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ACCOUNTING FOR TIME IN MITIGATING GLOBAL WARMING THROUGH LAND-USE CHANGE AND FORESTRY

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Abstract. Many of the proposed activities for mitigating global warming in the land-use and forestry (LUCF) sector differ from measures to avoid fossil fuel emissions because carbon (C) may be held out of the atmosphere only temporarily. In addition, the timing of the effects is usually different. Many LUCF activities alter C fluxes to and from the atmosphere several decades into the future, whereas fossil-fuel emissions avoidance has immediate effects. Non-CO_2 greenhouse gases (GHGs), which are an important part of emissions from deforestation in low-latitude regions, also pose complications for comparisons between fossil fuel and LUCF, since the mechanism generally used to compare these gases (global warming potentials) assumes simultaneous emissions. A common numeraire is needed to express global warming mitigation benefits of different kinds of projects, such as fossil fuel emissions reduction, C sequestration in forest plantations, avoided deforestation by creating protected areas and through policy changes to slow rates of land-use changes such as clearing. Megagram (Mg)-year (also known as "ton-year") accounting provides a mechanism for expressing the benefits of activities such as these on a consistent basis. One can calculate the atmospheric load of each GHG that will be present in each year, expressed as C in the form of CO_2 and its instantaneous impact equivalent contributed by other gases. The atmospheric load of CO_2-equivalent C present over a time horizon is a possible indicator of the climatic impact of the emission that placed this load in the atmosphere. Conversely, this index also provides a measure of the benefit of <u>not</u> producing the emission. One accounting method compares sequestered CO_2 in trees with the CO_2 that would be in the atmosphere had the sequestration project not been undertaken, while another method (used in this paper) compares the atmospheric load of C (or equivalent in non-CO_2 GHGs) in both project and no-project scenarios.

Time preference, expressed by means of a discount rate on C, can be applied to Mg-year equivalence calculations to allow societal decisions regarding the value of time to be integrated into the system for calculating global warming impacts and benefits. Giving a high value to time, either by raising the discount rate or by shortening the time horizon, increases the value attributed to temporary sequestration (such as many forest plantation projects). A high value for time also favors mitigation measures that have rapid effects (such as slowing deforestation rates) as compared to measures that only affect emissions years in the future (such as creating protected areas in countries with large areas of remaining forest). Decisions on temporal issues will guide mitigation efforts towards options that may or may not be desirable on the basis of social and environmental effects in spheres other than global warming. How sustainable development criteria are incorporated into the approval and crediting systems for activities under the Kyoto Protocol will determine the overall environmental and social impacts of pending decisions on temporal issues.

Key words: carbon dioxide, discount rate, global warming, greenhouse effect, land-use change, mitigation, time preference, deforestation.

1. Introduction

Temporal issues are among the most fundamental questions governing the amount of credit that will be given to different kinds of global warming mitigation measures. These issues include establishing both a time horizon and a discount rate (zero or otherwise) for carbon (C). Temporal issues will be key factors in determining whether efforts to mitigate global warming will include CO_2 sinks in the land-use change and forestry (LUCF) sector, and within the LUCF sector whether priority is given to plantation forestry or to avoiding deforestation.

Questions that are still undecided include whether megagram (Mg)-year (also known as "ton-year") accounting will be applied to calculating the benefit of mitigation activities under the Kyoto Protocol, what time horizon will be used, and whether a non-zero discount rate will be applied. For the first commitment period (2008-2012), these decisions will probably be made at the Sixth Conference of the Parties (COP-6) in November 2000, after taking into consideration the Intergovernmental Panel on Climate Change (IPCC) Special Report on Land-Use Change and Forestry (SR-LUCF), to be completed in May 2000 (Watson and Verardo, 2000). The question of whether any LUCF activities, especially forest conservation, will be included under the Clean Development Mechanism (CDM) established in Article 12 of the Kyoto Protocol (UN-FCCC, 1997a) will also be decided at that time. The Clean Development Mechanism provides a mechanism by which Annex B countries (countries that have commitments to limiting their national emission totals under the Kyoto Protocol) can finance activities in non-Annex B countries to offset the financing country's fossil fuel C emissions. Clean Development Mechanism projects must demonstrate that C benefits are additional to what would have occurred in the absence of the project.

Carbon dioxide (CO_2) sinks in general have been criticized as temporary and therefore inherently less beneficial than avoiding fossil fuel emissions (e.g., Matoon, 1998). Confusion has often resulted from lumping all LUCF activities in a single category as biotic sinks. Lashof and Hare (1999), for example, have argued that credits from biotic sinks under the Protocol carry a risk of having perverse effects on atmospheric CO_2 concentrations. However, Fearnside (1999a) has argued that this reasoning applies only to forest plantations, and that within the category of plantations it applies only to their role in CO_2 sequestration (as distinct from fossil fuel substitution). Lashof and Hare's argument is that, by allowing countries to emit more C from fossil stocks into the active C pool (biosphere + atmosphere), the increases in biotic C stocks that have been encouraged under the Kyoto Protocol as carbon offsets (1) have a risk of subsequent release into the atmosphere, and (2) reduce the options available for future responses in the forest sector because the capacity of these options to absorb C will have been saturated. However, Fearnside (1999a) has argued that, in the case of avoiding deforestation in low-latitude regions, the result is more like reducing fossil fuel C emissions than it is like carbon sequestration in plantations. C stocks in areas of high-biomass low-latitude rain forests are very unlikely to be allowed to regenerate to their present levels if these forests are cut down. Most of the C released from deforesting these areas is, therefore, an addition to what might be called the most active C pool (i.e., atmospheric C + C in rapidly cycling stocks such as plantation biomass) that is as permanent as is release of fossil C. Clean Development Mechanism or other activities that help low-latitude (tropical) forest countries avoid deforestation keep C out of the "most active pool" in the same way that avoiding fossil C emissions would. The C releases avoided are, for practical purposes, as irreversible as fossil fuel combustion (Fearnside, 1999a.

Mg-year accounting (Chomitz, 1998; Fearnside, 1995a, 1997a; Tipper and de Jong, 1998; Moura-Costa and Wilson, 2000) is useful for comparing avoided fossil fuel emissions with plantations and other mitigation options in the forest sector. Under a Mg-year system, credit would be given for the number of tons of C held out of the atmosphere each year. Discounting, zero or otherwise, would apply to the C value calculated for each year over the time horizon when the expectations for different proposed mitigation projects are compared ("not discounting" is really only a special case of discounting, where the discount rate is equal to zero). Discounting can be applied in conjunction with Mg-year accounting, although use of a non-zero discount rate is not required. It is also possible to apply discounting to net stock changes (i.e., to fluxes), rather than to the atmospheric load of C as in Mg-year accounting (e.g., Hourcade *et al.*, 1996; Schlamadinger and Marland, 1999).

Mg-year accounting recognizes that keeping a unit of C out of the atmosphere during any given year has the same value, whether the C atoms are cycled through successive short-lived products or whether they are held in a mahogany wood desk that lasts a century. Under a Mg-year accounting system, delaying deforestation merits credit irrespective of the long-term fate of the forest, although the cumulative credit that can be earned from a given forest stand is greater the longer the forest remains intact. Comparisons can be made between forest reserve creation and policies to slow deforestation by using C Mg-year accounting. Policies affecting the motives for deforestation will have rapid effect on GHG emissions, whereas the effect of reserve creation can only reduce emissions years in the future when available forests outside of the reserve have been exhausted.

The discounting applied here does not take into account threshold effects that may exist in the damage function relating climatic impacts to atmospheric changes. Our knowledge of such thresholds is currently insufficient to incorporate them in calculations of this kind, although this could be done when our understanding of the climate system improves. As of now, decisions must be based on the best available information, such as that in the IPCC's Second Assessment Report (SAR).

2. Duration of Sequestration

Carbon sequestration in forest and other types of land cover is inherently reversible, unlike avoided emissions of fossil fuel C (which is generally considered a permanent gain). Carbon dioxide sequestration must be distinguished from fossil fuel substitution, which can also be achieved by some LUCF options, such as charcoal substitution for mineral coal. Fossil fuel substitution through forestry is just as permanent as avoided emissions through measures such as enhancing energy efficiency (Hall *et al.*, 1993; Marland and Schlamadinger, 1997).

It has been argued that postponing deforestation is a valid mitigation measure even if the forests in question are later cut for harvesting or other purposes, including cutting up to the theoretical maximum of clearing all forests in a country (Fearnside, 1999b). The credit for such a delay depends on two key parameters: time horizon and discount rate (or other alternative time-preference scheme). From a CO_2 perspective, under some conditions postponing a given number of hectares of clearing for one year is equivalent to avoided emissions by reduced combustion of fossil fuels. In the fossil fuel case, avoided emissions are counted as a **permanent** gain, even though the same barrels of oil not burned in a given year will be burned just one year later. The fossil fuel displacement is assumed to cascade forward, either (1) indefinitely (i.e., assuming that fossil fuel stocks are infinite for practical purposes), (2) until after the end of the time horizon, or (3) until fossil fuel burning ceases at some fixed point in time due either to development of technological alternatives or to social changes. In the case of fossil fuels, the total stock of approximately 5000 Pg (petagrams = gigatons) C (Bolin *et al.*, 1979) is far beyond the capacity of human society to burn and to mitigate to acceptable levels of environmental impact, and can be considered infinite for practical purposes. While some categories of fossil fuels, such as natural gas, may be exhausted within a 100-year time horizon, one can assume that switching will then occur to other forms of fossil fuel energy.

In the case of deforestation, the assumption of an effectively infinite cascading effect can break down if the area of remaining forest is small enough that it could be exhausted within the time horizon under consideration. If a country runs out of forest (or of accessible or unprotected forest) within the time horizon, then no carbon advantage would accrue from postponing deforestation if the discount rate is zero (except for credit for delay generated by the time horizon, to be explained later).

