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Carbon benefits from Amazonian forest reserves: Leakage accounting and the value of time

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Abstract Amazonian forest reserves have significant carbon benefits, but the methodology used for accounting for these benefits will be critical in determining whether the powerful economic force represented by mitigation efforts to slow global warming will be applied to creating these reserves. Opportunities for reserve creation are quickly being lost as new areas are opened to deforestation though highway construction and other developments. Leakage, or the effects that a reserve or other mitigation project provokes outside of the project boundaries, is critical to a proper accounting of net carbon benefits. Protected areas in the Amazon have particularly great potential mitigation benefits over an extended time horizon. Over a 100-year time frame, virtually no unprotected forest is likely to remain, meaning that potential leakages (both leakage to the vicinity of the reserves and that displaced by removing protected areas from the land-grabbing market) should not matter much because any short-term leakage would be "recovered" eventually. The effect of the value attributed to time greatly influences the impact of leakage on benefits credited to reserves. Simple assumptions regarding leakage scenarios illustrate the benefits of reserves and the critical areas where agreement is necessary to make this option a practical component of mitigation efforts. The stakes are too high to allow further delays in reaching agreement on these issues.

Keywords Global warming, Greenhouse effect, Mitigation, Avoided deforestation, REDD, Kyoto Protocol, Reduced emissions, Deforestation, Brazil

1 Introduction

Increasing awareness of the urgency and magnitude of the measures needed to combat global warming should translate into an increased willingness to face contentious mitigation issues and agree on solutions. Of primary importance among such issues is the accounting for carbon benefits of Amazon forest reserves, especially the losses to “leakage,” or the effects on carbon emissions that occur outside of a mitigation project as a result of the project activity. For example, if creating a protected area expels population from the reserve to the surrounding forest, these people will continue to clear and their carbon emissions must be subtracted from the benefits attributed to the reserve. This is “in-to-out” leakage, and is the easiest to quantify and control. Individual families, normally of small farmers, can be identified and observed in their new locations. Their clearing can be unambiguously attributed to the project, regardless of questions of which side receives the burden of proof as to what effects are the result of the project activity and therefore count as “leakage.”

A second form of leakage is the movement of deforestation actors such as *grileiros*, or large operators who appropriate areas of public land by fraudulent means, after which they often subdivide and sell the claims to ranchers, loggers and others. When the government declares an area of forest as a reserve, the probability of *grileiros* successfully obtaining documentation for their claims decreases dramatically, with the result that *grileiros* entering the general area will direct their attention to areas of forest outside of the reserve. This form of “out-to-out” leakage is much more potentially damaging than is “in to out” leakage because the actors are different, with *grilagem* (the process of land appropriation by *grileiros*) being the start of much more rapid and large-scale clearing than that represented by the residents of a given area at the time it becomes a reserve. These residents are fixed in number, rather than coming from an essentially infinite pool as in the case of actors coming to the area from outside. The residents also tend to be small farmers with limited resources who clear much less than do *grileiros* or other outside actors (Fearnside 2008a). In addition to *grileiros*, other actor groups coming from outside play similar roles and are affected in similar ways by creation of reserves impeding later legalization of land claims. This is particularly important for organized groups of landless peasants, or *sem terras*; estimates of the number of landless families in Brazil range from 5 to 10 million (see Fearnside 2001). Because the entry of outside agents overshadows the effect of continued clearing by the local population, approaches sometimes suggested to countering these effects with programs for environmental education or for extension to promote agroforestry or other more productive and/or sustainable land uses are simply divorced from the reality of Amazonian deforestation processes.

The problem of out-to-out leakage is sometimes dismissed with the argument that these people would be entering the general area and clearing anyway, independent of the existence of a reserve, and so their actions can't be attributed to or blamed on the reserve. Nevertheless, the fact that the reserve has removed part of the land that otherwise would be subject to *grilagem* concentrates this activity in the remainder of the landscape. The net effect of this will be negative: although clearing in the remaining forest will be more rapid than it otherwise would be the removal of opportunities for *grilagem* in the reserve increases the cost of *grilagem* and reduces its profitability, therefore exerting a force in the opposite direction (Figure 1).

[Figure 1 here]

A third form of leakage is the diffuse effect that is transmitted through the economy by influencing commodity supplies and prices (see discussion in Fearnside 1995). For example, the residents of reserves created by the state government of Amazonas can agree to forego clearing for cash crops such as production of manioc flour for sale in Manaus in exchange for the benefits of the *bolsa floresta* (forest stipend) program under the *Iniciativa Amazonas* (Viana and Campos 2007). If the Manaus market is then supplied by manioc flour from increased production and clearing by other farmers scattered throughout the state, then the carbon benefit will have vanished though this form of economic leakage. The state's Secretariat of Sustainable Development and the Environment (SDS) believes that the market shortfall will be taken up by industrial producers of manioc in the southern Brazilian state of Paraná (outside of Amazonia). Paraná currently supplies most of the manioc flour consumed in Manaus. It should be noted, however, that the state government's Secretariat of Rural Production (SEPROR) has making the state of Amazonas self-sufficient in manioc flour production as one of its goals. Economic leakage from agriculture foregone by reserve residents will only be recovered at a later time if the agreements to forego clearing continue in force when forests outside of reserves are gone.

