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THE ROYAL SOCIETY

Designing a carbon market that protects forests in developing countries

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Firmly incorporated into the Kyoto Protocol, market mechanisms offer an innovative and cost-effective means of controlling atmospheric concentrations of greenhouse gases. However, as with markets for many other goods and services, a carbon market may generate negative environmental externalities. Possible interpretations and application of Kyoto provisions under COP-6*bis* and COP-7 raise concerns that rules governing forestry with respect to the Kyoto carbon market may increase pressure on native forests and their biodiversity in developing countries. In this paper, we assess the following two specific concerns with Kyoto provisions for forestry measures. First, whether, under the Clean Development Mechanism (CDM), by restricting allowable forestry measures to afforestation and reforestation, and explicitly excluding protection of threatened native forests, the Kyoto Protocol will enhance incentives for degradation and clearing of forests in developing countries; second, whether carbon crediting for forest management in Annex I (industrialized) regions under Article 3.4 creates a dynamic that can encourage displacement of timber harvests from Annex I countries to developing nations. Given current timber extraction patterns in developing regions, additional harvest pressure would certainly entail a considerable cost in terms of biodiversity loss.

In both cases, we find that the concerns about deleterious impacts to forests and biodiversity are justified, although the scale of such impacts is difficult to predict. Both to ensure reliable progress in managing carbon concentrations and to avoid unintended consequences with respect to forest biodiversity, the further development of the Kyoto carbon market must explicitly correct these perverse incentives. We recommend several steps that climate policymakers can take to ensure that conservation and restoration of biodiversity-rich natural forests in developing countries are rewarded rather than penalized. To correct incentives to clear natural forests through CDM crediting for afforestation and reforestation, we recommend for the first commitment period that policymakers establish an early base year, such as 1990, such that lands cleared after that year would be ineligible for crediting. We further recommend an exception to this rule for CDM projects that are explicitly designed

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to promote natural forest restoration and that pass rigorous environmental impact review. Restoration efforts are typically most effective on lands that are adjacent to standing forests and hence likely to have been recently cleared. Thus, we recommend for these projects establishing a more recent base year, such as 2000.

For the second and subsequent commitment periods, we recommend that climate policymakers act to restrain inter-annex leakage and its impacts by ensuring that crediting for forest management in industrialized countries is informed by modelling efforts to anticipate the scale of leakage associated with different Annex I 'Land use, land-use change and forestry' policy options, and coupled with effective measures to protect natural forests in developing countries. The latter should include expanding the options permitted under the CDM to carbon crediting for projects that protect threatened forests from deforestation and forest degradation.

Ultimately, carbon market incentives for forest clearing can be reduced and incentives for forest conservation most effectively strengthened by fully capturing carbon emissions associated with deforestation and forest degradation in developing countries under a future emissions cap. Finally, we note that these recommendations have broader relevance to any forest-based measures to reduce greenhouse-gas emissions developed outside of the specific context of the Kyoto Protocol.

Keywords: carbon markets; Clean Development Mechanism; biodiversity; plantations; reforestation; leakage

1. Introduction

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) strongly emphasizes the role of market mechanisms in reducing atmospheric concentrations of greenhouse gases (GHGs), and has prompted the development of an international trading scheme for carbon credits to this end. Though incorporating many elements of a 'free-market approach', the efficient, equitable, and effective functioning of this market will require careful construction of principles and rules that govern market operations and participation, to ensure both reduced net carbon emissions and a minimum of economic dislocation and environmental and social impacts. The agreements reached at COP-6*bis* and COP-7 in 2001 made significant strides in refining this trading mechanism and designing the rules that are to govern trading of carbon emissions quotas.

The parties reached several key decisions to define the menu of land-use, land-use change and forestry (LULUCF) options available to Annex I (industrialized) countries to meet their emissions–reductions obligations. They also affirmed as a core guiding principle that the implementation of LULUCF activities 'contributes to the conservation of biodiversity and sustainable use of natural resources' (UNFCCC 2002*a*). However, possible interpretations and application of some available LULUCF options may contribute to biodiversity loss by exacerbating deforestation and forest degradation trends in non-Annex I (developing) countries. Such outcomes also would increase GHG emissions and negatively impact forest-dependent communities. Here, we examine the potential seriousness of these threats and recommend steps that climate policymakers can take to address them.

