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Mitigation needs adaptation: Tropical forestry and climate change

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Abstract The relationship between tropical forests and global climate change has so far focused on mitigation, while much less emphasis has been placed on how management activities may help forest ecosystems adapt to this change. This paper discusses how tropical forestry practices can contribute to maintaining or enhancing the adaptive capacity of natural and planted forests to global climate change and considers challenges and opportunities for the integration of tropical forest management in broader climate change adaptation. In addition to the use of reduced impact logging to maintain ecosystem integrity, other approaches may be needed, such as fire prevention and management, as well as specific silvicultural options aimed at facilitating genetic adaptation. In the case of planted forests, the normally higher intensity of management (with respect to natural forest) offers additional opportunities for implementing adaptation measures, at both industrial and smallholder levels. Although the integration in forest management of measures aimed at enhancing adaptation to climate change may not involve substantial additional effort with respect to current practice, little action appears to have been taken to date. Tropical foresters and forest-dependent communities appear not to appreciate the risks posed by climate

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change and, for those who are aware of them, practical guidance on how to respond is largely non-existent. The extent to which forestry research and national policies will promote and adopt management practices in order to assist production forests adapt to climate change is currently uncertain. Mainstreaming adaptation into national development and planning programs may represent an initial step towards the incorporation of climate change considerations into tropical forestry.

Keywords Climate change · Adaptation · Tropical forests · Tropical tree plantations · Natural forest management

1 Introduction

The relationship between tropical forests and global climate change has received considerable scientific as well as political attention over the last decades (e.g. Shukla et al. 1990; IPCC 1996; Markham 1998; Lewis 2006). However, discussions have focused disproportionately on mitigation (i.e. reducing emissions or else enhancing sinks of greenhouse gases; IPCC 2000), while much less emphasis has been placed on how management activities might help tropical forest ecosystems adapt to climate change in order to maintain the provision of goods and services to society. The lack of attention to this theme has continued in recent international meetings on forests and global climate change, which either have excluded the tropics (e.g. IISD 2006), or have not explicitly considered the need to adjust tropical forestry practices in the context of a changing climate (e.g. Innes et al. 2005, pp. 72–104; Parrotta et al. 2005).

This omission is understandable. First, it reflects the wide appreciation of the critical role of tropical forests as globally significant standing stocks of above- and below ground carbon (Dixon et al. 1994). Second, atmospheric carbon sequestration through tree planting is the only currently eligible land use change activity for developing countries within the Clean Development Mechanism (CDM) of the United Nations Framework Convention on Climate Change (UNFCCC) for which there is an international carbon market and where Certified Emission Reductions are traded. By contrast, investment in adaptation to climate change is largely a national concern and may not yield immediate economic return. Because of associated uncertainties, the assessment of the future contribution of a given adaptation activity can also be speculative (Callaway 2004). Furthermore, in many countries climate change is perceived as a relatively minor threat to forests compared with socio-economically driven causes of land-use change such as pasture expansion, illegal logging, or otherwise uncontrolled forest conversion (Lambin et al. 2001). Finally, in cases where forests and forestry make, or are perceived to make, minor contributions to national economies (e.g. Keller et al. 2007), national governments may be more concerned with ensuring adaptation in other productive sectors such as agriculture or water supply.

There are, however, reasons to consider why tropical forestry may need to include climate change adaptation. First, tropical forests make important contributions to rural livelihoods (Sunderlin et al. 2005) and, partly because of this, natural resource users in developing countries are frequently considered highly vulnerable to climate change (Adger et al. 2003; Thomas and Twyman 2005). The enhancement of the adaptive capacity of both natural and planted forests may help to decrease the vulnerability of those whose livelihood depend on forest goods and services, especially the poorest (Innes and Hickey 2006). Second, without management for adaptation, the current potential of tropical forests to both remove and store atmospheric carbon may diminish thus feeding a positive feedback of carbon emissions (e.g. Gitz and Ciais 2004). Third, although only 7% of the 352M ha of natural forests that the International Tropical Timber Organization producer countries have set aside for sustainable production is being used that way (ITTO 2006), this figure is expected to increase. In Brazil alone, up to 50M ha of Amazonian forest are planned to be managed under sustainability criteria through the next decades (Verissimo et al. 2002; Schulze et al. 2008). The success of this expanded effort in sustainable management may depend on the implementation of adaptation measures to counteract already evident impacts of climate change on forest structure and function in this region (Lewis et al. 2006). Fourth, there is a global trend towards increased timber demand from tree plantations, including those in the tropics (Varmola et al. 2005; FAO 2006a). Under the current trends of global climate change, tropical timber plantations are expected to take a larger share of the global wood market than mid-to-high latitude plantations (due to anticipated dieback; Sohngen et al. 2001). Tropical plantations that are poorly adapted to future conditions may be unable to meet future demand.