Critical to the credit attributed to reserve creation and to the net effect of leakage is the question of how time is valued in the carbon accounting. Leakage in all forms results in reduction in the net benefit of the reserve over the short and medium terms, but this benefit is later "recovered" at some time in the future when the entire landscape outside of reserves is deforested (notwithstanding the patches of forest it may contain when it reaches this future equilibrium state). The value of time, for example as expressed through a discount rate, can make a tremendous difference as to the relative weight given to the short-term versus the long-term events in this process. Arguments for attributing a modest value to time (on the order of 1%/year) are given elsewhere (Fearnside 2002a). Opinions on this topic vary widely, ranging from zero discount (*e.g*., Kirschbaum 2006) to values on the order of 10%/year that characterize financial calculations (van Kooten et al. 1997). Many of the impacts of global warming depend on the time over which elevated temperatures are maintained, as opposed to depending only on the maximum temperature reached (*e.g*., Fearnside 2008b). These cumulative impacts include ice melting and sea-level rise.

The large potential for climate benefits from reserve creation, together with the rapid rate at which the advancing frontier is foreclosing future opportunities to create reserves means that we must find practical ways to assign credit to reserves. Reserve creation is one of the most effective ways to prevent deforestation and consequent emissions (Fearnside 2008c, Vitel et al. 2009). Reserves have a permanence that other measures (such as enforcement campaigns) lack, and therefore have benefits that accrue when the longer term is considered in carbon accounting. At the same time, reserve creation is cheaper than many other forms of mitigation, and even "paper parks" have immediate benefits though their effect in discouraging *grilagem*. The examples that follow illustrate an approach to the largest component of leakage affecting Amazonian reserves: the out to out leakage through clearing by actors such as *grileiros*.

2 Reserve scenarios

A numerical illustration of the effect of reserve creation and leakage on carbon emissions can help to make the issues explicit, especially the importance that is attributed to time. These illustrations make simple assumptions about leakage and deforestation rates rather than the much more complicated modeling and parameterization that would be required to include the causal processes such as those shown in Figure 1. In the hypothetical examples that follow, the total area of the region is assumed to be 100×10^3 km^2 and carbon emission is 100 tC/ha deforested. In the baseline (no reserve) scenario deforestation is proceeding at a constant rate that will completely deforest the area in 50 years (*i.e*., 2×10^3 km^2/year). In two project or mitigation scenarios a reserve is created that is 10×10^3 km^2 in area and is completely successful in preventing deforestation within its boundaries. In one reserve scenario there is no leakage, while in the other there is 100% leakage. The deforestation scenarios are shown in Figure 2. In both the no reserve scenario and the reserve with no leakage scenario the area outside the reserve is completely deforested in year 50, whereas in the 100% leakage scenario this point is reached in year 45. During the period that deforestation is taking place, deforestation is identical in the no-reserve and 100% leakage scenarios, and takes place at a slower rate in the no leakage scenario. All scenarios are compared using a 100-year time horizon (Fearnside 2002b). The 100-year time horizon is the one adopted by the Kyoto Protocol for purposes of comparing the global-warming impacts of different greenhouse gases based on global warming potentials (GWPs) developed by the Intergovernmental Panel on Climate Change (IPCC). Using the 100-year time horizon avoids serious distortions that arise if significantly longer horizons are used in comparing mitigation options (see Fearnside 2002b).

[Figure 2 here]

3 Leakage impacts

The benefits of creating a reserve, and the losses of these benefits caused by leakage, will depend on how time is valued. This value is created by three features of any calculation: the time horizon used, the discount rate applied over the course of this time horizon (be it zero or otherwise), and accounting for the natural process of carbon-dioxide removal from the atmosphere between the date of each emission and the end of the time horizon. The removal of carbon from the atmosphere is assumed to follow the path indicated by the Bern model used in the Third Assessment Report (TAR) of the IPCC, as indicated in Figure 3 (see Fearnside et al. 2000).

[Figure 3 here]

If an emission occurs in the first year, the carbon dioxide in the atmosphere will be partially removed by movement to natural sinks over the course of the 100-year time horizon. The effect on global temperature will be determined by the load of carbon dioxide remaining in the atmosphere at each point in time. If no removal by sinks occurred the area under a curve like that in Figure 3 would be 100 ton-years, but the modeled removal corresponds to an area of 46.4 ton-years. This is taken as the equivalent of “permanent” avoidance of one ton of carbon emission (see discussion in Fearnside et al. 2000, as well as possible alternative adjustments to represent time beyond the 100-year cutoff: Fearnside 2002b). The global-warming impact of a ton of carbon emission in each year (or the benefit of avoiding such an emission) can be calculated as a percentage of the effect of holding a ton of carbon out of the atmosphere for the full 100-year time horizon (Figure 4).