Concerns about potentially large impacts on native forests in developing countries arise from two quite different decisions. The first and most conspicuous decision entails the LULUCF project activities in developing countries that are eligible for carbon crediting under the Clean Development Mechanism (CDM). Parties at COP-7 restricted eligible project activities to afforestation and reforestation (A&R). At least for the first commitment period, 2008–2012, project activities designed to slow deforestation were not deemed eligible for crediting. The result of a complex political negotiation,[1] this decision eliminates for the near-term any carbon market incentive to address the *ca.* 20% of annual anthropogenic CO_2 emissions caused by forest conversion in the tropics (Prentice *et al.* 2001). In addition, it also raises concerns about whether CDM crediting for A&R will act as an incentive to clear natural forest for the purposes of establishing carbon plantations. Biodiversity considerations aside, such a process would undermine the carbon sequestration benefits from plantation efforts. Moreover, land that might be suitable for natural forest restoration could face competition from plantation efforts subsidized by carbon premiums, again leading to both biodiversity and GHG emissions additionality concerns. Climate negotiators have an important near-term opportunity to address these concerns, as the Subsidiary Body for Scientific and Technological Advice was tasked at COP-7 with developing more specific guidance by COP-9 on the treatment of additionality, environmental impacts (including 'impacts on biodiversity and natural ecosystems') and other key issues affecting the implementation of A&R projects in the CDM (UNFCCC 2002*b*).

The second potential impact on native forests in developing countries stems from the decision to credit forest management activities in Annex I countries under Article 3.4. This provides a carbon premium for standing natural forests in industrialized countries that, in effect, increases the opportunity cost of harvesting Annex I timber and makes timber in developing countries, which have no cap on emissions, relatively cheaper. This creates a potential carbon market incentive for 'inter-annex leakage' by redirecting timber harvests from industrialized to developing countries. For the first commitment period, such leakage may be minimal, as Article 3.4 sets country-specific caps for forest management at levels that allow carbon credits to be gained largely through business-as-usual activities (Bonnie *et al.* 2002). But several lines of evidence explored in this paper suggest that it is a potentially serious concern for future commitment periods, for which the rules have yet to be written.

2. Afforestation and reforestation in the CDM

Potential A&R project activities eligible for crediting under the CDM could range from small-scale agroforestry and native forest restoration to large-scale industrial plantations. The type of activities, and their geographic distribution, magnitude, and environmental and social impacts will depend on the rules governing A&R project implementation and eventual market-clearing prices for carbon credits. They will also depend on the interests of developing countries in soliciting particular types of projects, and the interests of prospective investors in seeking CDM project credits. Large-scale plantations, for example, may be of substantial interest to project investors because of their potential to generate profitable financial returns as well as carbon credits (Frumhoff *et al.* 1998; Brown *et al.* 2000).

Plantation forestry projects motivated by CDM carbon crediting need not have negative impacts on biodiversity. Plantations established on degraded lands and managed according to internationally recognized certification standards can, for example, provide both environmental and social co-benefits. In some cases, non-permanent plantations of exotic or native species can be designed to jump-start the process of native forest restoration and hence directly support forest and biodiversity conservation objectives (Parotta 1997*a*, *b*; Brown *et al*. 2000).

However, despite a widespread belief to the contrary, plantations in the tropics do not typically reduce pressure on natural forests. This stems from the fact that forests generally are not logged or cleared for the sawn wood, pulpwood or other products that plantations provide (Kanowski *et al*. 1992). Rather, natural forests supply a range of products that have yet to be reproduced in tropical plantations; in particular, the potential contribution of plantations to the global supply of tropical hardwoods remains insignificant (Sawyer 1993).

Poorly designed or located plantations can have significant negative impacts on biodiversity (Brown *et al*. 2000). For instance, permanent plantations in areas adjacent to natural forests eliminate in those locations the prospect of restoring native forests and their biodiversity. With specific regard to the CDM, of greatest concern is the potential for carbon premiums to accelerate deforestation by financing the clearing of forests to be replaced with plantation monocultures. This concern arises because the emissions associated with deforestation would not be constrained by a national cap (WBGU 1998; Brown *et al*. 2000).