In this paper we examine how forestry practices can contribute in maintaining or enhancing the adaptive capacity of tropical production forests to global climate change. We suggest the need for reassessing current practice in light of observed and projected changes in climate and climate variability in tropical forest regions. We also identify obstacles and opportunities for integrating tropical forest management in broader climate change adaptation. We will illustrate all of our points with concrete examples from the American tropics. By “adaptive capacity” we mean the ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2001).

2 Managing production tropical forests under a changing climate

Since the mid-1970s, warming trends in tropical forest regions have averaged 0.26°C per decade, consistent with global temperature rises linked to greenhouse gases; precipitation appears to have decreased, although these changes appear more drastic in northern tropical Africa than Asia or the Amazon (Malhi and Wright 2004). Dramatic atmospheric change has also taken place in some localities (e.g. Pounds et al. 2006). Overall, precipitation anomalies as predicted by different climate models point to likely decreases in certain tropical areas as well as likely increases in others (Neelin et al. 2006). In particular, projected changes in annual precipitation for the American tropics include a decrease in Central America and large uncertainties for northern South America and the Amazon; however, in some regions there is qualitative consistency among climate simulations (e.g. increased rainfall in Ecuador and northern Perú; Christensen et al. 2007). In addition, the frequency and intensity of extreme weather events (tropical storms, hurricanes, drought) are also expected to increase during this century partially due to human influence (Salinger 2005; IPCC 2007a). For example, both the recurrence and intensity of the El Niño Southern Oscillation (ENSO), the main driver of interannual variation in temperature and precipitation across most of the tropics, have increased during the last century with concomitant record droughts since 1976 (Malhi and Wright 2004), probably exacerbated by global warming (Timmermann et al. 1999; Federov and Philander 2000). Adaptation to climate change through forest management will have to include anticipatory actions such as reducing the sensitivity of the system, altering its exposure to the effects of change, and enhancing its ability (resilience) to recover after disturbance (Adger et al. 2005).

Although tropical forests have adapted to probably even more drastic climatic change over the last several thousands of years before the present (e.g. Colinvaux et al. 1996, 2000;

Morley 2000), the pace of current changes in the global climate as well as the concurrent imposition of anthropogenic stressors (recently reviewed in Laurance and Peres 2006) may be beyond their natural adaptive capacity. It is generally assumed that a given degree of forest structural and biological diversity at various scales is necessary for maintaining the adaptive capacity of forests to environmental change (Noss 2001; Drever et al. 2006). One approach to achieve this is by applying reduced impact logging practices (RIL) which greatly minimize the effects of timber harvesting on vegetation, soils, and water (Dykstra and Heinrich 1996; Johns et al. 1996; Sist 2000). However, complementary, on-site and off-site approaches may be needed. Next we discuss specific silvicultural practices to enhance the adaptive capacity of production forests under a changing climate and also mention key institutional and policy interventions that may facilitate the inclusion of climate change into tropical forest management. We structure our discussion in the context of natural forest and tree plantations (summarized in Table 1).

3 Natural forest management

3.1 Facilitating adaptive capacity of timber species

Natural forest management in the tropics typically involves the harvesting of timber trees above a minimum diameter on a polycyclic basis. This implies that successive generations of the species of interest will be derived from adult progenitors *in situ*. Each individual that reproduces will have both experienced and (to date) survived the environmental conditions associated with past or current climate change. If the survival—or failure to survive—of these individuals (and their progeny) is related to their genotypes, then, by definition (Grant and Grant 1995), natural selection will have occurred and adaptation will have taken place. The response to natural selection depends on the magnitude of phenotypic variation in adaptive traits, the degree to which it is under genetic control and the intensity of the selection (Falconer 1989; McKay and Latta 2002). There are a number of practical options to maximize this response.