[Figure 4 here]

The global-warming impact can be calculated using these percentages of the atmospheric load and the emissions calculated for each year for the scenarios with no reserve (Table 1), with a reserve with no leakage (Table 2), and with a reserve with 100% leakage (Table 3). Only the first 10 years of the 100-year calculation are shown. The effects of applying annual discount rates of 0%, 1%, 5% and 10% are also shown.

[Tables 1-3 here]

If the columns for each of the four discount rates are summed for the full 100 years, the total emission impact (10^3 t years C) can be calculated (Tables 4 and 5). Table 4 presents the calculation without the effect of atmospheric carbon decay in order to make the logic of the calculation more transparent. Here it can be seen that with no discounting, there is no difference between a reserve with no leakage and one with 100% leakage, since all of the area outside of the reserve (and none inside it) is deforested before the end of the 100 years in either case. However, when time is given value through a discount rate, the differences become apparent, with the no-leakage case providing more carbon benefit than the 100% leakage case. The higher the discount rate, the greater this benefit when expressed in percentage terms. In order to make meaningful comparisons it is necessary to standardize the calculated difference in leakage as a percentage of the no-reserve outcome. The benefit of avoiding leakage (in the last line of the second panel of the table) must also be standardized as a percentage of the no-leakage result. The same patterns are shown for the full calculation (Table 5) with the inclusion of both the atmospheric decay and discount rate effects.

[Tables 4-5 here]

Results for leakage impact (as % of the no-reserve impact) from Tables 4 and 5 are graphed in Figure 5. This makes apparent the increasing impact of leakage with higher discount rates, with the effect of discount rate decreasing as the discount rate rises.

[Figure 5 here]

4 Conclusion

Reserve creation in Amazonian forest areas has a real value in mitigating global warming and ways to account for benefits and their adjustment for leakage must be found as an urgent priority. Agreement on the treatment of time is critical to the value attributed to reserves. This author holds that accounting should be done using a 100-year time horizon, with inclusion of the effects of atmospheric carbon decay over this period plus a modest discount rate (on the order of 1%/year). Although continued advances in the modeling of deforestation processes will improve future estimates, simple assumptions can be used to generate reasonable scenarios to allow initiation of mitigation initiatives based on reserve creation on the short term.

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FIGURE LEGENDS

Figure 1 – Effects of reserve creation on the net effect of leakage. In causal-loop diagrams such as this, the sign by each arrow indicates the direction of change of the quantity at the tip of the arrow given an increase in the quantity at the tail of the arrow.

Figure 2 – Reserve-creation scenarios: In the no-reserve and no-leakage scenarios the entire area outside of reserves is cleared by year 50, while in the 100% leakage scenario this point is reached in year 45.

Figure 3 – Atmospheric carbon decay from the version of the Bern model used in the IPCC's Third Assessment Report (reproduced from Fearnside et al. 2000). The area under the curve for the full 100-year time horizon is 46.4 ton-years.

Figure 4 – Atmospheric carbon decay (Figure 3) expressed as the percent of the full mitigation effect of avoiding a ton of carbon emission in the first year and maintaining it out of the atmosphere for 100 years (*i.e.*, 46.4 ton-years) that is represented by the integral under the decay curve between each year and the end of the time horizon. This represents the percent of the "permanent" carbon equivalent if an avoided emission is achieved in the given year (or, conversely, the loss if an emission from leakage occurs in the given year). No discounting is included.

Figure 5 – The effect of discount rate on leakage impact. For comparison, curves are included with and without the effect of atmospheric carbon decay. As can be seen by comparing the "no atmospheric carbon" curve at 1% discount with the "with atmospheric carbon" curve at 0% discount, the effect of atmospheric carbon decay is approximately equal to a 1% discount. As the discount rate increases, the importance of this difference diminishes, becoming negligible at 10% annual discount. As the discount rate increases, the leakage impact (expressed as a percentage of the impact in the no-reserve scenario) increases substantially, with the rate of increase declining at higher discount rates.