Accelerated rates of forest degradation and deforestation may occur wherever carbon payments can sway the balance between financial costs and benefits of particular enterprises in forested areas. Substantial oil-palm investments in Indonesia, for example, are rendered viable only by the income from logging of natural forests that precedes plantation establishment (Casson 1999; LaFranchi 2000). A carbon premium linked to such plantations could expand still further the geographic range over which conversion of natural forest to oil palm is financially viable.

Indeed, precedents exist in which timber companies have pursued plans to clear native vegetation and establish timber plantations that generate carbon credits. In February 2000, for example, the Rio Foyel S.A. timber company proposed to harvest four thousand hectares of native forest in southern Argentina, to be followed by reforestation with exotic pine species. The stated objectives of the project were carbon sequestration and sustainable timber production. Regional authorities, local community members, and environmental organizations objected to the deforestation of native species, introduction of exotic species, and potential damage to the watershed. The company eventually withdrew the project proposal. While this particular project thus was averted, it illustrates how the prospect of income from carbon sequestration can encourage the timber sector to clear native forests (Biodiversidad en América Latina 2000).

Similarly, the Tokyo Electric Power Company (TEPCO) has been involved in efforts to clear native forests in Tasmania for the purpose of establishing carbon plantations (Cadman 2000). In a joint venture with Australian timber company North Forest Products, TEPCO has sought to generate of the order of 130 000 tonnes of carbon credits in this fashion. Although taking place in an Annex I country, this joint venture is again illustrative of the means by which a carbon market could fuel deforestation in developing countries through CDM A&R projects.

The potential scale of impacts to native forests and biodiversity in developing countries is not clear. To evaluate the scale accurately, one must first assess the extent to which carbon financing through the CDM is likely to lead more generally to an expansion of plantations in non-Annex 1 countries. This is difficult to predict. The

Table 1. *Extent and rate of plantation establishment*
(Reproduced from Pandey & Ball (1998).)

	total plantation (kha)	annual rate establishment (kha)	proportion for industrial roundwood (%)
developed countries	81 224	2560 (4%)	100
non-tropical developing countries	30 213	2358 (5%)	73
tropical countries	27 505	1654 (6%)	58
subtotals for tropical regions			
tropical Africa	2 434	120 (5%)	52
tropical America	5 973	230 (4%)	76
tropical Asia	19 098	1304 (7%)	45
totals	138 942	6572 (5%)	87

area dedicated to timber plantations in developing countries and their contribution to the world timber supply are already increasing rapidly (table 1), an expansion that is expected to continue even in the absence of a carbon market.[2]

Not simply a function of market forces, these rapid rates of plantation expansion in many developing countries, particularly in the tropics, result from generous government subsidies. Such subsidies often reflect government efforts to spur employment and economic development in areas able to support forests for industrial and fuelwood production (FAO 1997, 2001). In areas where a carbon premium is truly additional to existing subsidies or other incentives, growth in plantation coverage seems likely to continue on an upward continuum.

However, some developing country governments might seek carbon financing for plantations through the CDM as an alternative to existing subsidies for plantation establishment and hence reduce or eliminate subsidies as the carbon market financing develops. In these cases, a carbon premium would not accelerate plantation establishment over baseline rates. CDM financed plantations that merely replace those that would have funded by other sources would also not sequester carbon above baseline rates, however, and hence would not meet strict tests of additionality.