One is to maximize population sizes when selection pressure for survival is strongest; i.e. the seed and seedling stages. It may be that one cause of the relatively high local adaptation shown by many forest trees (Petit and Hampe 2006) is their high fecundity in comparison with other plants (Le Corre and Kremer 2003). High fecundity implies that those trees that survive to reproductive age (or harvest age) represent a small proportion of an initially large pool of seedlings, further implying that they have undergone a high selection intensity. To ensure high juvenile population sizes and thus promote high genetic variation at this stage, a few treatments can be applied such as controlled burning to enhance seedling establishment (e.g. in Central American closed-cone pine forests; Wolffsohn 1984), thinning (possibly as a part of controlled logging) aimed at stimulating crown development and eventual fruiting of seed trees (e.g. Guariguata and Saenz 2002), and the creation of canopy or ground disturbance for the regeneration of light demanding timber species (Fredericksen and Pariona 2002; Snook and Negreros-Castillo 2004; Grogan et al. 2005). Other options are to maximize the number of seed trees to be retained and harmonize the timing of tree harvesting to follow seed dispersal (e.g. Grogan and Galvão 2006); for dioecious species, retaining similar numbers of adult male and female trees to ensure reproduction and maintain genetically effective population sizes (Yeh 2000).

The natural distributions of many neotropical tree species cover a wide range of variation in precipitation and temperature (Greaves 1978; Pitman et al. 2001; Hodge et al.

Table 1 A broad classification of approaches and actions that may be needed for adapting tropical forest management for timber production to climate change

Approach	Actions by forest management type	
	Natural forest management based on selective logging	Tree plantations
Facilitating adaptive capacity of timber species	Maximize juvenile population sizes	Plant a range of genotypes and "let nature take its course"
	Maximize reproductive population sizes	
	Maintain inter-population movement of pollen and/or seeds by minimizing harvesting impacts on forest structure through reduced impact logging and by maximizing landscape connectivity	Implement appropriate species selection (particularly in transitional zones)
	Maximize genetic variation of planted seedlings when enriching logging gaps	Use seed sources adapted to expected future conditions
	Use of translocated material in enrichment planting	Use "stable" genotypes that tend to perform acceptably in a range of environments
Other silvicultural and management approaches	Intensify liana removal	Plant mixtures of species and implement appropriate species selection
	Minimize levels of slash through reduced impact logging	Widen buffer strips/fire breaks
	Widen buffer strips/fire breaks	
Institutional/policy	Increase awareness about enhancing the adaptive capacity of forests to climate change and define practical approaches and policies to this end	
	Promote good practices for fire management within, and adjacent to, production forests	
	Promote seed exchange and participatory genetic improvement programs for smallholders	
	Mainstream adaptation into national development in the context of the forestry sector	
	Evaluate costs and benefits of forestry activities aimed at enhancing the adaptive capacity of forests and establish appropriate financial mechanisms for implementation	

2002; Vozzo 2002; Cordero and Boshier 2003), which suggests that they have the genetic variation necessary to cope with environmental change within and possibly beyond these limits. However, common-garden studies have found marked genetic differentiation in quantitative traits between populations from specific climatic regions (e.g. Cornelius et al. 1996; Boshier and Henson 1997; Navarro et al. 2002). This implies that while, within the overall gene pool of a species, the potential for adaptation may exist, any one individual population is unlikely to have this potential. That is, the alleles needed for adaptation to climate change in a specific region may be present only, or in much higher frequencies, in populations from other regions. The problem then becomes one of "getting the variation where it is needed". This can be approached by enhancing or maintaining natural migration through landscape connectivity (maintenance of forest cover, tree corridors, trees outside forests). This would be relevant in the case where marked environmental variation (and, by implication, possible genetic differentiation) is found at a relatively small geographic scale, e.g. in mountainous areas or for species present both in riparian and neighboring “upland” forest. In areas characterized by relatively uniform temperature and rainfall regimes, the effectiveness of this strategy in the face of current rapid climate change is questionable, because useful alleles at high enough frequencies may not be found sufficiently close to target populations. In this case, the only feasible approach may be translocation through planting, as suggested by Ledig and Kitzmiller (1992).