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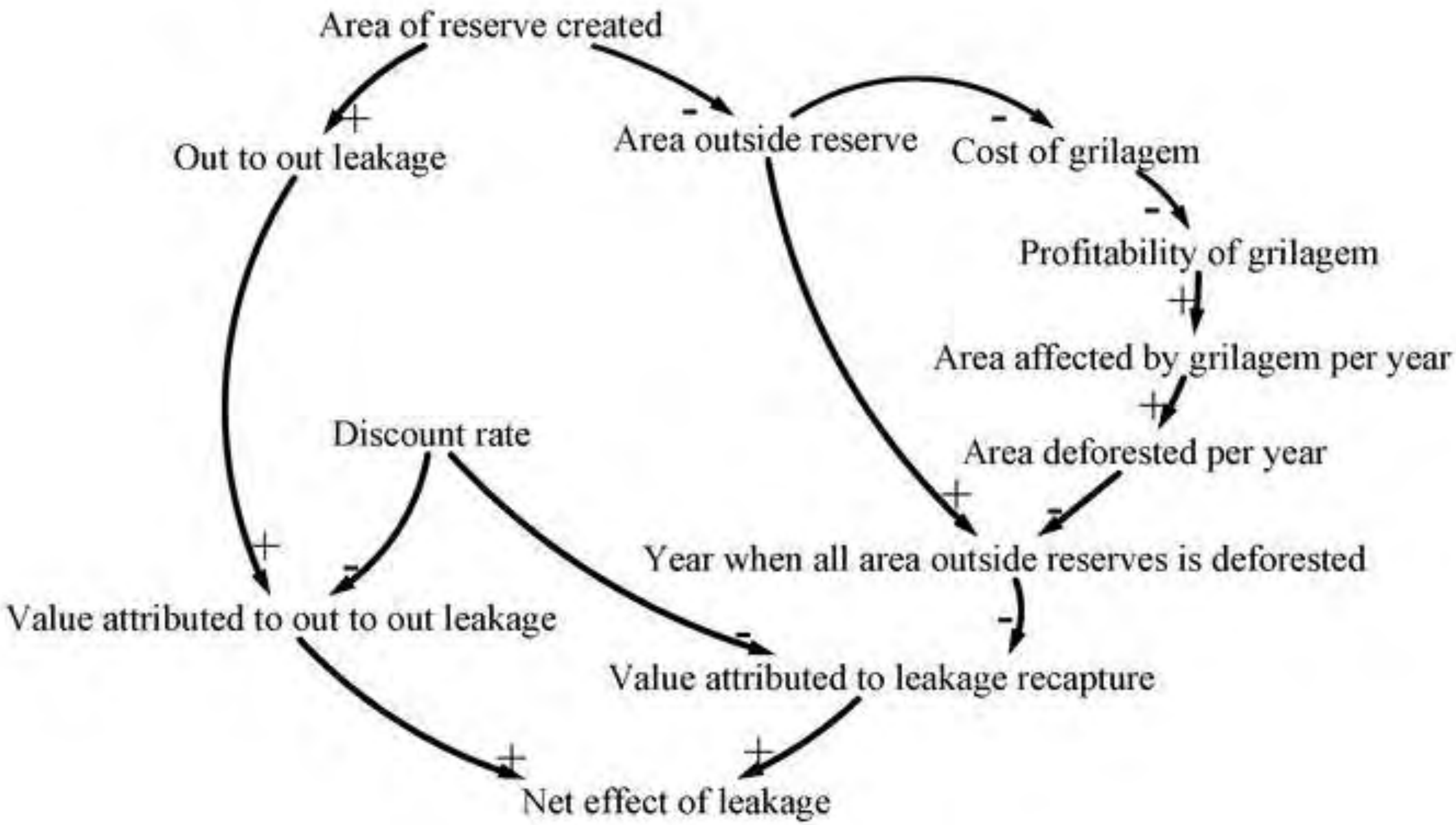

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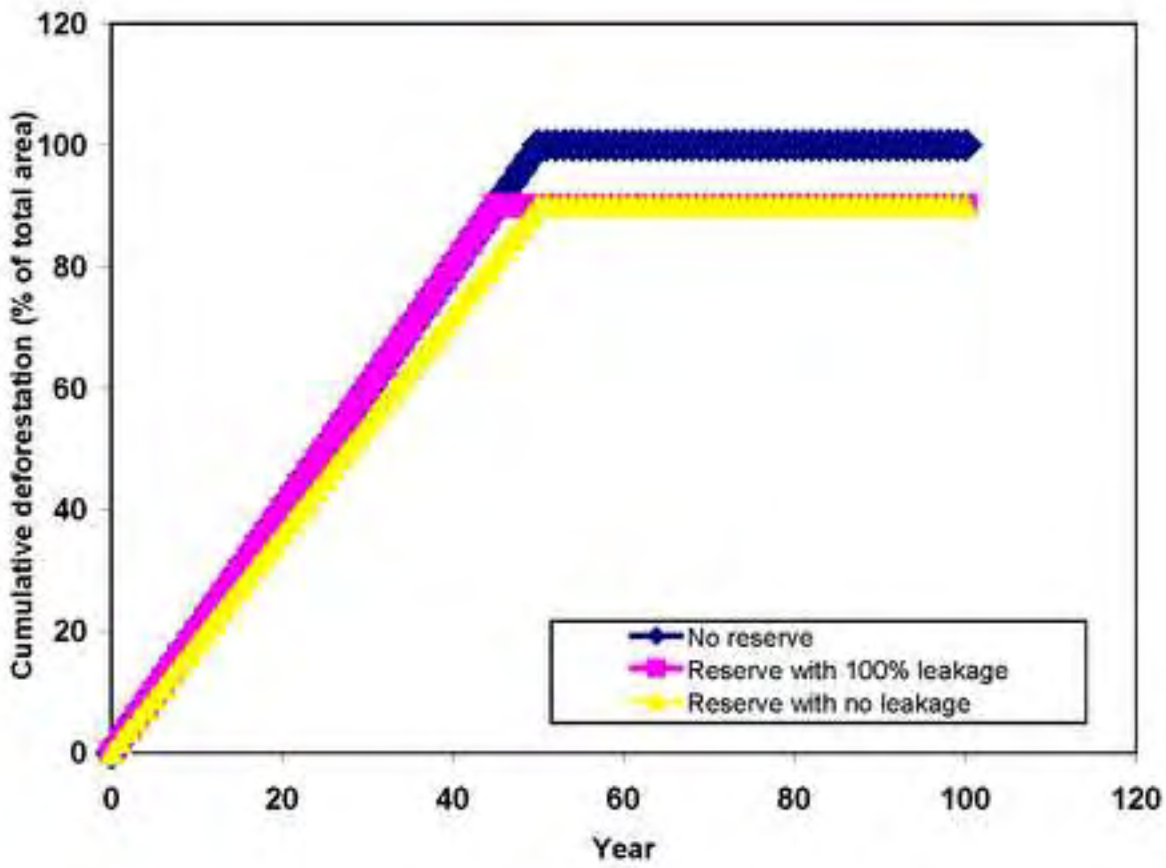

