Carbon accounting methodologies

Piers Maclaren and Justin Ford-Robertson[1]

[1]***Forest Research***, Private Bag 3020, Rotorua, New Zealand
E-mail: Justin.Ford-Robertson@ForestResearch.co.nz

ABSTRACT

Trading in carbon credits from afforestation and reforestation is foreshadowed by the Kyoto Protocol. Human-induced sinks can compensate for human-induced emissions, but given ongoing combustion of fossil fuels, there needs to be an ongoing contribution from sinks. Because forests are sinks only when they are expanding in area or carbon density, and because there is a limit to the quantity of growing stock per unit area, afforestation must be continuous. Given a limited global area of plantable land, this cannot continue in perpetuity. Forest sinks are a popular topic in the current decade because they are seen as being a relatively low-cost first step to reduction of net greenhouse gas emissions.

Before trading in carbon sinks can eventuate, however, numerous technical difficulties have to be resolved, including the acceptance of a standard method of carbon accounting. The concept of "tonne-years", whereby the quantity of carbon sequestered is multiplied by the time it is out of atmospheric circulation, appears to be gaining credence in international fora. This concept is flawed and threatens to undermine the "stocks" based accounting approach that is built into Article 3.3 of the Kyoto Protocol. A preferable approach is to accept that afforestation is merely the reverse of deforestation, and is a one-off movement of carbon from the atmosphere to the earth's surface. Carbon credits could be a one-off payment made to a land owner who undertakes to increase the long-term carbon density of a piece of land. No further transactions would be required unless the land owner makes land use/cover decisions which will change the long-term carbon density again. An efficient audit system could be implemented to verify the continued existence of the stated land cover.

Active trading in carbon credits would lead to an increase in the forested area of the world. While this might saturate the world with wood, and thereby reduce timber prices, it may also presage the way to an global economy based, in part, on bioenergy. Bio-fuels from sustainably harvested forests trap and store the current energy income of the planet (ie sunlight), just as fossil fuels represent the captured energy of previous millennia.

The long-term benefit of trading in carbon sinks, therefore, may be to stimulate planting and thereby permit the formation of a sustainable biomass resource. The current rationale for such trading—sequestration of carbon—is likely to prove ephemeral.

Keywords: Kyoto Protocol; carbon sinks; carbon sequestration; carbon accounting; tonne-years; stock change; carbon density; carbon credits.

1. INTRODUCTION

International trading in "carbon emission reduction units" (credits) from carbon sequestration by forests is foreshadowed by the Kyoto Protocol. The details of how such trading would be measured were not provided by that Protocol, and remain to be resolved.

Both the Framework Convention for Climate Change (FCCC) and the Kyoto Protocol frequently refer to the use of "sinks" as a means of meeting international obligations. It is important to use the correct terms, and to be clear on the meaning of these terms. Definitions are provided by the FCCC in Article 1:

> *"Reservoir" means a component or components of the climate system where a greenhouse gas or a precursor of a greenhouse gas is stored.* [In other words, a reservoir contains carbon stocks but no net flow of carbon is implied].
>
> *"Sink" means any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere.* [In forests, for example, a sink involves a flow from the atmosphere which increases stocks in vegetation.]
>
> *"Source" means any process or activity which releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere.* [Forests can be sources as well as sinks: it is merely necessary for their stock of carbon to decline, for example as a result of a decrease in their average age-class].

It is also important to distinguish between a forest and a stand. The word *forest* is used here to indicate a large-scale land use, comprising many stands. Whereas stands may accumulate carbon up to harvest and lose most of that carbon on harvest, a forest does not necessarily behave that way. A forest usually continues to retain a high carbon-density, despite individual stands being felled within it. The carbon density of a sustainably managed forest will fluctuate as a result of imbalances in the age-class distribution, but it will do so within certain bounds.