3.2 Other silvicultural and management approaches

Modified silvicultural activities in natural forests may be required in the context of climate change. For example, long-term increases in liana abundance have been recorded in many undisturbed neotropical forests. These changes have been attributed to faster growth induced by enhanced levels of atmospheric carbon and ambient temperature (Phillips et al. 2002; Wright et al. 2004). To the extent that liana abundance is driven by these causes, this may imply more lianas over time. Liana removal from crop trees prior to harvest is generally carried out in order to minimize collateral tree damage in forests managed under RIL practices (Johns et al. 1996; Sist 2000). An adaptation option would require additional input for their control by logging crews at successive rotations which could also minimize growth declines or else mortality of liana-infested timber trees (Phillips et al. 2005). In the case of trees, evidence of climate-driven, accelerated tree growth rates have also been detected across the Amazon basin over the last decades (Lewis et al. 2004; but not in Central America; Feeley et al. 2007). Increased productivity in the Amazon could shorten rotations between successive harvests (which currently span no less than 40years in Amazonian forests; Valle et al. 2006) but it may also favor, over the long term, dominance of fast-growing timber species (e.g. Laurance et al. 2004). The refinement of silvicultural techniques to generate levels of commercial regeneration within this ecological guild may be needed.

Enrichment planting can provide opportunities for maximizing genetic variation of selected timber species at the stand level, particularly those susceptible to commercial extinction in the absence of post-logging silvicultural interventions (Fredericksen and Putz 2003). For example, in Brazil it is now mandatory to plant mahogany (*Swietenia macrophylla*) seedlings in felling gaps after extraction of adult trees from the site (Grogan and Barreto 2005). Other high-value Amazonian timber species that show naturally low seedling densities under closed canopy are also in need of post-logging enrichment planting to ensure adequate stocking between harvest rotations (Schulze 2008).

Fire management in the context of a changing climate also deserves attention. Forest fires associated with extreme droughts (further projected to increase in neotropical forests; Cox et al. 2004; Nepstad et al. 2004; Scholze et al. 2006) like those during 2005 in the Western Amazon (Brown et al. 2006) can be countered through RIL practices which, in comparison to conventional logging, decrease the vulnerability of the forest to ground fire through a reduction of the size of both felling gaps (usually the most fire susceptible areas) and fuel loads (Holdsworth and Uhl 1997; Blate 2005). However, focusing only on the forest is unlikely to succeed. The recent increase in frequency and extent of forest fires in the Amazon may not be only due to the effects of more intense ENSO-related droughts but also to direct anthropogenic influences at forest edges (Barlow and Peres 2004; Laurance 2004). In fact, fires that spread from adjacent pastures seem the overriding cause of forest burning across the Amazon (Cochrane 2001), including those intruding into timber concessions (e.g. Pinard et al. 1999).

4 Tree plantations

In the case of planted forests, the range of approaches for enhancing adaptive capacity to climate change is perhaps wider than of natural forests, as both genetic material and silvicultural treatments can be adjusted more readily (Lamb et al. 2005). These are discussed below. Yet the most fundamental measure is the choice of appropriate species. It is useful to consider species-site matching as a two-step process. First, the selection of a group of species broadly appropriate for a given climatic zone. These could be (for the neotropics), "high altitude species" (e.g. *Alnus acuminata*, *Cupressus lusitanica*, *Eucalyptus globulus*), "seasonally-dry zone species" (e.g. *Bombacopsis quinata*, *Swietenia macrophylla*, *Tectona grandis*), "wet zone species" (e.g. *Carapa guianensis*, *Eucalyptus deglupta*, *Vochysia guatemalensis*). Second, the selection of species for specific conditions within that zone (e.g. *Cordia alliodora* for soils with low aluminum saturation, *B. quinata* for vertisols, *Calycophyllum spruceanum* for seasonally flooded areas). In general, we consider it unlikely that climate change considerations would, in the short term, lead to changes in species selection (particularly perhaps at the first step), because within the period of a fast-wood rotation (typically 10years or less), conditions would not change enough to shift the group of suitable species towards that more suitable for another location. However, current species choice should be regularly reviewed, particularly in transitional environments and longer-rotation hardwood species. It is also important to note that the challenge posed by climate change underlines the importance of careful selection even for current conditions; species that are poorly adapted at present to a given planting site are likely to be ill-prepared to deal with stress from future climate change.