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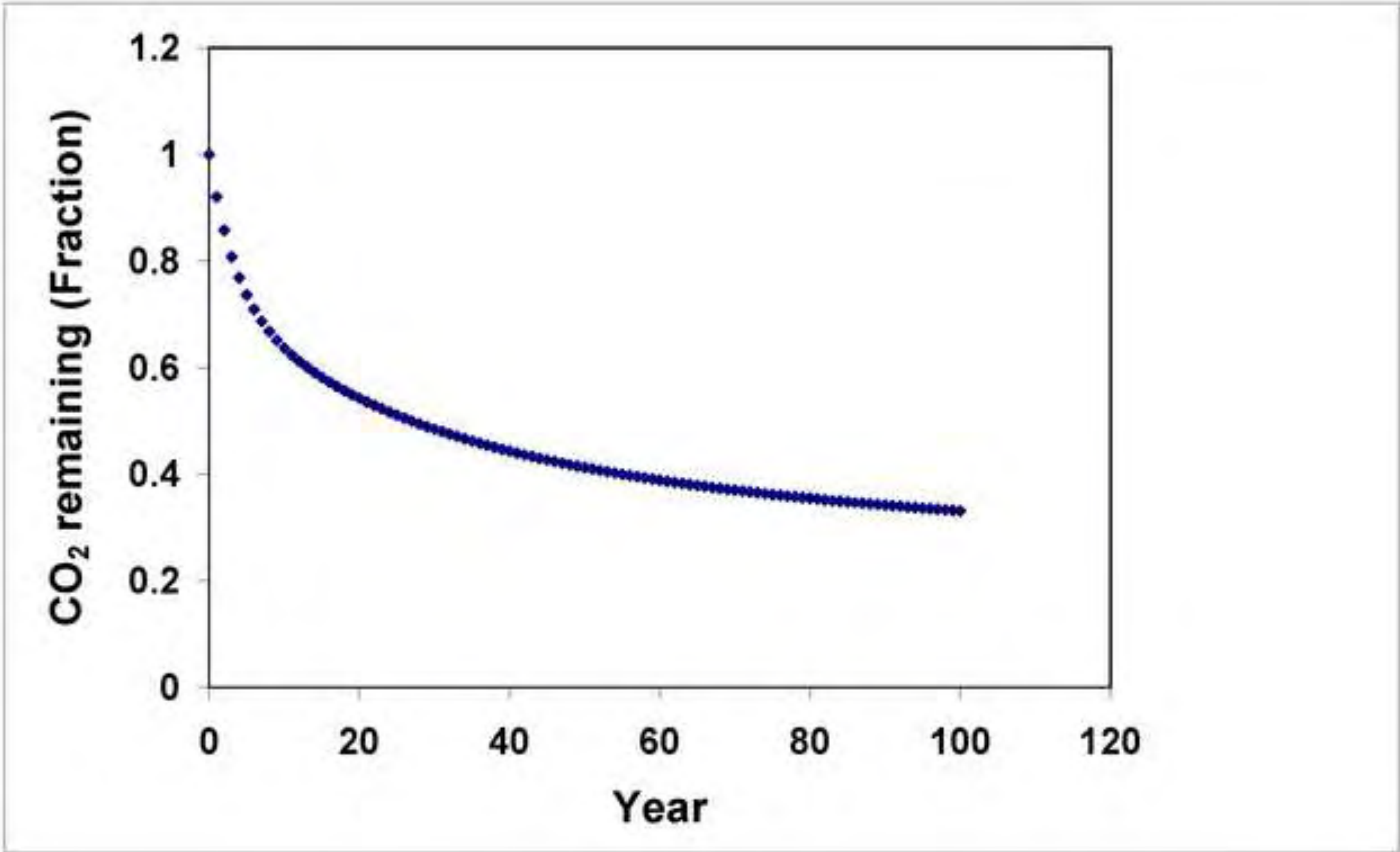