It is important to understand that the logic behind considering either fossil fuel or forest as permanent is **not** based on the assumption that specific atoms of C will remain in the ground or in the forest forever. Instead, the effect of delaying for one year a given amount of fossil fuel burning or a given amount of deforestation will be delaying for one year the time that C is released from each barrel of oil or hectare of forest that would be burned or deforested in subsequent years. The emission displacement cascades forward either forever or until the end of the time horizon, resulting in a permanent savings. In Figure 1, Mg number 1 (Mg_1) is burned in year 1 in the baseline scenario, but in year 2 in the mitigation scenario. By the end of the time horizon (year n), n Mg have been burned in the baseline scenario, but only n-1 Mg in the mitigation scenario. In the case of forest, this example does not include the effect of degradation (or aggradation).

[Figure 1 here]

The cascading effect of displaced emissions depends heavily on the assumption that the C reserve (either forest or fossil) will last beyond the end of the time horizon. If this is not the case, as in Figure 2 where only two Mg of C exist and the forest that contains them is destroyed within the time horizon in both the baseline and mitigation scenarios, no credit is gained by delaying deforestation in an accounting that considers only the total emission (i.e., where no removal of C from the atmosphere is considered). As will be shown later, even in a case such as this where forest runs out within the time horizon, delaying deforestation should receive some credit if a more complete accounting is made of the stocks in the atmosphere using a Mg-year approach. In this simplified example, the effect of degradation (or aggradation) is also not considered.

[Figure 2 here]

3. Time Horizons and Emissions Impacts

Establishing a finite time horizon, as in Figures 1 and 2, implies a value for time independent of any additional value for time preference that may be added through a mechanism such as a discount rate. The global warming potentials (GWPs) from the SAR (Schimel *et al.*, 1996) have been adopted by the Kyoto

Protocol (Article 5.3) for establishing the equivalence among different GHGs, and a 100-year time horizon has been specified for this purpose (UN-FCCC, 1997b). We assume that this time horizon will apply to other aspects of GHG accounting. Whether intended or not, choice of a time horizon has created a value for time under the Protocol. The 100-year zero-discount formulation used for GWPs adopted from the SAR is equivalent to an annual discount rate of approximately 0.9% with a very long (1000-year) time horizon (Fig. 3). A variety of arguments point to 100 years as a reasonable choice for policy-making with a minimum of perverse distortions (Fearnside, 2000a).

[Figure 3 here]

In the context of the present calculation, the impact of a GHG on global warming is represented by the amount of heat that it has blocked from escaping into space over the 100-year time horizon. In other words, it is proportional to the instantaneous radiative forcing of one Mg of the GHG multiplied by the number of Mg present in each year, summed over the years in the time horizon.

The parameters used in the SAR can be used to calculate the fraction of the atmospheric load from an emission that remains in any given year. C emitted to the atmosphere as CO_2 declines in a non-linear fashion in accord with the Revised Bern Model, which will be described shortly. Methane (CH_4) and nitrous oxide (N_2O) decline exponentially with half lives of 12.2 years and 120 years, respectively (Schimel *et al.*, 1996). While these gases remain in the atmosphere, their instantaneous radiative forcings (not to be confused with GWPs, which are integrated over a time horizon) per Mg of gas are 58 for CH_4 and 206 for N_2O, relative to a value of 1 for CO_2 (Shine *et al.*, 1995). For each year of the calculation, the atmospheric load of the non-CO_2 GHGs can be converted to CO_2 gas equivalents in terms of instantaneous radiative forcing, and then converted to C by multiplying by the ratio of the atomic weight of C to the molecular weight of CO_2 (12/44). An example is given in Table 1 for emissions from 1 ha of deforestation, using average per-hectare emissions from deforestation in Brazilian Amazonia in 1990 and treating all emissions as net committed emissions (i.e., treating all delayed emissions and CO_2 uptakes as occurring in the year of deforestation). The ability of Mg-year accounting to deal fairly with non-CO_2 GHGs is important, especially for quantifying the benefits of avoiding deforestation, which is a major source of these gases through biomass burning.

[Table 1 here]

Discounting can be used to express the impact of emissions of different gases occurring at different times in terms of immediate C emission equivalents. This can be thought of as a net present value, but we prefer the term immediate C emission equivalent to make clear that the adjustment includes both the effect of time and translating the effects of non-CO_2 GHGs into C (i.e., CO_2 C) equivalents.

The difference between the integrals of the C load in the atmosphere (and its radiative equivalent from the atmospheric loads of other gases) is not the only possible index of the benefit of delaying emissions. For example, one might choose the reduction in the atmospheric load of C at some fixed point in time, such as at the time the 2 × CO_2 milestone is passed in approximately 2070 (A in Fig. 4), rather than the difference in the integrals adopted here. The area under the curve in the delayed-emission case is smaller than that in the immediate-emission case by an amount that has been pushed beyond the end of the time horizon (B in Fig. 4). The difference between the integrals results in greater credit for delaying emissions than does the fixed-year approach. For example, a one-year delay results in a decrease of 0.71% in the integral but only a 0.46% decrease in the height of the curve (the instantaneous atmospheric load) in 2070.

[Figure 4 here]

When an emission of CO_2 enters the atmosphere, the atmospheric load of the GHG will begin to decay following a path that has the same integral over the first 100 years as an exponential decay with a time constant of 55 years. However, the precise path followed is more complex than this, so that over 500 years the integral is the same as an exponential decay with a time constant of 150 years. The actual decay will depend on the future composition of the atmosphere and feedbacks from climate change.

In the present paper the path assumed for C decline is that calculated by the version of the Bern Model used in the SAR (Schimel *et al.*, 1996). Lack of published output from the revised model has resulted in virtually all previous discussions of Mg-year accounting being based on the earlier model used in the 1990 and 1992 IPCC reports. The revised version incorporates greater uptake by the biosphere, described by the IPCC as a change that is "believed to be an important improvement" (Albritton *et al.*, 1995). The resulting more rapid decline in atmospheric C in the early years indicated by the revised model significantly increases the value of temporary sequestration of CO_2.

Output from the version of the Bern Model used in the SAR was illustrated graphically in the IPCC's 1994 special report

(Albritton *et al.*, 1995), but the only quantitative parameters published were for an approximation of the earlier version used in the IPCC's 1990 and 1992 reports (Albritton *et al.*, 1995):

$$F[CO_2(t)] = 0.3003 \exp(-t/6.993) + 0.034278 \exp(-t/71.109) + 0.35686 \exp(-t/815.727)$$

where "F" is the fraction of CO_2 remaining in the atmosphere and "t" is the time after emission in years.

The approximation of the output of the revised model is given by:

$$F[CO_2(t)] = 0.175602 + 0.137467 \exp(-t/421.093) + 0.185762 \exp(-t/70.5965) + 0.242302 \exp(-t/21.42165) + 0.258868 \exp(-t/3.41537).$$

When a Mg of C in the atmosphere decays as shown in Figure 4, the area under the curve over a 100-year time horizon is equal to 46% of the area of the rectangle that would represent the Mg of C remaining unchanged in the atmosphere over the same period. Keeping a Mg of C out of the atmosphere for a full 100 years therefore represents 46 Mg-year equivalents, rather than the 100 Mg-years that would be earned if the CO_2 entering the atmosphere had no movement to the ocean or other sinks. This is 16% lower than the corresponding number obtained using the older version of the Bern Model (55 Mg-years).

The number of Mg-year equivalents represents the global warming impact caused by the emission in question. If, rather than the Bern Model, the ratio of global CO_2 sinks to sources in the 1980s is used for estimating Mg-year equivalents, the value of 1 MgC of immediate emission is 42 Mg-year equivalents (Tipper and de Jong, 1998). Because both terrestrial and ocean CO_2 sinks could become saturated over the next century (Cao and Woodward, 1998; Sarmiento *et al.*, 1998), use of a higher value would be wise in order to avoid risk of under-compensating current GHG emissions (Tipper and de Jong, 1998).

If release of the Mg of C were delayed for ten years, then the curve (Fig. 4) would be shifted to the right, and part of it would pass beyond the time horizon (only 90 years would be considered). The difference between the integrals of the two curves would represent the gain earned from having delayed the emission. As the year of emission is delayed successively further into the future, the impact of a one-Mg emission declines from 46 Mg-years in the first year to zero in year 100. Emitting one Mg in year 50 has 60% of the impact of emitting one Mg in the first year. Conversely, a mitigation project that results in a temporary delay of a C emission will gain progressively more credit the longer the emission is postponed. It will gain 100% of the credit of a permanent displacement if the delay lasts for 100 years, and 40% of the credit if the delay lasts for 50 years.

The above calculations consider the difference between the mitigation and baseline scenarios by comparing the integrals of the atmospheric load of C over the time horizon. Somewhat different results are obtained in computing the benefits of LUCF mitigation projects such as forest (silvicultural) plantations if attention is focused on the C in the trees (e.g., Moura-Costa and Wilson, 2000). The distinction between C in trees and C in the atmosphere is important because atmospheric C is subject to removal through natural processes that transfer it to CO_2 sinks such as oceans and the biosphere, whereas C present in the trees is assumed to remain fixed. In the Moura-Costa method (Fig. 5 A), an equivalence time is calculated as the point at which the area of the rectangle representing biomass C is equal to the area under the atmospheric C decay curve over the 100-year time horizon. A different approach (the Lashof method: Fig. 5 B) reasons that, if C release is delayed because it is held in trees (as in Figure 1), the benefit will be represented by the difference in the integrals of the two curves within the time horizon, which is equal to the area of the tail of the second curve that is pushed beyond the end of the time horizon as a result of the delay. The second method is used in the present paper.

[Figure 5 here]

In the case of evaluating the C benefits of avoided deforestation, the size of the remaining forest relative to prevailing rates of deforestation is critical (Fig. 6). The difference in the cascading effect between countries with forest at risk of being cleared completely within the time horizon and those that have sufficient forest to exclude this possibility can be illustrated by a hypothetical example. Consider a hypothetical country with only 3 ha of remaining forest and deforestation proceeding at a rate of 1 ha/year (Fig. 6). This is similar to the example in Figure 2, but includes the effect of forest degradation. Areas of forest that have been saved from deforestation in a mitigation scenario may still lose C through degradation or destruction by such forces as extreme weather events under current climate regimes or under regimes altered by climate change, outbreaks of insects or diseases, and invasion by loggers or deforesters. Concern with permanence is one of the main concerns about the use of biotic sinks as climate change mitigation projects (e.g., Lashof and Hare, 1999; Mattoon, 1998, but see Fearnside, 1999c).