4.1 Facilitating adaptive capacity of timber species

As outlined some time ago by Ledig and Kitzmiller (1992), taking account of climate change for seed sourcing may require some departure from current practice. The generally accepted "current wisdom" continues to be that, where information from genetic tests is lacking, "local seed is best". Under climate change, this may no longer be the case, as local seed sources are more likely to be adapted to historic, rather than near-current (i.e. the next planting season) and future conditions; one response under this is to choose seed sources expected to be better adapted. For example, Sáenz Romero et al. (2006) assessed the genetic variation of populations of *Pinus oocarpa*, an economically important timber species in Mexico, across an altitudinal gradient. They concluded that managers should assist *P. oocarpa* populations to adapt whenever carrying out planting programs by moving seed genotypes at given intervals upwards in anticipation of projected trends of increasing temperature (IPCC 2007b).

Similarly, results of provenance trials may suggest specific actions. Coastal provenances of *Pinus caribaea* var. *hondurensis* show greater structural stability when exposed to cyclones (Gibson et al. 1983; Nikles et al. 1983), whilst provenances of the same species from high rainfall locations have shown lower survival than provenances from lower-rainfall origins when both are planted on relatively dry sites (Hodge et al. 2001). However, it may not always be clear which sources represent the best balance between adaptation to near-current and future conditions. Two responses to this uncertainty are possible. First, generalist ("stable", in breeders' terminology) genotypes can be used, i.e. those which show wide adaptability to a range of conditions; this option is only feasible where field tests exist and where they have sampled a wide enough range of conditions. Second, germplasm mixtures that may contain very high genetic variation may be used. For example, Ledig and Kitzmiller (1992) suggested using a mixture of provenances (e.g. the local seed sources and sources expected to be adapted under a range of climate change scenarios). Poorly adapted, inferior trees would be removed during thinning or through differential early mortality. This approach recognizes the uncertainty present in the projections of future climate conditions and takes advantage of conventional silvicultural practice in order to ensure well-adapted trees for the final harvest. As in the case of species selection, the urgency of implementation of such approaches may be less in the case of fast-growing species as, at least in the industrial context (see below), current germplasm may be replaced in the short-medium term through replanting with other sources.

In considering current practice and the potential for applying germplasm selection and development, it may be useful to distinguish industrial tree planting and smallholder tree planting. In the particular case of industrial plantations, approaches to adaptation to climate change based on germplasm selection and development are more likely to be implemented because industrial forestry is generally much better funded than smallholder forestry. Although we have been unable to identify any modifications of neotropical industrial tree breeding aimed specifically at adaptation to climate change, existing tree improvement programs that continuously incorporate new selections would, nevertheless, secure the use of germplasm one generation, at most, 'behind' current climatic conditions; in other words, it will permit a delayed 'tracking' of climate change. At the same time, there are clear deficiencies in current management of genetic resources by some private enterprises. For example, one medium-sized enterprise in Pará, Brazilian Amazon, is basing much of its reforestation efforts on only two clones of *Eucalyptus urograndis* developed under the quite different ambient conditions of Minas Gerais, some 1,600km to the south (J.P.C., personal observation, February 2007). In view of uncertainty over future climatic changes, such practices appear to be short-sighted.

The types of responses feasible in smallholder forestry may be different than in industrial forestry and reflect the fact that smallholders plant trees in various situations and for various reasons. One is externally led tree planting programs; that is, sponsored or promoted by government and non-government organizations where farmers often receive free or subsidized seed or seedlings. In these programs, germplasm is often sourced with little or no technical criteria and without any provision or plan for replacement in subsequent rotations. New germplasm will most likely come from the same germplasm sources as before (Simons et al. 1994). When smallholders plant trees under their own initiative, they also often use germplasm collected on-farm or from neighboring farms (e.g. Weber et al. 1997). Even under stable climatic conditions, such practices may lead to use of germplasm that is poorly adapted or genetically depauperate (e.g. *Inga edulis* in Amazonia; Hollingsworth et al. 2005). When technical assistance is being offered under both situations, managers would be well-advised to ensure that initial (founder) populations include adequate genetic diversity, both by maximizing number of seed trees and using provenance mixtures (as discussed above).