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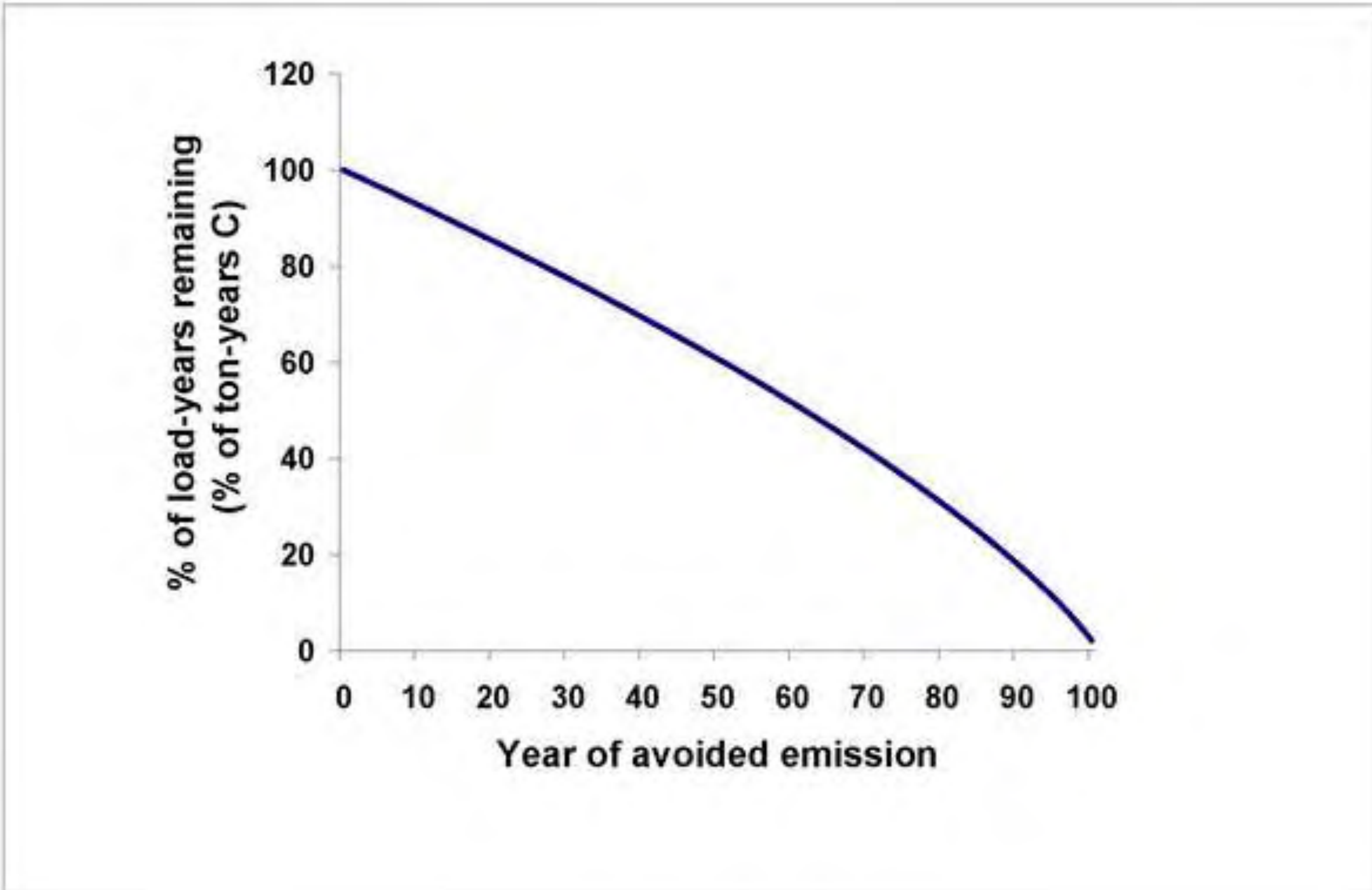