Carbon premiums for A&R plantation projects in the CDM thus give rise to serious concerns over potential impacts on native forests and biodiversity. While the potential scale of the problem is difficult to predict, the fact that carbon financing enhances incentives for accelerated forest degradation and deforestation strongly suggests that parties should act to eliminate these incentives. A straightforward way to do so would be through the selection of an appropriate base year, such that land cleared after that year would be ineligible for A&R crediting under the CDM. For example, setting 1990 as a base year would imply that only lands that were demonstrably deforested prior to 1990 would be eligible for A&R projects. This would neatly eliminate the potential for carbon crediting to accelerate negative impacts to native forests. However, such a base-year rule would come at a cost. As noted above, well-designed A&R projects under the CDM have the potential to provide positive biodiversity co-benefits by promoting the restoration of natural forests. But restoration projects need to be established in close proximity to standing forest, that is, on lands that are likely to have been recently deforested. Hence, a tightly enforced rule setting an early base year would also effectively eliminate crediting for many A&R projects with substantial potential for positive impacts on biodiversity. This perverse outcome could be reduced by setting a relatively recent base year (e.g. 2000) for projects that are explicitly designed to promote native forest restoration and pass rigorous environmental impact review.

3. Inter-annex market leakage

Market-driven leakage of carbon emissions arises when emissions reductions require a change in economic activity, but the market signal that elicited the original activity persists. It is a problem facing both the energy and LULUCF sectors (Chomitz 2000). For the LULUCF sector, the concern is that, by crediting key LULUCF interventions in industrialized countries in the absence of caps on emissions from timber harvests and deforestation in developing countries, a carbon market could redirect harvests and associated emissions to the latter. That is, if carbon premiums alter forest management systems and harvest patterns such that the timber supply from Annex I regions declines, developing countries may respond by increasing their share of global timber markets. Carbon benefits from LULUCF measures in Annex I countries would then be reduced or negated by accelerated harvests in developing countries, with substantial impacts to biodiversity should these harvests be directed to natural forests.

What is the potential for such inter-annex leakage? Timber markets can respond rapidly to policy changes by changing supply sources. For example, timber market leakage has been documented following forest protection in the Pacific Northwest (PNW) region of the US, displacing harvests to the southern US, Canada, and, to a lesser extent, newer plantation producers such as New Zealand and Chile (see figure 1). Similar displacement from industrialized to developing countries may be expected should carbon premiums reduce Annex I timber harvests. In particular, softwood products, as opposed to hardwoods, are the segment of the world timber market that exhibits significant overlap between Annex I and non-Annex I production (Brooks 1995; Leslie 1999). This is because softwoods generally are more likely to be transformed into highly substitutable intermediate products, such as pulp and fibre, whereas hardwoods tend to yield more-differentiated end products. Thus, reduced softwood harvests in Annex I regions would be replaced to some degree by equivalent products from the non-Annex I regions.

As noted above, such leakage is likely to be minimal for the first Kyoto Protocol commitment period of 2008–2012, since Article 3.4 sets country-specific caps for forest management at levels that allow carbon credits to be gained largely through business-as-usual activities (Bonnie *et al.* 2002). For future commitment periods, the degree to which carbon markets would prompt relocation of harvest pressure from Annex I to non-Annex I countries will depend on a range of factors. These include each region's share of the global timber market, emissions–reductions targets, and carbon crediting rules for future commitment periods and their impacts on carbon prices.

Annex I countries dominate global production and trade, accounting for four-fifths of softwood production and just over half of hardwood production (see table 2). This dominant position of Annex I countries in global timber output indicates that, if

Table 2. *Global and Annex I industrial roundwood production and trade*
(All figures given in units of m^3. Data reproduced from the UN Food and Agriculture Organization's FAOSTAT database at http://www.fao.org/forestry.)

	softwoods			hardwoods		
	1990	1995	1999	1990	1995	1999
world						
production	1 159 805 920	944 876 350	936 735 789	541 641 424	567 918 190	568 672 261
imports	41 942 796	50 179 248	60 042 493	40 651 080	44 364 468	40 584 406
exports	42 628 955	48 142 563	59 341 856	40 775 275	40 674 689	37 078 771
Annex I						
production	695 469 000	732 811 000	747 751 242	216 317 000	270 206 000	304 218 353
imports	29 455 988	38 105 500	47 505 500	27 969 670	29 968 900	26 896 500
exports	32 806 945	42 565 900	56 245 900	8 446 850	20 761 600	20 843 300
Annex I share of world						
production	60%	78%	80%	40%	48%	53%
imports	70%	76%	79%	69%	68%	66%
exports	77%	88%	95%	21%	51%	56%

biotic carbon sequestration projects significantly reduce harvests in Annex I countries, the impact will be felt in international timber markets.