[Figure 6 here]

In the hypothetical example (Fig. 6) the forest is assumed to be rapidly degrading: 20 MgC/ha is lost to degradation between the first and the second year, 30 MgC/ha is lost between the second and the third year, and 10 MgC/ha is lost between the third and the fourth year. The emission from 1 ha of deforestation would be 100 MgC if it were cut in year 1, 100 – 20 = 80 MgC if it were cut in year 2, 80 - 30 = 50 MgC in year 3 and 50 - 10 = 40 MgC in year 4. In the baseline scenario, the emission from degradation in the second year of 20 MgC/ha will apply over the two remaining hectares of forest (the third hectare is already cut), making the degradation emissions 20 × 2 = 40 MgC and the total in that year 80 + 40 = 120 MgC. In the third year the degradation of 30 MgC/ha will apply only to the one remaining hectare of forest, making the total emission in the third year 50 + 30 = 80 MgC. In the fourth year both deforestation and degradation C emissions are zero because all forest has already been cleared. The total emission over the four years is 300 MgC.

In the mitigation scenario, deforestation is postponed by one year. In this case the degradation in the second year will apply to 3 ha rather than 2 ha, and will decrease in the two subsequent years as successively less standing forest is present to degrade. At the end of four years the total (cumulative) emission will also be 300 MgC. Here no net gain in C has been achieved **except** for that which comes from credit for having delayed the emission, the credit being based on the effect of atmospheric C stocks decaying over time (i.e., Fig. 4), plus any additional credit that may be awarded using a discount rate with a value greater than zero to represent time preference.

The effect of correction for decay in atmospheric C stocks is shown by the last row of numbers in both the baseline and the mitigation scenario sections in Figure 6. Here, the total emission in each year is multiplied by the corresponding proportion of the (full) impact of an immediate emission of a Mg of C, to obtain the immediate emission equivalent in Mg of C. The total in the baseline scenario is 279.1 MgC, while that in the mitigation scenario is 263.6 MgC, resulting in a gain of 15.4 MgC. Although such a gain is not insignificant, it is substantially lower than what can be gained if the forest lasts beyond the end of the time horizon. It should be noted that the values would be approximately double those in this example if a more realistic net emission per hectare of deforestation of 200 MgC/ha were used; within the bounds of uncertainty this represents the per-hectare net committed emission (i.e., adjusting for CO_2 uptake in secondary forests after deforestation) of clearing in 1990 in Brazilian Amazonia, which averaged 194 MgC/ha (Fearnside, 1997b).

If the forest lasts beyond the end of the time horizon, then the credit that can be gained from delaying deforestation increases substantially (Fig. 7). In this hypothetical example, the time horizon is set at the end of year four. As in the previous example (Fig. 6), deforestation proceeds at 1 ha/year and the forest degrades at the same rapid rate. An important difference is that, because not all of the forest will be cleared before the end of the time horizon in the mitigation scenario, one must follow the fate of an additional hectare of forest that would have been cleared in the baseline scenario. This displaced area degrades from 100 MgC/ha in year 1 to 40 MgC/ha at the end of the time horizon in year 4. These 40 MgC/ha represent a net gain in the total emission, being equal to the 400 MgC total emission in the baseline scenario minus the 360 MgC total emission in the mitigation scenario. With a Mg-year equivalence accounting of the immediate emission equivalent, the net gain is 363.6 – 315.8 = 47.8 MgC, which is much greater than the 15.4 MgC gain in the case where the forest runs out before the end of the time horizon.

[Figure 7 here]

Possible effects of forest degradation (or aggradation) in forest areas saved from deforestation could be corrected by appropriate adjustments in the crediting system (e.g., as in Figs. 6 and 7). Whether actions changing forest degradation and/or aggradation will be included among the additional activities under Article 3.4 of the Kyoto Protocol is still undecided (Schlamadinger and Marland, 1998). This will be critical for determining the baseline for emissions trading under Article 17 for any tropical countries that join Annex B of the Protocol. For non-Annex B countries, credit under the Clean Development Mechanism (Article 12) will be based on additional C effects in a project scenario as compared to a baseline or no-project scenario. Assuming that deforestation avoidance is included under the Clean Development Mechanism, it remains undecided whether effects such as degradation would be included in the accounting. Nothing prevents degradation (or aggradation) effects from being estimated and the corresponding adjustments made to C credit earned. Forest aggradation, the opposite of degradation, could also be adjusted for in the areas that are saved from deforestation. The principle is relevant that changes that result in damage to the atmosphere (i.e., forest degradation) should have obligatory adjustments, while changes that result in atmospheric benefits (i.e., forest aggradation) should be optional (Sathaye, *et al*., 1997).

It is important to note that the examples given in Figures 6 and 7 do not include a discount rate on C benefits to reflect society’s time preference (to be discussed in the next section). Over a 100-year time horizon, applying a discount rate, even if no greater than 1-2%/year, would add substantially to the attractiveness of delaying deforestation as compared to other mitigation options, because delaying deforestation results in substantial reduction in annual emissions in the short term. All C accounting implies a discount rate, whether it is zero or otherwise. A decision to use a zero discount rate is just as much a decision as choosing any other rate. There is no escape from facing the choice of specifying a value for time. Sound reasons exist for adopting a discount rate for C greater than the zero value currently used in most discussions of C accounting.

4. Time Preferences and Discounting

4.1. RATIONALE FOR DISCOUNTING

Applying to C either discounting or some alternative form of time preference can be justified for reasons other than the selfish interests of the current generation weighting (Fearnside, 2000c, Richards, 1997). Global warming impacts need to be separated into two categories that are calculated and reported separately: impacts that can be expressed in terms of money, and those that cannot, especially human life impacts (Fearnside, 1998). Discounting is the mechanism by which a value for time is normally translated into economic decision-making.

Value for time, or the social rate of time preference, is a combined result of the pure rate of time preference (time preference based solely on an event’s position in time, independent of how wealthy we expect to be at that time) and the utility (the utility per unit of wealth multiplied by the expected wealth per capita). Two approaches exist for deriving these values: a prescriptionist approach based on ethical principles, usually assigning a low or zero value to the pure rate of time preference (e.g., Cline, 1992), and a descriptionist approach based on observed economic behavior (e.g., Nordhaus, 1991). Annual discount rates (social rates of time preference) over the long term are usually in the 0.5-3% range for prescriptionists and in the 3-6% range for descriptionists (Arrow *et al.*, 1996). The result is that prescriptionists recommend greater spending on mitigation and adaptation than do descriptionists because long-term impacts of climate change have a greater net present value at low discount rates (Arrow *et al.*, 1996). It is important to note, however, that the effect of discount rate on the overall level of spending justified by climatic change is not the same as the effect on how the money would be allocated among different mitigation response options: higher discount rates will increase the relative attractiveness of options with rapid effects on atmospheric GHG levels, such as slowing deforestation.

Derivation of the social rate of time preference requires values for three factors, all of which are subjects of controversy: the pure rate of time preference, which is often described as the result of "impatience" or "myopia" is greater than zero if based on the observed behavior of individuals (whose behavior is influenced by awareness of their own mortality), but which can be argued to be zero from the perspective of whole societies. Sensitivity tests of discounting in the Dynamic Integrated Model of Climate and the Economy (DICE) by Nordhaus (1997) indicate that optimal allocation to combating global warming is most sensitive to the pure rate of time preference. The other parameters are the expected level of wealth in the future and the marginal utility per unit of additional wealth, which is expected to range from 1.5 to 0.8 (Scott, 1989; Pearce and Ulph, 1995; see Arrow *et al.*, 1996).

Many people will die as impacts begin to appear from global warming. Using Fankhauser's (1995) estimates for a jump to double the pre-industrial CO_2 concentration with the world (including its population size) as it was in 1990, the result would be loss of US$ 221 billion (in 1990 prices) annually, exclusive of human life losses, that would total 138,000 lives per year (115,000 of which would be in non-OECD countries) (see Pearce *et al.*, 1996). The above reasoning assumes that global warming initiates a step-function change in death rates, rather than an increase that lasts for a finite period of time. All such estimates are subject to great uncertainty, especially on the high side due to its unbounded nature.

It is important to understand that avoiding mortality, even by delaying global warming by a single year, represents a permanent gain. This is true even though the individuals so saved may die the next year from this or some other cause. The avoided mortality benefits cascade forward in the same way as avoided C emissions in Figure 1. Based on global emissions from fossil fuel and tropical forest land-use change (Table 2), one can calculate the human life value of avoided C emissions (including immediate emission equivalents gained from delaying emissions or temporary sequestration of C). This calculation does not consider the CO_2 sink of 0.5 PgC/year in temperate and boreal forest growth. Note that the value of 2.4 PgC/year for emission from tropical forest land-use change (Fearnside, 2000d) used in Table 2 is 50% higher than the 1.6 PgC/year value used by the SAR, and that the additional size of the missing sink implied by this difference results in the impact per Mg of current emission being reduced in proportion to the change in the total anthropogenic emission. It is 26% higher than the value of 1.9 PgC estimated by Houghton (1999). Each million Mg of avoided emission results in the saving of 16.4 lives (Table 2). The obviously unrealistic assumption of fixed global population size over the 1990-2070 period makes this value conservative by a factor of two or more (Fankhauser and Tol, 1997). The human-life value of delaying global warming gives time a value that is independent of arguments based on money, and provides a rationale for applying some form of time preference, as by discounting, to C.