A standing forest contains carbon and is therefore always a reservoir, but—unless the stocks of carbon are increasing—it may not also constitute a sink. If the carbon stocks remain constant but the forest area is expanding, it does represent a sink, but this cannot happen indefinitely. Even if 500 million hectares of land were afforested worldwide, and resulted in a "one-off" increase in carbon-density of 100 tonnes/ha, this amounts to only 50 Gt C removed from the atmosphere. (The term "one-off" refers to a single, isolated event). The IPCC Second Assessment Report examined scenarios of carbon accumulation from 1991-2100 of 630-1410 Gt C, so it can be seen that the potential contribution of afforestation is very small.

There is a duty to maintain and enhance reservoirs (FCCC, Articles, 3.3, 4.1c), but this activity is unlikely to generate internationally acceptable "credits" that are tradeable on a large scale. Existing stocks are similar to fossil fuel reserves ie if they remain where they are (even increasing in size) they are excluded from the accounting process. If they are consumed, there are emissions to the atmosphere. Providing credits for avoided deforestation and debits for deforestation is clearly double counting.

The scope of forestry activity that is allowable under Kyoto rules is considerably less than the total possible. Unless the forest has been established since 1990 as a result of "direct human-induced" activity, it is not eligible for credits under Article 3.3. Even then, if international trading takes place, it may be necessary to prove that the carbon sink is "additional to any that would occur in the absence of the certified project activity".

In order to set up an effective carbon trading system, the first step is to determine which changes in carbon stocks due to land use change and forestry are included (as above). The second step is to quantify those changes. The third step is to account for those changes in a standardised fashion which is transparent and verifiable to external auditors. This paper addresses some issues involved in that third step.

2. THE ACCOUNTANT'S DILEMMA

In implementing the Kyoto Protocol, decisions will need to be made on many borderline or "grey" areas. For the sake of simplicity, let us assume a relatively straightforward situation that is familiar to the author. In New Zealand, there are large areas of pasture that are unsustainable in their present land use for reasons of (among other factors) soil erosion. Vegetation cover has been maintained at a low level of biomass for many decades and this situation is likely to continue in the absence of direct human-induced intervention. Many additional environmental and human benefits would likely occur as a result of afforestation (Maclaren 1996). As a result of deliberate action to sequester atmospheric carbon, let us assume that some pasture is planted in radiata pine, a tree species whose growth rates and characteristics are reasonably well known.

At the beginning of the period, biomass carbon is minimal. There are perhaps 10 tonnes of carbon per hectare in the form of grass (leaves plus roots). Soon after planting, however, the biomass accumulates rapidly, with carbon comprising almost exactly half the oven-dry weight (Matthews 1993). All of the carbon has been derived from the atmosphere, because it is well known that carbon enters vegetation almost entirely through the leaves and not through the roots. The oven-dry weight of the biomass can be directly observed at intervals by standard forestry inventory techniques, or can be predicted with the use of models.

After a certain period of time each stand of trees is felled and replanted. Most of the stemwood carbon is removed from the site to be made into wood products. The accounting of such carbon is the subject of continuing international discussions, but is outside the main theme of this paper. Remaining behind in the forest are below-ground biomass, unmerchantable stemwood, branches, foliage and any understorey vegetation. This dead material decays slowly, releasing its carbon to the atmosphere.

Fig. 1 describes this process for radiata pine grown on a typical New Zealand site, under a typical regime. The graph is the output of a simulation model (*C_Change*. Beets *et al.* 1999) derived from repeated measurements of tens of thousands of permanent sample plots, each containing about 20 trees. We can be sure that the graph is reasonably accurate, but this can be verified by an auditor at any point in time using independent inventory techniques.