4.2 Other silvicultural and management approaches

There is evidence that use of mixed species plantings over monocultures may reduce vulnerability of the system over the long-term (Jactel et al. 2005; Kelty 2006). Mixes of tree species with contrasting phenologies, different below- and above ground architecture, and/or nitrogen-fixing ability can increase biomass production compared to monocultures (Lamb 1998; Petit and Montagnini 2006) while providing economic risk reduction and earlier financial returns (Hartley 2002). One of the largest monospecific tree plantations in the American tropics (about 0.6M ha of *Pinus caribaea* var. *hondurensis* in Venezuela) suffered massive (fungus-induced) tree mortality mediated by water stress during the very intense 1997 El Niño drought (Cedeño et al. 2001). In another (extra-tropical) example, after large-scale, climate-mediated destruction of forests, including coniferous monocultures in France during 1999, new silvicultural practices to increase stand diversity and hence to improve adaptive capacity were recommended (Bastien et al. 2000). Although tree monocultures are easier to manage and simplify both nursery and harvesting costs (Kelty 2006), current concerns about climate change and long-term sustainability may enhance awareness and further stimulate the interest of industrial foresters in mixed-species plantations, an option which they have largely disregarded (Nichols et al. 2006).

5 Institutional and policy approaches

In addition to the technical approaches discussed above, institutional and policy interventions will be needed in order to facilitate the incorporation of climate change into tropical forestry. One of these relates to dissemination of practical guidance. There are relatively detailed UNFCCC guidelines for estimating and reporting greenhouse gas emissions and carbon dioxide removals associated with different land uses, land-use changes and forestry activities (Penman et al. 2003), but little or no published guidance on adaptation to climate change in tropical production forests. The available guidance to assess impacts and vulnerability of forests to climate change in order to delineate adaptation options is both generic and outdated (e.g. Carter et al. 1994; Scholes and Linder 1998) while recent guidance on developing broad adaptation strategies (e.g. Lim and Spanger-Siegfried 2005) does not include forestry activities within its illustrative set of examples. Probably because of these deficiencies, forestry activities in general, and climate-mitigation forestry projects in particular, rarely acknowledge that tree planting efforts may be vitiated if for example a plantation is poorly adapted to the climate changes it is supposed to mitigate. Although some global initiatives for independent carbon forestry certification are fostering the inclusion of adaptation measures (e.g. the Climate, Community, and Biodiversity Project Design Standards (CCBA 2005)), these still do not mention specific practice. A more explicit dissemination of tools and approaches for enhancing the adaptive capacity of natural and planted forests seems necessary.

Enhancing the adaptive capacity of smallholder planted forests to future climate conditions may also necessitate targeted assistance. Smallholder tree farmers unable to supplement by themselves their local germplasm with strategically selected germplasm from other, perhaps distant tree populations, will be in need of technical help. Relatively large-scale tree improvement programs focused on smallholders, such as those implemented in Costa Rica (e.g. Mesén et al. 1993) or Perú (e.g. Weber et al. 2001; Cornelius et al. 2006) can be an option but only for a few of the highest priority species of the tens or hundreds used by them (Sotelo Montes and Weber 1997). For a wider set of species, smaller scale, local participatory tree genetic improvement (Simons and Leakey 2004) offers another opportunity. The exchange of tree germplasm through “seed fairs” such as those organized in Madre de Dios, lowland Perú (P. Casanova, Asociación de Agricultura Ecológica; personal communication to J.P.C.) is also an alternative or complementary approach. Yet the need for field-testing in (possibly non-local) environments corresponding to future conditions may go beyond local capacities and thus may be in need of additional support from governmental and non-governmental organizations.

Fostering the prevention or control of burning outside and inside production forests, while maintaining wide buffer zones, may be necessary. Although some enterprises in

Brazil dedicated to long-term timber production have fully implemented guidelines aimed at protecting the forest from fires (Pokorny et al. 2005), results are nevertheless varied. Fire management in the context of timber production seems to remain of low priority in other parts of the Amazon (e.g. Gould et al. 2002) while in Guatemala, fires intruding production forests appear to be effectively controlled due to sustained, participatory prevention and mitigation efforts (Nittler and Tschinkel 2005). Institutional, governance, and technical issues are equally important in fire management and prevention and the right balance among these will be dictated by specific site conditions (Barlow and Peres 2004). Generic approaches to fire management and prevention are already in place (e.g. FAO 2006b) and waiting for local modification.