[Table 2 here]

The human-life benefit of delaying global warming is illustrated schematically in Figure 8. Here it is arbitrarily assumed that global warming-induced mortality simply ramps up in a linear fashion from zero in 2000 to the SAR figure of 138,000 deaths/year in 2070 (the approximate year of 2 × CO_2), and remains constant thereafter. Delaying global warming by one year shifts the curve to the right, creating a gain of 138,000 lives regardless of what time horizon is adopted (so long as it is after 2070). It should be emphasized that this gain is not reduced by discounting C, and that human life is not discounted.

[Figure 8 here]

Various other arguments for discounting have been put forward by different authors, although none of these controversial arguments is necessary to justify the use of discounting (or of some alternative means of expressing time preference) in global warming calculations. One argument is that expected increases in the wealth of the population suffering global warming impacts will reduce the perceived loss of utility from the monetary impacts of global warming because wealthier people attribute less value to a given amount of monetary loss (Azar and Sterner, 1996). The opposite relationship between wealth and value has been suggested for human life losses (Fankhauser and Tol, 1997), and strongly contested (Fearnside, 1998). Yet another argument for discounting is that it favors temporary carbon sequestration activities that buy time for expected technological improvements reducing the future cost of mitigation per Mg of C (Chomitz, 1998). Another line of argument would even indicate negative discount rates: greater movement of C to ocean and terrestrial sinks as a result of CO_2 fertilization and other effects of future increases in atmospheric CO_2 levels, as well as greater time that atmospheric loads of C could be present to decay while still below dangerous levels, led Wigley *et al*. (1996) to suggest that C emissions are better now than later. Schneider (1997) counters the argument of Wigley *et al*. (1996) by noting that greater loads of carbon in the atmosphere might trigger non-linearities, sometimes referred to as “climatic surprises.” In addition, immediate policy responses can restore efficiency that is hampered by pre-existing market failures, such as spillovers in research and development markets (Schneider and Goulder, 1997).

Exponential discount rates greater than zero can have perverse effects on economic decision making because even catastrophic events in the long-term future are reduced to insignificance (Cline, 1992; Costanza, 1991; Fearnside, 1989; Pearce, 1991; Price, 1993). Rejection of discounting in these contexts must be tempered with recognition of its appropriateness in the context of carbon accounting. Pretending that time has no value also has potential perverse effects.

The effect of discounting reducing long-term costs and benefits to insignificance is a characteristic of the exponential discounting most commonly employed in economic analyses. A variety of alternative time-weighting mechanisms has been proposed to avoid this consequence, including hyperbolic discounting where the annual discount rate decreases as time progresses (Schneider *et al*., 2000), Heal discounting (Heal, 1997) where the discount rate falls in steps, for example using a market rate (the opportunity cost of capital) for the first 30 years and thereafter using a discount rate derived from a zero rate of pure time preference and conservative assumptions about long-term economic growth, a generation-weighting system that results in a thicker tail of the distribution than does traditional discounting (but only within a limited time horizon) (Fearnside, 2000c), and an alternative to pass a fixed percentage of decision-making weight beyond the end of the time horizon (Fearnside, 2000a).

Agreement on a discount rate or other time-preference weighting arrangement for C is fundamental to comparing forest-sector options with fossil fuel substitution (Fearnside, 1995a, 1999c). Interpretation would be greatly simplified if the discount rate chosen is consistent with choices for global warming potentials (Lashof and Ahuja, 1990). Discounting C need not be the same as money, although some advocate that the same rate should be applied (e.g., van Kooten *et al*., 1997). The implications of discount rates as high as those for money are substantial for the relative impacts of different activities (Fearnside, 1997a). The choice of discount rates for other purposes, such as private investment decisions, public expenditures, and public regulation of renewable natural resources management, all have independent rationales. Since decisions are so sensitive to discount rate choices (for example, the difference between a 3% and 6% annual discount rate is a factor of 20 over the course of a century), the consequences of allowing choices on global warming decisions to be determined by discount rates derived in other spheres could be severe.

4.2. CONSEQUENCES OF DISCOUNTING

The impact of one Mg of C emission at different discount rates is shown in Figure 9, indicating the percent of full impact recognized depending on the year that an emission occurs (considering a discrete approximation using one-year increments). For example, for the zero-discount case, the impact of a one-Mg emission is 46 Mg-years if emitted in year 0 (i.e., the area under the baseline curves in Figure 5), and declines to 46 − 17 = 29 Mg-years if emitted in year 46 (i.e., the mitigation case in Figure 5 B). The impact of emitting one Mg in year 46 is therefore 29/46 = 63% of the immediate emission impact (Fig. 9). From the zero-discount line, progressively larger discount rates cause impact to decrease rapidly in the first years after emission (Fig. 9). The converse of Figure 9, for purposes of calculating credit for delaying emissions through sequestration, is given in Figure 10.

[Figures 9 and 10 here]

Discounting can radically alter choices of energy sources and mitigation options (Fearnside, 1995a, 1997a; Marland *et al.*, 1997; Price and Willis, 1993). The length of the time horizon has a strong effect on the importance of discounting. As time horizons become longer, the distortions become greater if no discounting is applied. In the case of forest sector options that can transfer C to very long-term pools, these pools can dominate the results if very long horizons are considered without discounting. In the case of an infinite or very long time horizon, equilibrium conditions will apply. Slow buildup of C in very-slow-turnover classes of wood products dominates the results at equilibrium, but occurs at such remote times that it has little bearing on present decisions when discounting is applied. These problems also apply to calculations made under the assumption that the shadow price of C increases at the same rate as the discount rate for money, thereby allowing analysis without discounting C (Fearnside, 1995a).

In the energy sector, higher discount rates for C will progressively reduce the attractiveness of building hydroelectric dams to substitute for fossil fuel-based thermal generation. This is because dams produce substantial emissions from concrete, steel and energy use during the construction phase years before any power is generated, followed soon after filling the reservoir by a large peak of additional emissions of CO_2 from above-water decay of flooded trees (if the dam is in a tropical forest area) as well as emissions of CH_4 (Fearnside, 1995b, 1997a). Thermal power, in contrast, produces little emission during power plant construction, followed by emissions at a constant rate over many decades, emissions impacts and energy benefits coming in direct proportion and at the same time. Consequently, the cost of carbon benefits earned by switching from thermal to hydroelectric power will increase with higher discount rates for C, approaching infinity at the breakeven point between the two energy sources. Similarly, higher discount rates will tend to reduce the benefits attributed to wind, solar and energy-efficiency projects compared to fossil fuel power plants to the extent that they involve larger emissions related to building the capital equipment (with no emissions during operation). Higher financial discount rates also make these projects less economically attractive.

In forest-sector options, higher discount rates for C would favor deforestation avoidance (by slowing rates of forest loss) over plantation silviculture because deforestation produces large and immediate releases of GHGs, while plantations accumulate C slowly. As discount rates for C increase, the cost per Mg of C can be expected to climb for forest plantation mitigation options, but would remain relatively flat for avoided deforestation. Policy measures with immediate effects on reducing deforestation rates will be favored over creation of protected areas which can only be expected to result in reduced deforestation rates years later when the remainder of the available forest has been exhausted. This can be seen by considering a hypothetical case to illustrate the implications of Mg-year accounting and discounting for the two major categories of deforestation avoidance efforts: creation of protected areas and policy changes to slow rates of clearing.

Consider a country (Fig. 11 A) that is clearing its remaining forest at a constant rate and will run out of forest in nine years. If a park is created from 1/18 (5.5%) of the remaining forest (Fig. 11 B), the available forest will be exhausted in 8.5 years, after which there will be no more clearing. Note that this implies some simplifying assumptions as compared to real cases: deforestation activity shifts completely from the reserve area to other sites (i.e., there is 100% leakage), and deforestation proceeds linearly until the last tree is cut. The alternative strategy—policy measures to reduce clearing rates—is illustrated in Figure 11 C, where clearing rate is reduced by 50% and proceeds to destroy the entire forest in 18 years.

[Figure 11 here]

The effect of discount rate on the choice between park creation and policy measures to slow deforestation is shown in Figure 12, using as an example the same scenario as Figure 11 with a baseline deforestation time of nine years. If the park option is to be as attractive as the slowing deforestation option, the area of park that would need to be created, expressed as a percent of the remaining forest area, increases steadily with increasing discount rates; examples for 50% and 40% reduction in deforestation rate are shown from the family of curves that would describe this relationship.

[Figure 12 here]

Another means of visualizing the choice between parks and slowing deforestation is illustrated in a second example (Fig.

13). A ratio of the atmospheric impact the under slowing deforestation scenario and under the park creation scenario greater than one indicates that park creation would be preferable. Here a baseline time to deforestation of 45 years is assumed, and a fixed park area of 1/9 (11%) of the remaining forest. The annual discount rates needed to cause a switchover in deforestation avoidance strategy are substantially lower in this example than in the previous one: for a 25% reduction in deforestation rate, parks are favored if the annual discount rate is less than 1.45%, whereas for a 50% reduction in deforestation rate slowing deforestation is the favored option at all discount rates.

[Figure 13 here]

Results such as those in Figure 11 are highly dependent on all of the emissions in all of the scenarios compared occurring within the time horizon. If, for example, the time to complete deforestation under the baseline scenario extends beyond the time horizon, then park creation will receive no credit (or partial credit in the case of deforestation ending soon after the time horizon). If slowing deforestation results in the demise of the forest being pushed beyond the end of the time horizon, then policy changes to slow clearing rates get substantially more credit. These discontinuities may be seen as either benefits or distortions, depending on the point-of-view. Choice of the time horizon is the critical factor in determining when they come into play. The shorter the time horizon, the more countries will be affected by this factor. At 100 years, Brazil would only escape the time horizon effect after about 200 years, given (extremely optimistic) linear extrapolation of recent deforestation rates as the baseline.