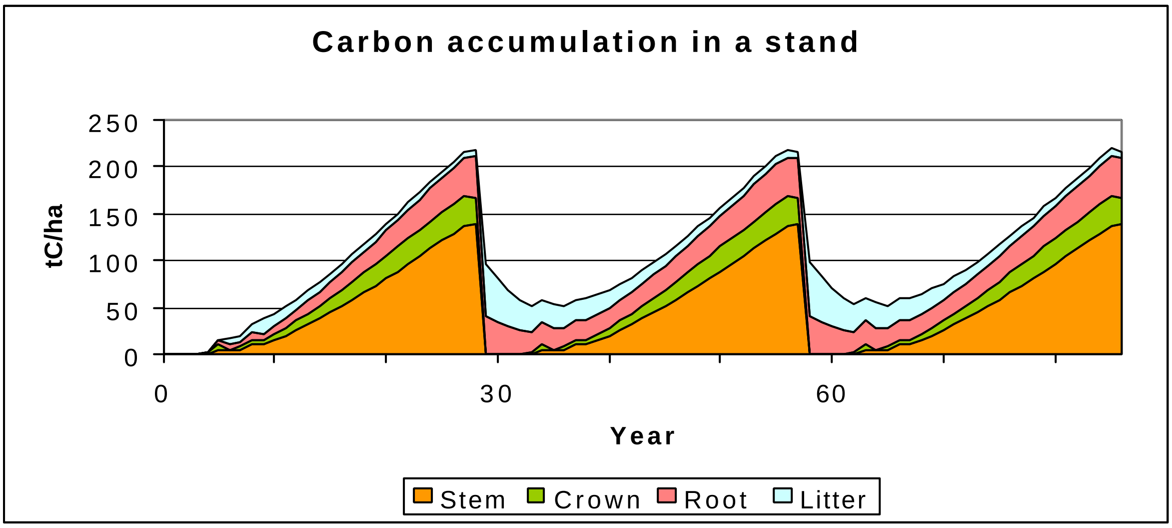


Figure 1: Carbon accumulation in a stand

Let us assume that the grower of the trees wishes to sell "carbon credits" to a utility company, whether local or from another industrialised country. The utility company is faced with the prospect of voluntary emission reductions, substitution with carbon-neutral fuels, paying carbon taxes or accepting quota restrictions on emissions. Purchase of carbon credits offers a potentially low-cost alternative to any of these.

For this trade to receive the blessing of the international community, there must be proof that atmospheric carbon has been reduced by at least the face value of the credits. For example, international auditors must be sure that there is no double-counting by selling the same credits to several buyers.

At least three proposals have been made as to the method of accounting, and these are discussed below.

2.1 Real-time accounting

The carbon in the stand in Figure 1 increases non-linearly up to harvest and then decreases abruptly. After harvest, carbon stocks do not revert to the initial level because of the presence of roots and slash, which take some time to decompose. Real-time accounting would allow a credit for every increase in carbon stocks and require a debit for every decrease. What are the advantages and disadvantages of this approach?

One advantage of real-time accounting is that it reflects the reality of what is actually occurring on the ground. If a grower has increased the biomass on a given site by 10 tonnes carbon during the previous year, and can prove this, then it is equitable for this amount to be claimed as a credit. Conversely, if biomass stocks have decreased, then it is equitable for the grower to pay a penalty similar to that arising from fossil fuel combustion. "Payment in arrears" for the sequestered carbon ensures that it can be independently verified.

One disadvantage is that forest inventories are not cheap relative to the likely value of carbon credits. The costs of annual inventories would soon negate any gain in the transaction. Predictive models could be used to reduce the number of inventories required, but even the best models have to be calibrated and validated from time to time.

Instead of transactions based on the gains and losses of a single stand, stands could be pooled into a larger operational unit (a *forest*). Losses in one stand could be compensated by gains in others, so only the net difference would need to be reported and traded. Nevertheless, good inventories must be maintained at the stand level in order to perform this calculation. Transaction costs would extend indefinitely into the distant future.

