how to estimate adaptation costs, the proposed methodology can significantly contribute to the literature and help policy makers to be aware of the magnitude of the economic dimension of adaptation to climate change.

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Annex

In Table I, corresponding regions for Indian vegetation types are shown. The first column is the BIOME4 classification. The second column is the matching classification using multi temporal IRS wide field sensor (WiFS) data[4] and the fourth column is the spread of regions where such vegetation types exist in India. This mapping is done based on comparisons between various studies, Champion & Seth Classification and expert ecologist opinion.[5] In addition, the ranking of forest types based on net primary productivity (NPP) is obtained from the findings of Ravindranath *et al.* (2006) for each vegetation type.

Roughly we can see that deciduous forest lands around central India, mixed forests in North Eastern states and mid high Uttaranchal; semi deciduous forest lands in Himalayan foothills, parts of Western Ghats; and conifer forests in the Himalayas are vulnerable to shifts towards low productivity forests. However some parts of these regions will also experience shifts to high productivity forests along with other forest types like shrub lands and grass lands (central south India), montane and cold mixed forests in higher Himalayan states.

[4] P.K. Joshi *et al.* / Remote Sensing of Environment 103 (2006) 190-202
[5] Champion, H.G. & Seth, S.K. (1968): A revised survey of forest types of India. New Delhi Govt. Publication.

Table I. Types of forest BIOMES

Vegetation types (NHR)		NPP	Regions in India
TPXS	Tropical xerophytic shrubland	10	Central Highlands and areas of South India
TPD/WL	Tropical deciduous forest/woodland	5	Rajasthan, MP, Maharashtra, Orissa, UP, Karnataka, AP, TN, Punjab, Haryana
WM	Warm mixed forest/ Temperate Evergreen/Broadleaved	4	NE, WB, Uttaranchal (1500-3000m)
TPSD	Tropical semi-deciduous forest	3	Andaman & Nicobar Islands, Himalayan Foothills, East of Western Ghats, Chota Nagpur, NW hills
TPS	Tropical savanna	6	Gujarat, Central India
TPEG	Tropical evergreen forest	1	Western Ghats, Upper Assam, Arunachal Pradesh, A&N, TN, AP, Himachal Pradesh
TMC	Temperate conifer forest	2	E&W Himalayas (1800-3000m)
TMSW	Temperate sclerophyll woodland	9	HP, J&K, Higher Uttaranchal
CC	Cool conifer forest	8	Central and Western Himalayas, NE hills
ET/M	Evegreen taiga/montane forest	11	Nilgiri, Anamalai and Tirunelveli hills above 1500 mts.
CLDMX	Cold mixed Forests	7	HP, J&K, Higher Uttaranchal

Table II summarises the match between our adaptation options and the ongoing schemes in Indian National forestry programs.

Table II. Adaptation options and unitary costs for forest shifts in India

	Adaptation option	Policy option	Cost ($/ha.yr)	Forest types	Source
A1	fauna and flora migration/biological corridors	Development of migration routes	$42.76 per Km per year	TMSW, TMC, CC, CLDMX	NATIONAL FORESTRY ACTION PROGRAMME (NFAP)
A2	adaptation of the PA system	na	na	na	Na
A3	plantation of drought tolerant species to avoid fragmentation	Tree plantation*	$30.00 per hectare per year	TPEG, WM/T, Temperate evergreen, TMC	NATIONAL FORESTRY ACTION PROGRAMME (NFAP)
		Multi species plantation programme: arising of plantation, including nursery, chain link fencing, planting and maintenance cost	$560.00 per hectare per year	TPEG, ET/M, TPSD	NATIONAL FORESTRY ACTION PROGRAMME (NFAP)
A4	allow natural adaptation: species dispersal (management)	Promotion of natural regeneration	$108.13 per hectare per years.	TPXS, TPD/WL, TPS	NATIONAL FORESTRY ACTION PROGRAMME (NFAP)
A5	enable population mortality and colonization	Treatment of degraded forest land	$388.84 per hectare per year	TPXS, TPD/WL, TPS	
A6	negotiation of conservation easements as protection from development	Afforestation and wildlife	$22.71 per hectare per year	TMSW, TMC, CC, CLDMX	NATIONAL FORESTRY ACTION PROGRAMME (NFAP)

Table II. Adaptation options and unitary costs for forest shifts in India (cont.)

	Adaptation option	Policy option	Cost ($/ha.yr)	Forest types	Source
A7	community instruments to reduce forest dependency	Horticulture and vegetable cultivation	$50.00 per hectare per year	WM/Temperate Evergreen, TMC, CC	NATIONAL FORESTRY ACTION PROGRAMME (NFAP)
		Horticulture and crash crops cultivation	$50 per hectare per year	TPEG, WM/T, Temperate Evergreen, TMC	NATIONAL FORESTRY ACTION PROGRAMME (NFAP)
		Cultivation, horticulture	$19.50 per hectare per year	TMSW, TMC, CC, CLDMX	NATIONAL FORESTRY ACTION PROGRAMME (NFAP)
A8	flexibility in sylvicultural management	na	Na	na	na
A9	modification of rotation times	na	Na	na	na
A10	plantation of productive species	Tree plantation and tree cop mix	$33.33 per hectare per year	WM/Temperate Evergreen, TMC, CC	NATIONAL FORESTRY ACTION PROGRAMME (NFAP)
		Tree plantation	$30.00 per hectare per year	TPEG, WM/T, Temperate evergreen, TMC	NATIONAL FORESTRY ACTION PROGRAMME (NFAP)
		Multi species plantation programme: arising of plantation, including nursery, chain link fencing, planting and maintenance cost	$560 per hectare per year	TPEG, ET/M, TPSD	NATIONAL FORESTRY ACTION PROGRAMME (NFAP)

Source: National Forestry Action Programme (NFAP).

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