5. Sustainable Development Implications of Mitigation

The above consequences of discounting C have a variety of implications for other environmental and social costs and benefits. Generation of electrical power from fossil fuels has significant health consequences through air pollution (Rosa and Schechtman, 1996). On the other hand, hydroelectric power can have tremendous impacts on biodiversity, indigenous peoples and resettlement, as well as impacts on health, fisheries and a long list of other concerns. Two of the most notorious dams in the world in terms of these associated impacts are the Belo Monte/Altamira (formerly Babaquara) complex in Brazil and the Three Gorges Dam in China (Barber and Ryder, 1993; Dai Qing, 1994; Fearnside, 1988, 1994, 1996a; Santos and de Andrade, 1990). Both of these have been put forward in recent debates over the Clean Development Mechanism as possibly meriting C credit! The almost total lack of connection between discussions in the carbon sphere and those in other spheres of environmental and social impact assessment is evident.

In the forestry sector, the effect of discounting C in favoring deforestation avoidance over forest plantations is highly beneficial from the biodiversity standpoint. On the other hand, the effect in favoring policy initiatives over establishing protected areas is perhaps not the best result for long-term maintenance of biodiversity (Fearnside, 1999d). Natural forests provide critical environmental services, including maintenance of biodiversity and watershed functions (e.g., Daily, 1997; Schneider, 1998).

The associated environmental and social impacts of energy and forestry choices that are influenced by decisions regarding time preference for C make clear the need for explicit consideration of these impacts in decision making on global-warming abatement. They cannot be addressed indirectly by fiddling with the discount rate in order to achieve progress on an alternative environmental and social agenda through global-warming mitigation efforts. Neither can these concerns be compartmentalized as beyond the ken of mitigation decisions and left up to each country to decide as it sees fit through whatever system of environmental impact assessment, if any, it may have. Such a solution would both favor the implantation of mitigation projects in countries with little or no environmental and social impact regulation and would result in projects being funded that grossly violate standards in the funding countries (the two hydroelectric dam examples mentioned earlier provide glaring examples). How sustainable development criteria are applied in carrying out global-warming mitigation measures under the Kyoto Protocol will be crucial in determining the associated impacts and benefits of the projects (e.g., Fearnside, 1996b, 1999e). Sustainable development criteria and procedures represent another undecided area in Kyoto Protocol implementation.

Countries often have very different views as to what constitutes sustainable development. The United Nations Framework Convention on Climate Change (UN-FCCC) clearly recognizes the sovereignty of each country in deciding how to mitigate global warming within its borders. LUCF activities funded internationally for carbon credit under the Kyoto Protocol will inevitably have to meet the sustainable development criteria of **both** the countries receiving and those providing the funds (Fearnside, 1999a). Specifying the criteria to be used in this winnowing process and the institutional mechanism for carrying it out are tasks that can only be done by the Parties. As a hypothetical example, a country might propose to cut a tropical forest containing endangered species and tribal peoples in order to implant a *Eucalyptus* plantation with C benefits. The criteria used to define sustainable development will determine whether such a project would receive funding and/or carbon credit, and thereby determine the environmental and social implications of the mitigation effort. In addition to screening out unacceptable projects, sustainable development criteria could also play a role through a reward system to encourage more desirable projects. Premiums for benefits in such areas as biodiversity and social parameters could be incorporated into the carbon crediting structure adopted by the Parties (e.g., Schneider, 1998; Schneider *et al.*, 2000). The extent that such a system is implemented will determine the extent to which the effects of discount rate choices for C will guide development in desirable or perverse directions, or a mixture of both.

6. Conclusions

1.) Mg-year equivalence provides a needed mechanism for comparing the global warming impacts of different activities and the benefits of different mitigation projects. It allows temporary sequestration of CO_2 to be compared on a equitable and consistent basis with permanent C sequestration or fossil fuel emission avoidance.

2.) Time preference, expressed by means of a discount rate on C, can be applied to Mg-year equivalence calculations to allow societal decisions regarding the value of time to be integrated into the system for calculating global warming impacts and benefits. The moral choice of specifying a value for time, zero or otherwise, cannot be avoided.

3.) Time-preference choices for C through discount rate (or alternative mechanisms) can strongly influence economic decisions and the social and environmental impacts and/or benefits of the favored mitigation options. For example, the choice between creating protected areas and instituting policy measures to slow deforestation rates is heavily depending on time preference. Pending decisions on sustainable development criteria under the Kyoto Protocol could be critical in determining the consequences that C time-preference choices have in spheres other than global warming.

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FIGURE LEGENDS

Figure 1. Cascading effect of displaced emissions: case where C reserve (forest or fossil) lasts beyond the end of the time horizon. In this example no account is taken of movement of carbon from atmosphere to other pools over the time horizon. A net gain is achieved.

Figure 2. Cascading effect of displaced emissions: case where C reserve (forest) runs out within the time horizon. In this example no account is taken of movement of CO_2 from atmosphere to other pools over the time horizon. No net gain is achieved.

Figure 3. Discount rate equivalent of a time horizon. The area under a negative exponential curve at approximately 1% annual discount (assuming truncation at year 1000) is equal to that under the 100-year time horizon zero discount system adopted for global warming potentials.

Figure 4. Alternative indices of the value of delaying emissions. Benefit in a fixed year, such as 2070 (option A) is one measure. The difference between the integrals within the time horizon, which is equal to the area pushed beyond the time horizon in the curve for the delayed emission (option B) is the index used in the present paper.

Figure 5. Alternative methods of crediting CO_2 sequestration. Method (A) follows C in planted trees, results in a greater calculated benefit for delaying an emission (through sequestration) than does Method (B), which follows atmospheric pools of carbon.

Figure 6. Effect of forest degradation on mitigation through avoided deforestation: case where forest is destroyed before the end of the time horizon.

Figure 7. Effect of forest degradation on mitigation through avoided deforestation: case where forest lasts beyond the end of the time horizon.

Figure 8. Human-life benefit of delaying global warming. This provides a rationale for discounting independent of arguments based on money.

Figure 9. Discount rate effects on the impact of C emissions in different years.

Figure 10. Discount rate effects on C credit earned by delaying emissions for different periods.

Figure 11. Comparison of park creation versus policy changes to slow deforestation in a hypothetical country where continuation of the current rate of deforestation would eliminate the remaining forest in nine years (A.). Here, creation of a park from 1/18 (5.5%) of the remaining forest (B.) is compared with a policy change slowing deforestation by 50% (i.e., doubling the time to the expected demise of the forest to 18 years) (C.). In the park creation case, deforestation is assumed to continue unchanged outside of the park (i.e., there is 100% leakage). The graphs at the right include effects of CO_2, CH_4 and N_2O. A 100-year time horizon is assumed.

Figure 12. Effect of discount rate on the area of park that would need to be created to be equivalent to deforestation rate reductions of 50% and 40%. If park area is 5.5% of remaining forest and the deforestation rate reduction is 50% (as in Fig. 11), the switchover from parks to slowing deforestation as the preferred strategy occurs at an annual discount rate of 0.73%, assuming a time horizon of 100 years.

Figure 13. Relation of the relative impact on the atmosphere of park creation versus slowing deforestation at different discount rates. In this example, a 25% reduction in deforestation rate would be preferable to creating a park from 11% of the remaining forest if the annual discount rate is less than 1.45%, but the 25% deforestation rate reduction would be preferable at discount rates above this value; a 50% deforestation rate reduction would be preferable to a park of the same size at all discount rates. A 45-year baseline time to deforestation and a 100-year time horizon are assumed.

Table 1:
Climatic impact per hectare of tropical deforestation, including effects of non-CO_2 GHGs and disco

Year	Atmospheric load (t gas)[a]			CO_2-C equivalent (t)[b]			Tot
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	Dis 0 %
1	677	0.97	0.09	185	15.42	5.09	
2	623	0.92	0.09	170	14.57	5.06	
3	581	0.87	0.09	158	13.76	5.03	
4	540	0.82	0.09	149	13.00	5.00	
5	520	0.78	0.09	142	12.28	4.97	
:	:	:	:	:	:	:	
10	441	0.58	0.09	120	9.25	4.83	
:	:	:	:	:	:	:	
25	350	0.25	0.08	95	3.94	4.43	
:	:	:	:	:	:	:	
50	281	0.06	0.07	77	0.95	3.83	
:	:	:	:	:	:	:	
75	246	0.01	0.06	67	0.23	3.32	
:	:	:	:	:	:	:	
100	225	0.00	0.05	61	0.06	2.87	
Total				8,509	278.18	387.68	

(a) Per-hectare emissions are average net committed emissions for 1990 deforestation in Brazilian Amazonia (Fearnside, 2000b). Atmospheric loads of all gases decline as in the IPCC's Second Assessment Report (SAR) (Schimel *et al.*, 1996): CO_2 declines non-linearly in accord with the Revised Bern Model while CH_4 and N_2O decline exponentially with half lives of 12.2 and 120 years, respectively.
(b) Instantaneous radiative forcings per ton of gas are taken from the SAR (Shine *et al.*, 1995): 1 for CO_2, 58 for CH_4 and 206 for N_2O.