Real-time carbon accounting holds little attraction for either the seller or the buyer of credits. The seller does not want the risk of a large carbon debit at harvest, especially given the possibility of rising carbon values as international requirements become more stringent. The prospect of a perpetual reporting obligation is also a cause for concern to forest growers. The buyer wants to purchase a known amount of carbon credits, to correspond with a known amount of emissions, or at least to restrict contractual commitments with forest growers to a fixed term.

2.2 Tonne-year accounting

A novel approach, "tonne-year accounting", has been developed to make it easier to trade carbon at the project level (Chomitz 1998; Dobes *et al.* 1998; Enting 1998; Fearnside 1995; Fearnside *et al.* in press; Greenhouse Challenge Office 1997; Moura-Costa 1996; Moura-Costa and Wilson in press; Tipper and de Jong 1998). Tonne-years combines the quantity of carbon sequestered in a project with the longevity of the project. It was originally proposed as an effective way to prevent deforestation: it rewards those who preserve forests in proportion to both the amount of carbon held and the duration for which they held it. The same principle has been applied to afforestation.

At first glance, it may seem that a person who has planted a crop of trees only to fell them later has provided no greenhouse benefit from the activity. At the end of the rotation, the carbon has been returned to the atmosphere and there is no net change. But this ignores the fact that, for a full rotation, the carbon has been held in the form of vegetation and has not been causing global warming. Some benefit has been provided. If a large number of such people were to be considered in the aggregate, and if their plantings were staggered so that stands were not being felled in the same year, then there is no doubt that the encouragement of afforestation—even if each individual stand is a temporary phenomenon—would result in a decreased quantity of atmospheric carbon at any particular accounting date.

Another argument is the possibility that mitigation of greenhouse gas emissions by afforestation could be easily reversed (by fires, pests, lax management, etc). A deferred payment rewards those who have demonstrated that they have not only increased carbon stocks but managed to maintain those stocks. The longer the persistence of the stocks, the more the credit, up to a maximum amount.

Stocks-based accounting is appropriate only for CO_2 , which comprises the vast bulk of anthropogenic emissions, but the Kyoto Protocol refers to a basket of six greenhouse gases. Changes in CH_4 and N_2O emissions cannot be monitored by tracking their stocks in the biosphere. Their emission depends largely on variables other than the stocks of carbon and nitrogen in the system. It is sometimes argued that tonne-years is an appropriate way to treat such gases, and all gases should be treated the same way.

Lastly, there is the matter of the "natural sink". It is not necessary to provide a perfect balance of sources and sinks from human activity, it is stated by some commentators, because there are natural sinks, including forests and the ocean. It is sufficient merely to remove carbon from the atmosphere for a time equivalent to that which would allow those sinks to restore atmospheric concentrations to their former level. Put another way, equivalence parameters are based on the length of time that CO_2 must be retained in biomass for it to prevent the cumulative radiative forcing effect exerted by a similar amount of CO_2 during its residence the atmosphere. Calculations based on this premise, in the IPCC Special Report (Watson et al. 2000), suggest that between 42 and 150 tonne-years are equivalent to one tonne of emission reductions. For example, if an equivalence factor of 50 is assumed, to counteract an emission of 1tC it would take 50tC to be sequestered in one year, or 1tC sequestered and maintained in the biosphere for 50 years. In either case, there would be no penalty for release of the biospheric carbon after the specified time period.

Several objections can be made to the tonne-year approach:

2.2.1 The use of a reservoir to counteract a source.

What size dam is needed to absorb the flow from a river? No dam is sufficiently large. Reservoirs cannot counteract sources. The effect of a source can only be counteracted only by a sink. If one side of the "equation" is measured in tonnes/year (the river) and the other in tonne-years (the dam), there can never be a direct comparison. The act of filling the dam is a sink, but once the dam is full it makes no difference how long the water is retained.