One of the reasons why global policy has had little effect in incorporating climate change into tropical forestry may be because of the often controversial, multi-faceted nature of international policy making on forests themselves (see e.g. Persson 2005). This in turn has prevented the global carbon market to significantly influence the area under tree plantations established through the CDM; and to date, natural forest management is not yet eligible under the CDM. Nevertheless, discussions under the UNFCCC are currently dealing with establishing an international instrument to curb carbon emissions from tropical deforestation. Among several alternatives, the role of the international carbon market is being considered in the debate (Moutinho et al. 2005; Gullison et al. 2007). Although many methodological issues still need to be agreed upon, the reduction of carbon emissions from deforestation could present an opportunity for further implementing or else adjusting management practices to enhance the adaptive capacity of production forests to climate change. For example, fostering the application of carbon-retentive, RIL guidelines (Pinard and Putz 1996; Pinard and Cropper 2000).

Developing and implementing adaptation strategies for tropical forests may also necessitate institutional interventions aimed at raising the awareness of society about current and/or future climate changes. Climate change risks are seldom perceived by foresters, forest managers, or those forest-dependent communities in tropical latitudes. For most of them, climate change may represent a continuation of existing challenges and environmental stresses (Rojas 2004) and even if they acknowledge climate-related risks, changing attitudes may not be straightforward (see e.g. Wesche et al. 2006 for a temperate example). A study along the lines of Williamson et al. (2005) aimed at assessing the perceptions of climate change risk in temperate forests could be useful in the context of tropical forestry by helping to formulate future management options and policy development at the national or local level.

6 Conclusions

Current tropical forest management practices are based on the assumption that the climate will not vary to the extent that long-term productivity (and profitability) may be affected. Clearly, the selection of adaptation options is sometimes difficult because of the uncertainties regarding projections of future climate change (e.g. Dessai and Hulme 2007). However, more effort and resources seem to have been devoted at detecting the impacts of global climate change on protected tropical forests (reviewed in Clark 2007) than on maintaining their adaptive capacity as production systems. In advancing the incorporation of climate change considerations into tropical forestry, we foresee that at least two big challenges will have to be met.

First, we consider that mainstreaming adaptation into national development and planning programs is a prerequisite for adequate action to cope with current and future climate change impacts. There is already guidance on this (Lim and Spanger-Siegfried 2005; Thompkins et al. 2005) that can be applied to the tropical forestry sector. In addition, and as the impacts of climate change also threaten the economic development of other sectors, many of which depend on the provision of forest goods and services, tropical forestry could benefit from being explicitly included into broader adaptation policies. As an example, among the 20 National Adaptation Programmes of Action (NAPAs) prepared by Least Developed Countries (LDCs) under the UNFCCC, at least 16 of them mention forestry projects within their adaptation priorities (http://unfccc.int/adaptation/napas/items/2679.php; accessed on 21 August 2007). The inclusion of forest ecosystems within NAPAs has been prominent due to their relatively high importance for local livelihoods (e.g. water regulation, food and fuelwood sources) and for the protection of coastlines (however, LDCs may still need guidance on how to enhance the adaptive capacity of their forests). Tropical forestry in the context of adaptation to climate change could also be made more prominent if the NAPA approach is extrapolated beyond that of LDCs.

The second challenge is a financial one, as adaptation entails a cost. In some cases, the private sector may decide to invest in adaptation measures, purely on the basis of commercial self-interest (e.g. modifications to tree improvement programs) although this will only come about if it has access to sound information on risks and associated costs. In other cases, government agencies could require the implementation of practical measures aimed at enhancing the adaptive capacity of forests as a condition for granting management concessions. However, funding of climate adaptation measures that generate wider public benefits of only indirect interest to industry or that are aimed at smallholders or other vulnerable groups may require alternative financing mechanisms which may not be currently available. The scarcity of funding underscores the importance of ensuring that adaptation measures are incorporated in the formulation and implementation of national and international initiatives concerned with forests, from broader policy interventions to local research and development projects.

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