Table 2:

Human life value of delaying global warming

Item	Value	Units	Source
Mortality at 2 X CO_2, with constant population	138,000	lives/year	(Fankhauser, 1995; Pearce *et al*., 1996)
Fossil fuel annual emission 1981-1990	6	PgC/year	(Watson *et al*., 1992: 29)
Tropical forest land-use change annual emission 1981-1990	2.4	PgC/year	(Fearnside, 2000d).
Total annual anthropogenic emission 1981-1990	8.4	PgC/year	Calculated as fossil fuel + tropical land-use change annual emissions
Value of avoided emission	60,870	MgC immediate emission	Calculated as total annual anthropogenic emission / mortality at

		equivalent/life	2 X CO_2
Value of avoided emission	16.4	lives/million MgC immediate emission equivalent	Calculated as mortality at 2 X CO_2 / total annual anthropogenic emission

Fig 1

Cascading effect of displaced emissions: large forest case

				Time Horizon ↓	Total emission (tC)
Year	1	2	3 . . . n		
Baseline Scenario	ton_1	ton_2	ton_3 . . ton_n		n
Mitigation Scenario		ton_1	ton_2 . . ton_{n-1}		n-1
Benefit					1

Fig. 2

Cascading effect of displaced emissions: small forest case

					Time Horizon ↓	Total emission (tC)
Year	1	2	3	...	n	
Baseline Scenario	ton_1	ton_2				2
Mitigation Scenario		ton_1	ton_2			2
Benefit						0

Fig. 3

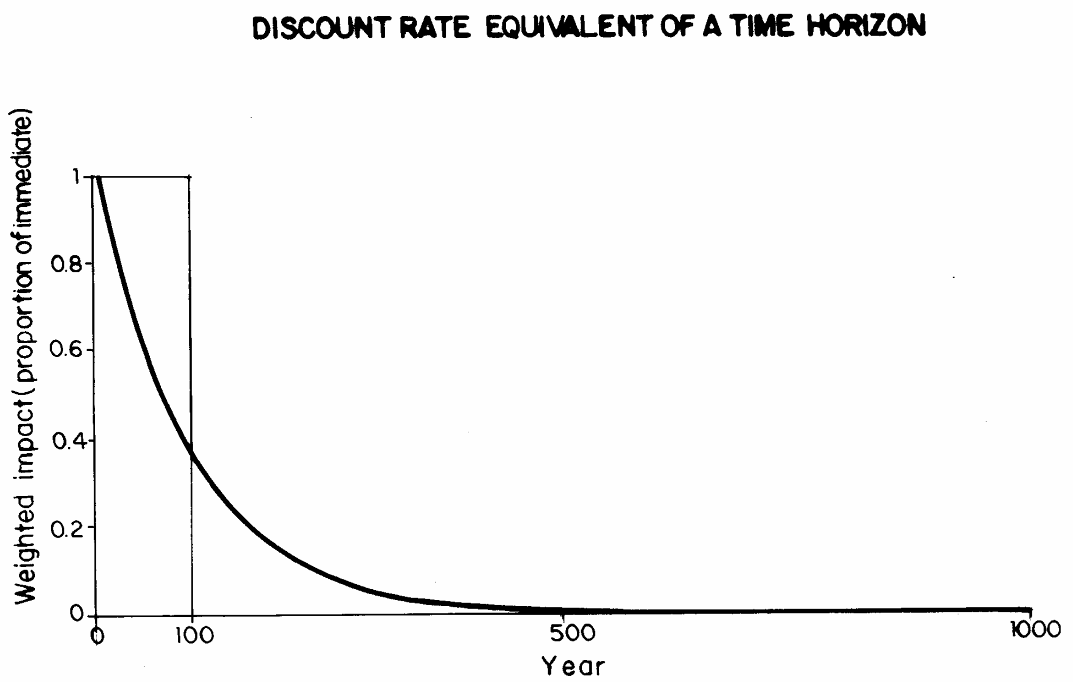

DISCOUNT RATE EQUIVALENT OF A TIME HORIZON
Weighted impact (proportion of immediate)
1
0.8
0.6
0.4
0.2
0
0
100
500
1000
Year

Fig. 4

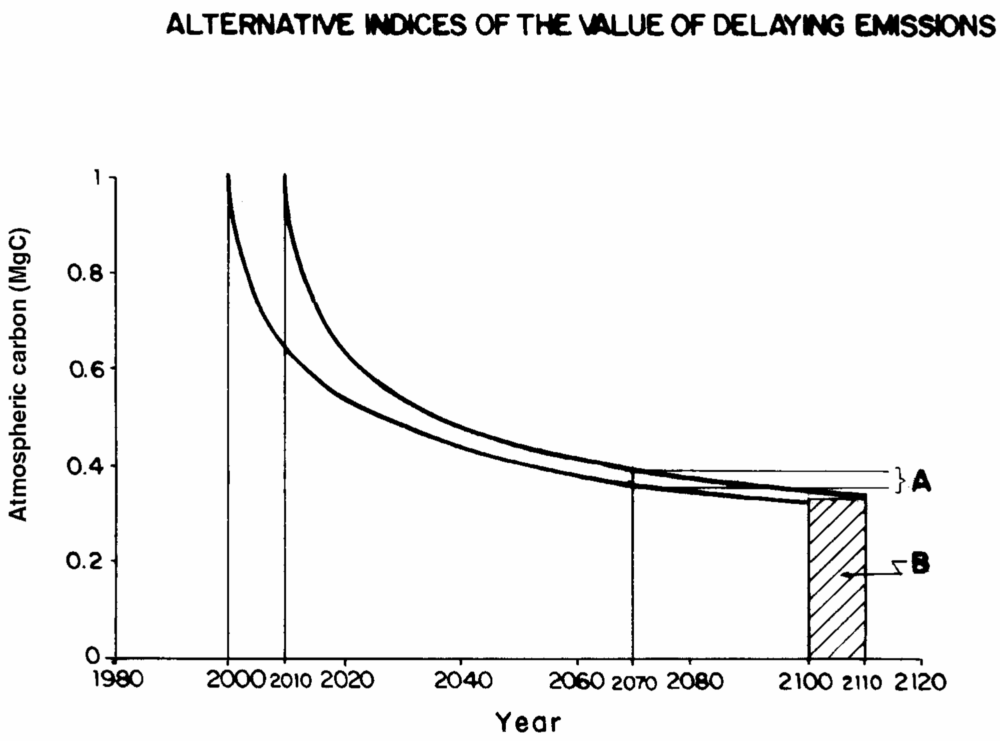
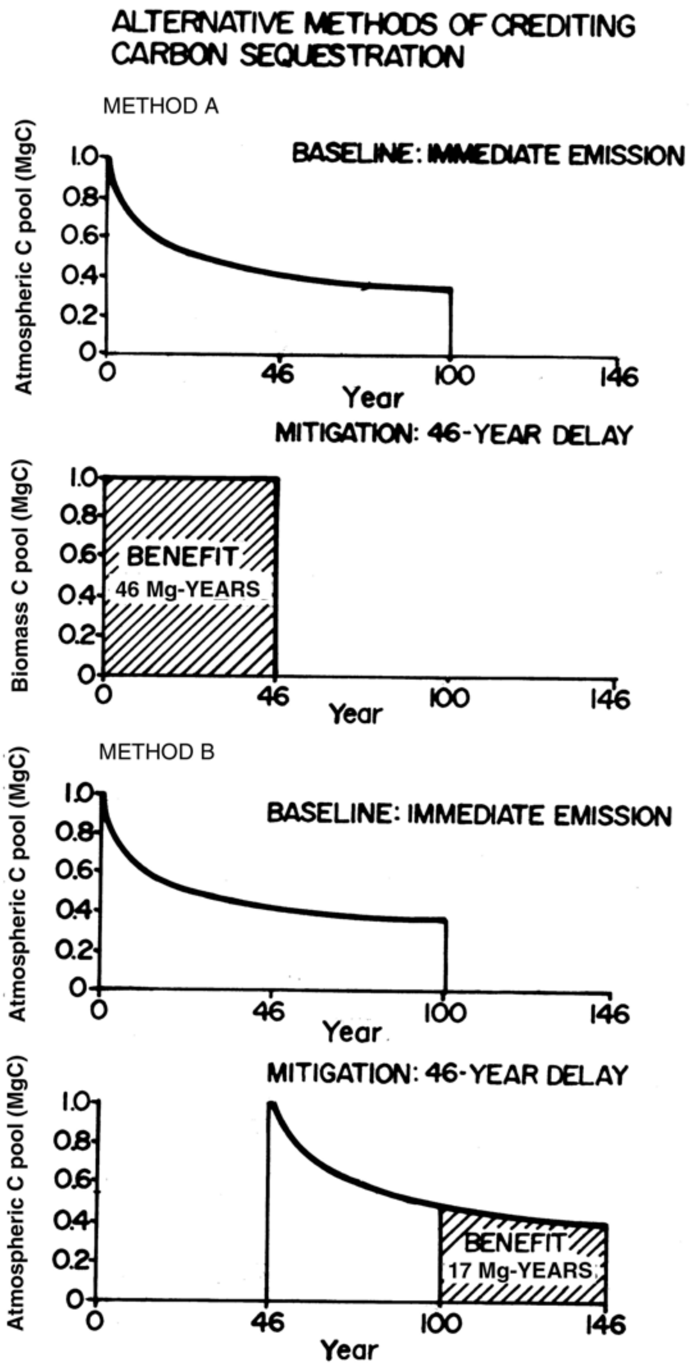

ALTERNATIVE INDICES OF THE VALUE OF DELAYING EMISSIONS
Atmospheric carbon (MgC)
1
0.8
0.6
0.4
0.2
0
1980
2000
2010
2020
2040
2060
2070
2080
2100
2110
2120
Year
A
B

Fig. 5



ALTERNATIVE METHODS OF CREDITING CARBON SEQUESTRATION
METHOD A
BASELINE: IMMEDIATE EMISSION
Atmospheric C pool (MgC)
1.0
0.8
0.6
0.4
0.2
0
0
46
100
146
Year
MITIGATION: 46-YEAR DELAY
Biomass C pool (MgC)
BENEFIT
46 Mg-YEARS
Year
METHOD B
BASELINE: IMMEDIATE EMISSION
Atmospheric C pool (MgC)
Year
MITIGATION: 46-YEAR DELAY
Atmospheric C pool (MgC)
BENEFIT
17 Mg-YEARS
Year

Effect of Forest Degradation on Mitigation through Avoided Deforestation: Small Forest Case

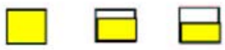
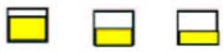
						Total emission (MgC)	Immediate emission equivalent (MgC)
	Year:	1	2	3	4		
	Emission: (MgC/ha of deforestation)	100	80	50	40		
Baseline Scenario	Deforested area						
	Deforestation emission	100	80	50	0		
	Degradation emission	0	20 X 2	30	0		
	Total	100	120	80	0	300	
	Immediate emission equivalent	100.0	110.4	68.6	0.0		279.1
Mitigation Scenario	Deforested area						
	Deforestation emission	0	80	50	40		
	Degradation emission	0	20 X 3	30 X 2	10		
	Total	0	140	110	50	300	
	Immediate emission equivalent	0	128.8	94.4	40.4		263.6
Benefit						0	15.4