2.2.2 The dubious reliability of the natural sink.

A comparison of fossil fuel emissions and atmospheric carbon concentrations seems to indicate that there is a "missing natural sink" in Northern hemisphere forests. Of the 6.2 Gt of carbon released by fossil fuel combustion during the decade 1988-1997, some 3.3 Gt remained in the atmosphere and 2.3 Gt was transferred to the oceans. The remainder (0.7 Gt carbon per year) is believed to flow into terrestrial ecosystems (Watson *et al.* 2000). The error limits for this sink are ± 1.0 Gt, however, so that it may not actually exist. Assuming that the sink is real, its mechanisms are far from clear. How long can it function before it becomes carbon-saturated? Indeed, may it not turn around and become a source? One estimate from the Hadley Centre (White et al. 1998) is that, as a result of increased temperatures and reduced rainfall in Brazil, global vegetation may switch rapidly from being a sink to a source towards the middle of the twenty-first century.

As another example of this concern, let us assume that the missing sink is the result of the expansion of forests in northern temperate latitudes during the last few decades (e.g., Kauppi *et al.* 1992). There is a limit to their areal spread, before they start encroaching on other land uses. There is also a limit to their growing stock (biomass per hectare). Trees cannot grow past a maximum height or basal area. Forest litter must also reach a maximum sustainable level. Carbon dioxide fertilisation could well result in an elevation of previous growth rates, but other factors must eventually become limiting. In any case, increased growth from any type of fertilisation does not necessarily imply higher levels of growing stock.

One simple explanation for a temperate forest sink could be the age-class distribution of the estate. If the estate comprises a high proportion of younger age-classes, then growing stock would be expanding and there would be a powerful sink. As the younger stands reach maturity, however, and are harvested or else become senescent, then this sink will disappear and may well turn into a source (Maclaren *et al*. 1996). Forest estate modelling is an arcane art, and even trained foresters are not always conversant with it, so this commonplace explanation for forest growth is often overlooked in favour of unproven effects, such as carbon dioxide fertilisation, climate driven effects, or acid deposition.

Given the uncertainty surrounding the duration of the “natural sink”, it seems unwise to factor it into calculations that create an equivalence for tonne-years (carbon sequestered) and tonnes/year (carbon emissions reduced).

2.2.3 The expropriation of the natural sink.

Even if there exists a natural sink, and even if it is believed that this sink will continue in perpetuity, there remains the question of how the “credits” from this sink should be allocated? Are they the property of the entire human race, to be divided equitably, or can they be appropriated by any agency that sequesters carbon? Although this is a political, rather than a scientific question, it needs to be pointed out that, in equating a finite term of sequestration with an infinite term of emission reductions, the proponents of tonne-year accounting are attributing the benefits of the natural sink solely to those who sequester carbon. The benefits could equally well be allocated to other parties.

Another viewpoint is that the extraction of carbon from the air decreases the size of the natural sink, as this is a function of atmospheric carbon concentrations. The “decay curve” for an emission has an exact counterpart in the declining usefulness of a sink. With this argument, the “equivalence time” for a sink (i.e., the time for the sink to counteract the radiative forcing of a source) is exactly the same as the arbitrary figure used for calculating GWPs (Global Warming Potentials). Thus if 100 years has been used as the time beyond which no radiative forcing is considered, then a sink must be maintained for 100 years to counteract a source of the same magnitude.

2.2.4 Tonne-years as a way of avoiding commitments.

Trading in “tonne-years” says nothing about the longevity of the carbon sink. One tonne sequestered for 50 years is equivalent to 50 tonnes sequestered for one year. Let us suppose an annual woody crop is grown that is capable of fixing 50 tonnes of carbon in a year, and 50 tonne-years is assumed to be equivalent to one tonne of emission reductions. The grower harvests and replants this crop every year. Does this imply that the grower can emit one tonne of carbon from fossil-fuel combustion in perpetuity, at no penalty? If this is the case, it reduces the rationale for restricting sinks to woody crops. Why not annual crops of grain? The accounting costs of including all such biomass production would overwhelm the capacity of most countries, but would have little effect on atmospheric carbon concentrations.