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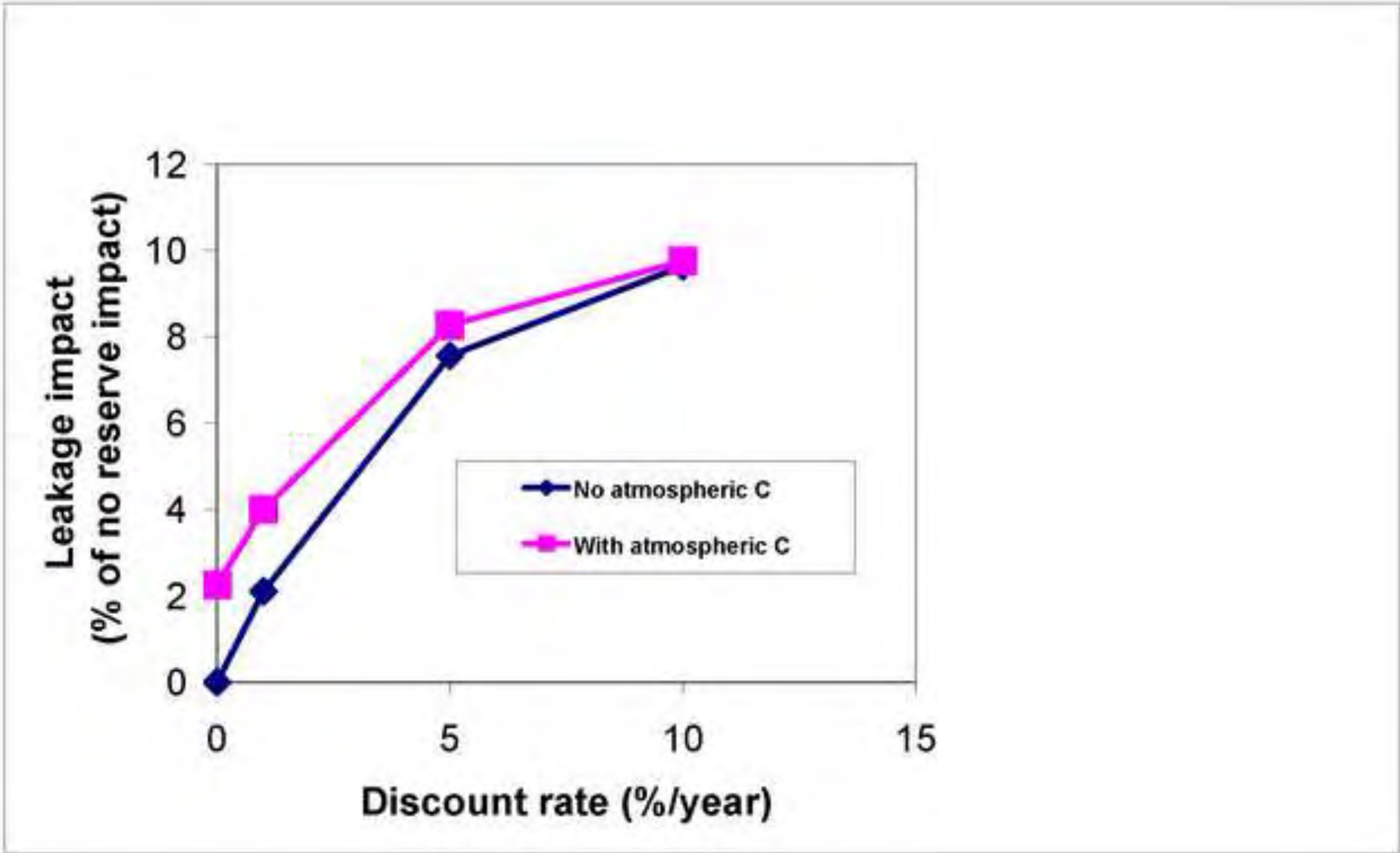

table-1

Click here to download table: Table 1-baseline first 10 years.doc

Table 1 - Baseline (no reserve) scenario for first 10 years, with inclusion of atmospheric carbon decay

Year	Percent atmospheric load (TAR Bern model)	Area deforested inside reserve	Area deforested outside reserve	Total deforested (cumulative)	Deforestation in year (km^2)	Emission in year (10^3 tC)	Emission adjusted for atmospheric load	Discounted emission (10^3 t-years)			
								0%	1%	5%	10%
0	100.00	0	0	0	0	0	0.00	0	0	0	0
1	99.29	0	2	2	2	20	19.86	19.86	19.66	18.86	17.87
2	98.57	0	4	4	2	20	19.71	19.71	19.32	17.79	15.97
3	97.85	0	6	6	2	20	19.57	19.57	18.99	16.78	14.27
4	97.13	0	8	8	2	20	19.43	19.43	18.66	15.82	12.75
5	96.41	0	10	10	2	20	19.28	19.28	18.34	14.92	11.39
6	95.68	0	12	12	2	20	19.14	19.14	18.02	14.07	10.17
7	94.96	0	14	14	2	20	18.99	18.99	17.70	13.26	9.08
8	94.23	0	16	16	2	20	18.85	18.85	17.39	12.50	8.11
9	93.50	0	18	18	2	20	18.70	18.70	17.08	11.79	7.24
10	92.76	0	20	20	2	20	18.55	18.55	16.78	11.11	6.47

table-2

Click here to download table: Table 2-Reserve no leakage first 10 years.doc

Table 2 -- Reserve with no leakage scenario for first 10 years, with inclusion of atmospheric carbon decay