Fig. 6

Fig. 7

Effect of Forest Degradation on Mitigation through Avoided Deforestation: Large Forest Case

						Total emission (MgC)	Immediate emission equivalent (MgC)
	Year:	1	2	3	4		
	Emission: (MgC/ha of deforestation)	100	80	50	40		
Baseline Scenario	Deforested area						
	Deforestation emission	100	80	50	40		
	Degradation emission	0	20 X 3	30 X 2	10		
	Total	100	140	110	50	400	
	Immediate emission equivalent	100.0	128.8	94.4	40.4		363.6
Mitigation Scenario	Deforested area						
	Deforestation emission	0	80	50	40		
	Degradation emission	0	20 X 4	30 X 3	10 X 2		
	Total	0	160	140	60	360	
	Immediate emission equivalent	0	147.2	120.1	48.5		315.8
Benefit						40	47.8

Fig. 8

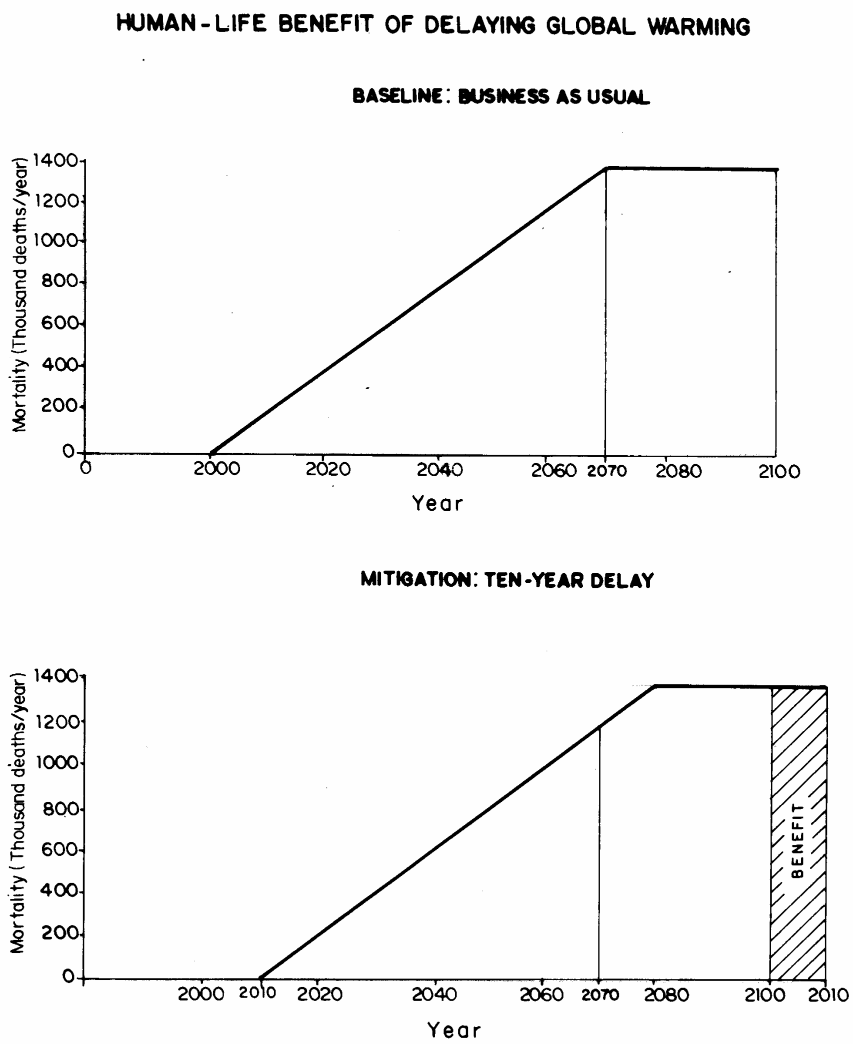

HUMAN-LIFE BENEFIT OF DELAYING GLOBAL WARMING
BASELINE: BUSINESS AS USUAL
Mortality (Thousand deaths/year)
1400
1200
1000
800
600
400
200
0
0
2000
2020
2040
2060
2070
2080
2100
Year
MITIGATION: TEN-YEAR DELAY
Mortality (Thousand deaths/year)
1400
1200
1000
800
600
400
200
0
2000
2010
2020
2040
2060
2070
2080
2100
2010
Year
BENEFIT

Fig. 9

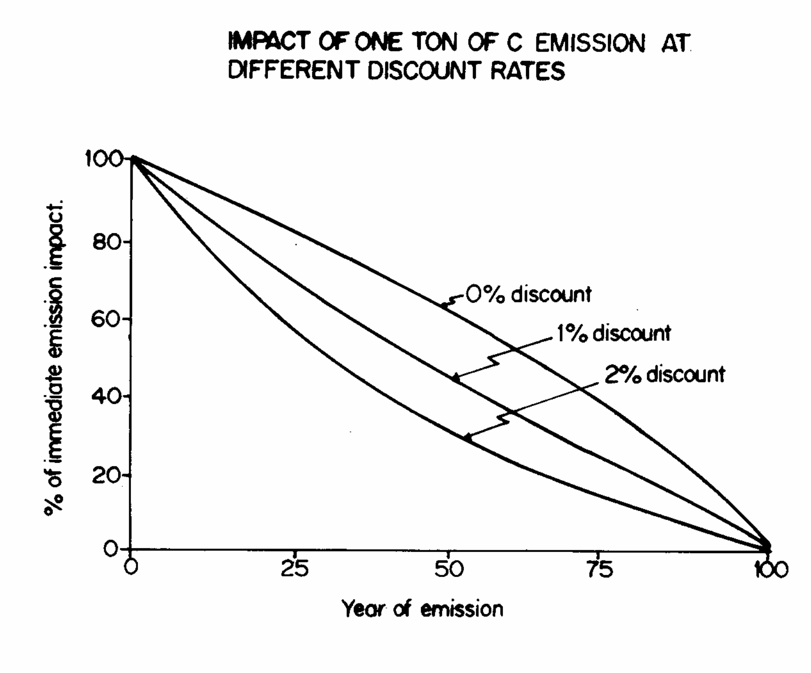

IMPACT OF ONE TON OF C EMISSION AT DIFFERENT DISCOUNT RATES
% of immediate emission impact.
100
80
60
40
20
0
0
25
50
75
100
Year of emission
0% discount
1% discount
2% discount

Fig. 10

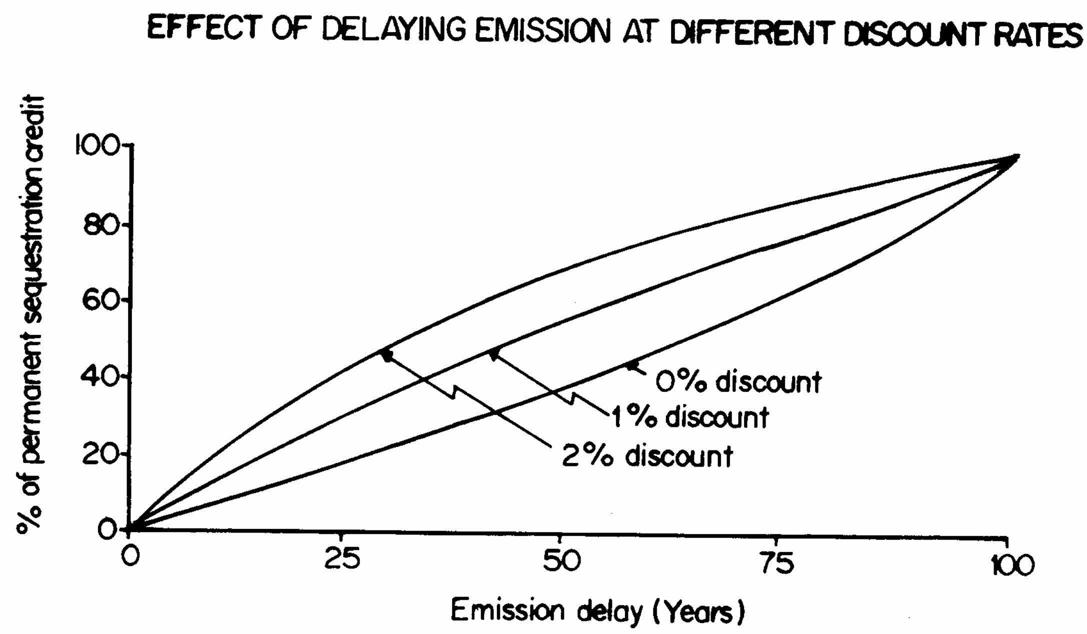

EFFECT OF DELAYING EMISSION AT DIFFERENT DISCOUNT RATES
% of permanent sequestration credit
100
80
60
40
20
0
0
25
50
75
100
Emission delay (Years)
0% discount
1% discount
2% discount