To avoid this difficulty, it has been suggested that a rider needs to be attached, stipulating a maximum value of credits that can be claimed from any specific piece of land. Yet to circumvent this rider, a forest owner would need only to fell the crop every year and to replant in a different area. Eventually, all plantable land would have used up its allowable carbon credits and this loophole would be closed. The land would be restored to pasture, the carbon would be restored to the atmosphere, but many land-owners would be wealthier having received credits.

2.2.5 The long term consequences of tonne-year accounting.

If sequestration of one tonne of carbon for (say) 50 years is equivalent to one tonne of emission reductions, then after 50 years sequestration is better than emission reductions. Is it rational to consider that sequestered carbon could ever be better than emission reductions? Also, a country need only accumulate a Kyoto Forest with carbon stocks fifty times its annual emissions to enable it continue business as usual. New Zealand, for example, is in a position to be able to do this.

2.2.6 Tonne-years as a disincentive to reforestation.

It is suggested that tonne-year accounting is accompanied by a similar payment schedule. Due to the lower 'credit value' of sequestered carbon relative to avoided emissions, re/afforestation projects would not be as attractive as emission avoidance. Some proponents support tonne-years for this very reason, but given that enhancement of sinks and reduction of sources have the same effect on atmospheric carbon concentrations, this could be seen as inequitable.

2.2.7 The practical difficulty of estimating tonne-years

For tonne-years to work, we need an exact profile of the standing carbon in a forest from the beginning to the end of an accounting period, with error limits. This presupposes accurate and verifiable models. It would be a lot easier just to undertake inventories at two points in time and subtract the difference. In the latter case, it is not necessary to know the events in the intervening period.

2.2.8 Tonne-years is not compatible with the Kyoto Protocol

The Kyoto Protocol (Article 3.3) states that afforestation, reforestation and deforestation should be "measured as verifiable changes in stocks in each commitment period". For example, if a country (or, presumably, an individual or company) holds 1 Mt carbon in the form of "Kyoto forest" on 1 January 2008, and two Mt carbon on 31 December 2012, then they are presumably entitled to 1 Mt carbon in credits. On the other hand, if they have merely retained the 1 Mt carbon, and not increased it, then they are not eligible for any credits. The tonne-years approach, depending on how it is interpreted, might enable them to claim credit for maintaining a static level of carbon stocks in the form of vegetation.

Some proponents of the tonne-year approach argue that carbon sinks be measured in terms of stock changes, as specified by the Kyoto Protocol, but the credit for those sinks be deferred, so that only a small percentage (0.7% has been suggested) is allowed in any year. Allowable credits continue for as long as the stocks persist, up to a total of 100 years, thus providing some guarantee of permanence to the stock changes.

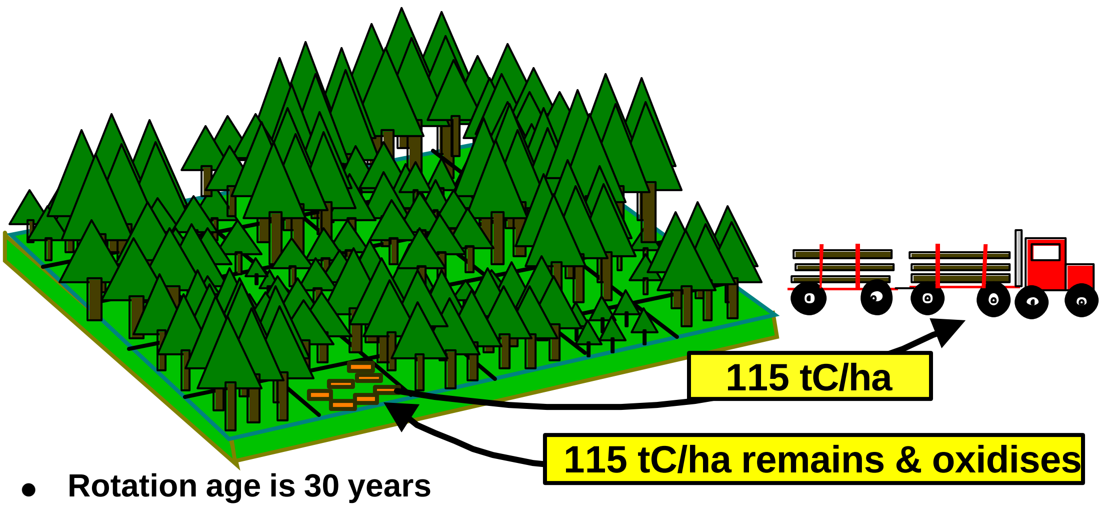
The separation of carbon accounting from provision of credits, creates several problems. One is that symmetrical accounting should be required for debits. Suppose there is a loss in carbon stocks during a commitment period, could the debits for this be deferred over the same period as for credits? If so, this is equivalent to borrowing emission allowances from the future. Also, it is inequitable with respect to payment of debits for stock changes in fossil fuels.