Carbon market prices under Kyoto may well be sufficient to exert an impact on timber harvests in Annex I countries. Various analyses estimate that market clearing carbon prices would settle in the neighbourhood of \$20, \$40 or as much as \$80 per tonne (Fankhauser 1995; Roughgarden & Schneider 1999; Totten 1999). In a survey of several sophisticated modelling efforts, EIA (1998) presents estimates ranging from about \$100–200 per tonne. These could be high-end estimates, as they assume that the US, a large potential source of demand for carbon credits, participates in the international carbon market. The role played by the US in a future carbon market remains uncertain, however. Without US participation, lower aggregate demand for carbon credits will result in lower carbon prices than anticipated by these studies.

Carbon market prices within the range of projections reported above would most likely motivate both decreased harvests from natural forests and increased afforestation in industrialized countries. Analyses of Douglas fir exploitation in the Pacific Northwest and Loblolly pine exploitation in the southeast US indicate that the price of carbon needs to be at least \$20 per tonne to encourage increased retention of land for forest or retention of trees during harvests (Van Kooten *et al.* 1995; Murray 2000; Wayburn *et al.* 2000). Wayburn *et al.* (2000) find that prices over \$100 per tonne allow carbon to compete directly with alternative development and short rotation harvest schedules. In marginally productive areas, lower carbon prices may be sufficient to promote afforestation efforts (Parks & Hardie 1995, 1996; Stavins 1999; Plantinga *et al.* 1999). McCarl & Schneider (2001) calculate that a carbon price of \$50 per tonne could prompt nearly 5 million hectares of afforestation efforts in the US.

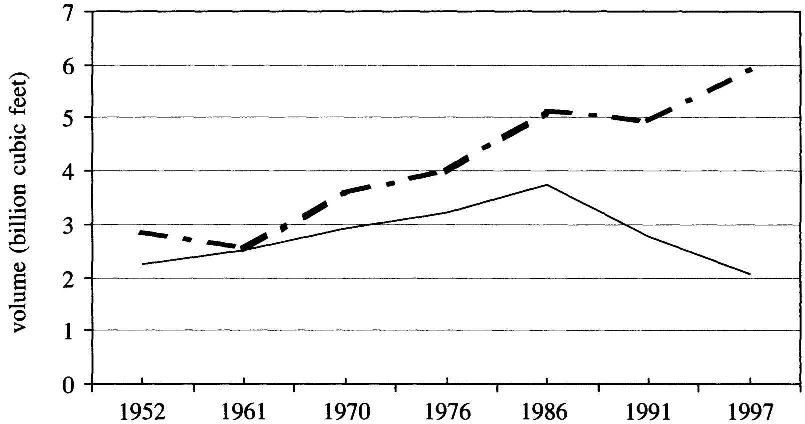

Figure 1. In 1989, a significant area of national forest in WA and OR was set aside as critical habitat for the northern spotted owl. This figure depicts the marked decline of timber harvests in this region after 1989. The harvest response in the southern US (broken line) conformed to predictions of timber market models. While softwood removals in the PNW (solid line) fell between 1986 and 1997, annual softwood removals in the south increased from 5.13 billion cubic feet to 5.9 billion cubic feet over the same time period (1 cubic foot equals 0.0283 m^3). By the mid-1990s, eastern Canada and the southern US had increased softwood production enough to offset most of the decrease in timber harvests resulting from restrictions in the western US. Note that softwood removals in the South did not immediately increase in response to the decline in harvests in PNW forests, due to the economic recession of 1988–1991. Meanwhile, increased exports from New Zealand, Chile, and Russia compensated for the decline in PNW exports to the Pacific Basin (Haynes *et al.* 1995; USDA Forest Service 2001; Guan & Munn 2000; Sedjo 1995; Brooks 1995). Data for southern US reflects softwood timber harvest only.

Taken together, these lines of evidence provide strong cause for concern that Kyoto carbon market incentives to reduce timber harvests in Annex I industrialized countries could motivate increased harvests in developing countries, particularly those producing softwoods at competitive market prices. Sophisticated modelling efforts building on the work of Sedjo & Sohngen (2000) are needed to more precisely anticipate the prospective scale of inter-annex leakage resulting from stronger incentives to reduce industrialized country forest-carbon emissions.