Fig. 11

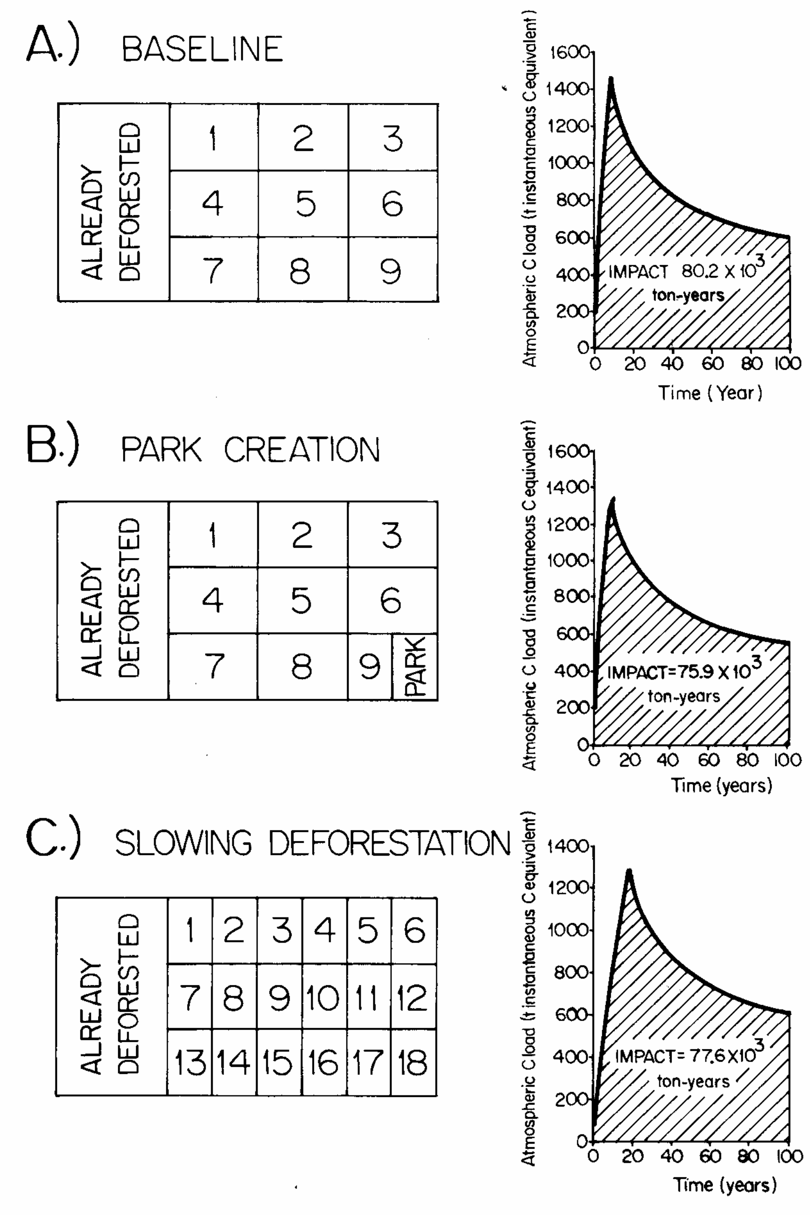

A.) BASELINE
ALREADY DEFORESTED
1 2 3
4 5 6
7 8 9
IMPACT 80.2 X 10^3 ton-years
Atmospheric C load (t instantaneous C equivalent)
Time (Year)
B.) PARK CREATION
ALREADY DEFORESTED
1 2 3
4 5 6
7 8 9 PARK
IMPACT=75.9 X 10^3 ton-years
Atmospheric C load (instantaneous C equivalent)
Time (years)
C.) SLOWING DEFORESTATION
ALREADY DEFORESTED
1 2 3 4 5 6
7 8 9 10 11 12
13 14 15 16 17 18
IMPACT= 77.6X10^3 ton-years
Atmospheric C load (t instantaneous C equivalent)
Time (years)

Fig. 12

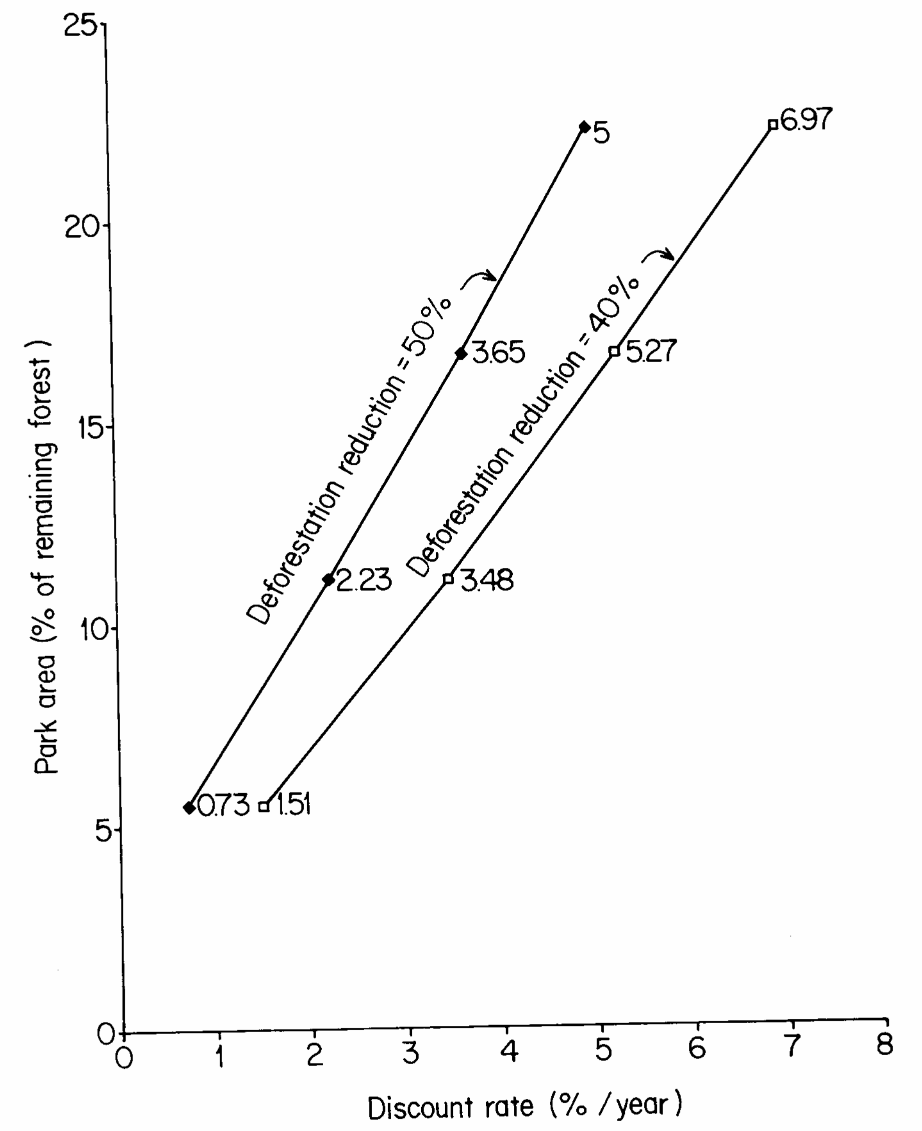
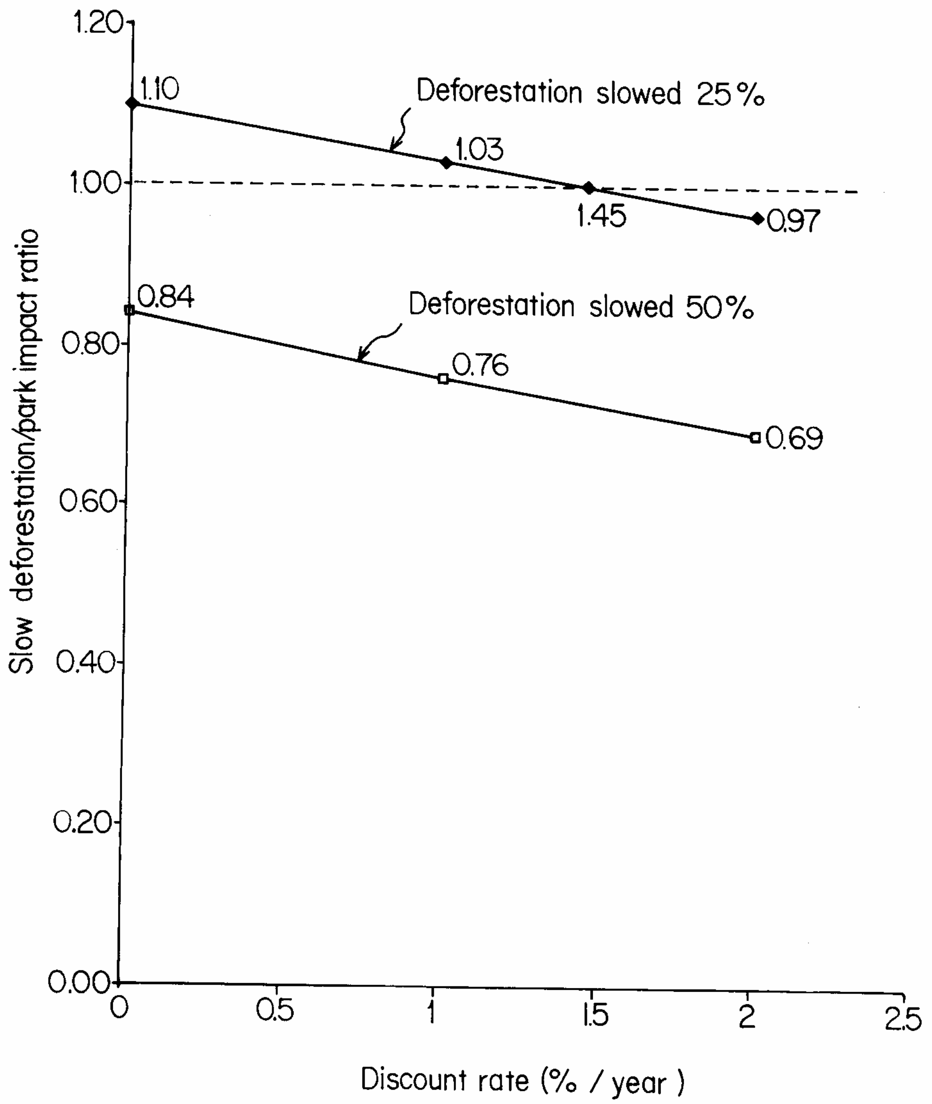

25
20
15
10
5
0
Park area (% of remaining forest)
0
1
2
3
4
5
6
7
8
Discount rate (% / year)
Deforestation reduction = 50%
Deforestation reduction = 40%
0.73
2.23
3.65
5
1.51
3.48
5.27
6.97

Fig. 13


1.20
1.10
Deforestation slowed 25%
1.03
1.00
1.45
0.97
0.84
Deforestation slowed 50%
0.80
0.76
0.69
0.60
0.40
0.20
0.00
0
0.5
1
1.5
2
2.5
Slow deforestation/park impact ratio
Discount rate (% / year)