Year	Percent atmospheric load (TAR Bern model)	Area deforested inside reserve	Area deforested outside reserve	Total deforested	Deforestation in year (km^2)	Emission in year (10^3 tC)	Emission adjusted for atmospheric load	Discounted emission (10^3 t-years)			
								0%	1%	5%	10%
0	100.00	0	0.0	0	0	0	0.00	0	0	0	0
1	99.29	0	1.8	1.8	1.8	18	17.87	17.87	17.69	16.98	16.08
2	98.57	0	3.6	3.6	1.8	18	17.74	17.74	17.39	16.01	14.37
3	97.85	0	5.4	5.4	1.8	18	17.61	17.61	17.09	15.10	12.84
4	97.13	0	7.2	7.2	1.8	18	17.48	17.48	16.79	14.24	11.47
5	96.41	0	9.0	9.0	1.8	18	17.35	17.35	16.50	13.43	10.25
6	95.68	0	10.8	10.8	1.8	18	17.22	17.22	16.22	12.66	9.15
7	94.96	0	12.6	12.6	1.8	18	17.09	17.09	15.93	11.94	8.18
8	94.23	0	14.4	14.4	1.8	18	16.96	16.96	15.65	11.25	7.30
9	93.50	0	16.2	16.2	1.8	18	16.83	16.83	15.37	10.61	6.52
10	92.76	0	18.0	18.0	1.8	18	16.70	16.70	15.10	10.00	5.82

table-3

Click here to download table: Table 3-Reserve with 100% leakage first 10 years.doc

Table 3 – Reserve with 100% leakage scenario for first 10 years, with inclusion of atmospheric carbon decay

Year	Percent atmospheric load (TAR Bern model)	Area deforested inside reserve	Area deforested outside reserve	Total deforested	Deforestation in year (km^2)	Emission in year (10^3 tC)	Emission adjusted for atmospheric load	Discounted emission (10^3 t-years)			
								0%	1%	5%	10%
0	100.00	0	0	0	0	0	0.00	0	0	0	0
1	99.29	0	2.0	2.0	2	20	19.86	19.86	19.66	18.86	17.87
2	98.57	0	4.0	4.0	2	20	19.71	19.71	19.32	17.79	15.97
3	97.85	0	6.0	6.0	2	20	19.57	19.57	18.99	16.78	14.27
4	97.13	0	8.0	8.0	2	20	19.43	19.43	18.66	15.82	12.75
5	96.41	0	10.0	10.0	2	20	19.28	19.28	18.34	14.92	11.39
6	95.68	0	12.0	12.0	2	20	19.14	19.14	18.02	14.07	10.17
7	94.96	0	14.0	14.0	2	20	18.99	18.99	17.70	13.26	9.08
8	94.23	0	16.0	16.0	2	20	18.85	18.85	17.39	12.50	8.11
9	93.50	0	18.0	18.0	2	20	18.70	18.70	17.08	11.79	7.24
10	92.76	0	20.0	20.0	2	20	18.55	18.55	16.78	11.11	6.47

Table 4: Emissions and reserve benefits without inclusion of atmospheric carbon decay

	Discount rate (%/year)			
	0%	1%	5%	10%
Scenario	Total emission impact (10^3 t-years C)			
No reserve	1,000	782	351	179
Reserve, no leakage	900	704	316	161
Reserve, 100% leakage	900	720	342	178
Leakage difference	0	-16	-27	-17
Leakage difference as % of no reserve	0.0	2.1	7.6	9.6
Scenario	Benefit of reserve (10^3 t-years C)			
No reserve	0.00	0.00	0.00	0.00
Reserve, no leakage	100.00	78.21	35.08	17.91
Reserve, 100% leakage	100.00	61.74	8.55	0.64
Leakage difference	0.00	16.47	26.53	17.26
Leakage difference as % of no leakage	0	21	76	96

Table 5: Emissions and reserve benefits with inclusion of atmospheric carbon decay

	Discount rate (%/year)			
	0%	1%	5%	10%
Scenario	Total emission impact (10^3 t-years C)			
No reserve	806.82	643.76	309.36	166.26
Reserve, no leakage	726.14	579.39	278.42	149.64
Reserve, 100% leakage	744.32	605.17	304.01	165.86
Leakage difference	-18.18	-25.78	-25.59	-16.22
Leakage difference as % of no reserve	2.3	4.0	8.3	9.8
Scenario	Benefit of reserve (10^3 t-years C)			
No reserve	0.00	0.00	0.00	0.00
Reserve, no leakage	80.68	64.38	30.94	16.63
Reserve, 100% leakage	62.50	38.59	5.35	0.40
Leakage difference	18.18	25.78	25.59	16.22
Leakage difference as % of no leakage	23	40	83	98