Modelling inter-annex leakage will also help clarify the extent to which it may lead to increased harvests from natural forests or plantations. Where leakage leads to expanded harvests from plantations, it has the worrisome potential to motivate the further expansion of plantations in areas most appropriate for the conservation and restoration of natural forests. This parallels the potential impact of carbon crediting for A&R plantation projects under the CDM discussed in the preceding section. One key difference is that the scope for constraining such negative impacts is more limited. Redirected plantation investments will not be subject to any carbon market rules, whereas A&R projects will be subject to CDM rules on additionality and environmental impact.

Where leakage leads to expanded harvests in natural forests, it generally will have sharply negative impacts on biodiversity. The logging practices that currently predominate in tropical forests characteristically result in substantial collateral damage to non-commercial trees during harvest, increased frequency and intensity of fire compared with unlogged forests, and, in some regions, sharply increased rates of bushmeat hunting and colonization along logging roads. These impacts substantially reduce biodiversity by altering the structure, function and species composition of forests relative to undisturbed or carefully managed natural forests (Frumhoff 1995; Putz *et al.* 2000*a*; Bennett & Gumal 2001).

Leakage of timber harvests from industrialized to developing country forests will also tend to increase net carbon emissions to the atmosphere. Tropical forests generally have higher carbon densities than temperate forests (Olson *et al.* 1983; Dixon *et al.* 1994; Nilsson & Schopfhauser 1995; Prentice *et al.* 2001) but lower densities of commercial species, and conventional logging practices in many tropical countries result in high collateral damage to non-commercial species (Holmes *et al.* 2000; Putz *et al.* 2000*b*; Pulkki 1998; Gullison *et al.* 1997). Thus, increasing timber supplies from tropical, non-Annex I forests to replace supplies from Annex I countries will in general raise the average amount of carbon released per volume of harvested timber (Houghton & Hackler 1999, 2000).

Climate policymakers need to recognize the potential for inter-annex leakage and the consequent substantial negative impacts on forest biodiversity and carbon emissions in developing countries. For the second and subsequent commitment periods, they can act to restrain such leakage and its impacts by ensuring that crediting for forest management in industrialized countries is informed by modelling efforts to anticipate the scale of leakage associated with different Annex I LULUCF policy options, and coupled with effective measures to protect natural forests in developing countries. The latter should include expanding the options permitted under the CDM to carbon crediting for projects that protect threatened forests from deforestation and forest degradation. Ultimately, inter-annex leakage can be most effectively mitigated by fully capturing carbon emissions associated with deforestation and forest degradation in developing countries under a future emissions cap.

4. Conclusion

In the near-term, LULUCF activities undertaken through the Kyoto carbon market pose little prospect of contributing substantially to the conservation of biodiversity. This is because Parties chose, for the first commitment period, to render ineligible for CDM crediting projects slow deforestation in developing countries. Moreover, their decision to allow crediting for A&R projects in the CDM raises the prospect of net negative impacts to biodiversity by increasing the financial attractiveness of plantations relative to maintaining or restoring native forests. Such impacts may be exacerbated in the second and subsequent commitment periods by inter-annex leakage resulting from decreased timber harvests in industrialized countries.

As climate policymakers refine the first commitment period rules governing crediting for A&R projects in the CDM, they can substantially reduce the incentive for conversion of native forests to carbon plantations by restricting A&R plantation activities to locations not recently cleared. This can be accomplished through a carefully designed 'base year' rule that also allows for CDM project financing of native forest restoration in these same areas. But as long as threatened native forests in developing countries are excluded from an international market that values carbon sequestered in forests in Annex I countries and plantations everywhere, market biases will tend to accelerate their harvests and conversion.

Climate policymakers can take a significant step towards correcting this market bias by fully crediting forest conservation in the CDM in the second and subsequent commitment periods. Ultimately, carbon market incentives for forest clearing can be reduced and incentives for forest conservation most effectively strengthened by fully capturing carbon emissions associated with deforestation and forest degradation in developing countries under a future emissions cap.

A final comment relates to the role of the US. Following the US withdrawal from the Kyoto process, the impact on forests in developing countries will also depend on the course of domestic US climate-change mitigation policy. However it is constructed, US policy is likely to include a significant role for LULUCF measures to achieve net carbon emissions reduction (and, we hope, serious measures to reduce energy sector emissions). Hence, US policies could give rise to similar concerns. For example, should a US climate-mitigation strategy reduce domestic timber harvests, it would promote a dynamic similar to the inter-annex leakage issue discussed above. Conversely, sound US investments in forest conservation in developing countries can substantially reduce net emissions and protect high value biodiversity.

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Endnotes

1. This compromise decision reflected the diverse positions of influential parties and non-governmental organizations (NGOs) (Fearnside 2001). These included: strong objections to any LULUCF projects in the CDM by several European Union negotiators seeking to minimize the extent to which industrialized countries could avoid domestic energy sector emissions reductions in meeting their emissions–reductions targets; effective lobbying by Brazil for inclusion of A&R, reflecting an interest in attracting plantation investment, and exclusion of avoided deforestation, reflecting in part a desire to minimize attention on the large contribution of Brazilian deforestation to global emissions; greater interest among several Annex I parties (e.g. Japan, Canada, Australia) in gaining credits for domestic LULUCF measures than for CDM investments; and a lack of consensus on LULUCF in the CDM by influential NGOs. Many forest-rich developing countries and NGOs, as well as leading climate, forest and other environmental scientists strongly supported the inclusion of sound forest conservation projects in the CDM (Cochabamba Declaration 1999; Belém Manifesto 2000; UCS 2000), but they lacked a sufficiently strong voice at the negotiations.

2. The most recent comprehensive analysis of global plantation forestry estimates that forest plantations amounted to 187 million hectares worldwide in 2000. Of this global total, plantations located in tropical and other developing countries cover *ca.* 130–140 million hectares (FAO 2001; Pandey & Ball 1998), a substantial increase over estimated plantation coverage in tropical and other developing regions of roughly 80 million hectares in 1995, and 40 million hectares in 1980. The rate of increase is somewhat lower than these numbers suggest, as the 2000 data include rubberwood plantations that were not included in the earlier estimates (FAO 2001).

In order to meet growing world demand for timber and pressing needs for fuelwood, continued growth in the plantation sector is highly likely (FAO 2001; Hardcastle 1999). Growth in demand for wood proceeds at *ca.* 0.75–1% per year, although this growth rate is likely to fall in the long-term due to slowing population growth and changes in technology (Sohngen *et al.* 1998). Simulations by Sohngen *et al.* (1998) suggest that this growing demand will fuel average timber price increases of *ca.* 0.4% yr^{-1} in the near-term, and slower increases further in the future. Sohngen *et al.* (1998) further suggest that this price trend is sufficient to double the area of timber plantations over a period of *ca.* 150 years, without any premium or subsidy linked to carbon sequestration. Others estimate that contribution of plantations to global timber supply may increase even faster: projections in Carneiro & Brown (1999) imply a contribution from plantations anywhere from 29–55% of global supply by 2050, and ABARE–Jaakko Pöyry (1999) estimate that the plantation share may reach 44% as soon as 2020.

Preliminary estimates suggest that the geographic distribution of future plantation growth in the near-term is most likely to be concentrated in developing regions. Whereas Europe, Russia, and North America are anticipated to be largely self-sufficient in industrial timber, Africa and South America are expected to need *ca.* 2 million hectares, and Asia another 8 million hectares, both to meet industrial wood needs. Fuelwood requirements, however, are likely to dominate overall growth in tropical plantations, since it must be produced relatively close to the point of consumption. Hardcastle (1999) estimates that Africa will require 12–25 million hectares of fuelwood plantations and Asia another 22–44 million hectares. If recent trends in plantation establishment are indicative of near-term future expansion, then plantations in Asia are also likely to further expand. Asian plantations accounted for 40% of global industrial plantations in 1995 and nearly 60% of plantations established since 1985 (FAO 2001).

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