2.3 Carbon density accounting

The benefit to the atmosphere, however, lies in the initial decision to convert the land use from pasture—which has a low carbon density—to forest with a higher long term average carbon density. Just as deforestation implies a one-off movement of carbon from vegetation to the atmosphere, so afforestation is the reverse.

A landscape of stands planted on a staggered basis would result in a more uniform level of carbon stocks. At the extreme, a forest with an even age-class distribution often called a *normal* forest (Ford-Robertson 1971), would retain a constant quantity of carbon (Figure 2). Carbon removed in harvested stands would exactly equal the carbon absorption by all other stands. If the accountant was allowed to budget at the landscape, rather than the stand level, transaction costs of real-time accounting could be greatly reduced. Avoiding annual assessments of carbon stocks in favour of 5- or 10-yearly assessments could also reduce costs.

First, let us consider an area of natural forest comprising several hundred tonnes of carbon per hectare in the form of biomass. A farmer clearfells, burns, and de-stumps the land, and establishes pasture. Following this period of deforestation, levels of biomass carbon are very low. There has been a one-off change in carbon density (tonnes of carbon per hectare) and a one-off movement of carbon from the earth's surface to the atmosphere. The activity of this farmer is very similar in its effect on carbon balances, to releasing carbon into the air from burning coal. The fact that one pool of carbon was above-ground, and one below-ground, makes no difference to atmospheric carbon budgets. A rational international agreement designed to reduce carbon emissions should penalise both activities to the same extent.



- **Rotation age is 30 years**
- **Contains 30 stands, one of each age-class**
- **Averages 110 tonnes/ha more carbon than when was in pasture**
- **Amount of carbon fixed by the forest equals (amount removed by truck) + (amount oxidised in forest)**
- **Forest is a reservoir. but not a sink.**

Figure 2:A steady-state "normal" forest

Now let us suppose that—years later— a new owner takes possession of that same area of pasture and wishes to restore the forest cover. Trees are planted, and take time to achieve the level of carbon stocks that existed prior to the original forest clearance, but eventually the same quantity of carbon has been extracted from the air. The effect on the atmosphere has been equal and opposite to deforestation, and credits should also be equal and opposite. Quantification of the credits can be provided by standard forest inventories, albeit customised to assess total oven-dry biomass rather than stemwood volumes.

2.3.1 Calculation of credits payable

In order to assess the credits allowable to a forester, a biomass inventory would be conducted at both the start and the finish of the period in question. This is consistent with "stocks based" approach of the Kyoto Protocol. The difference between the two inventories is the credit. In order to ensure that the stock changes can be verified, credits must be issued *after* the changes have taken place. That is not to say that companies cannot negotiate to buy credits in advance of their physical reality, in the same way that other commodities are sold on "futures" markets.

One critical factor is that credits must *not* be given for stocks that exceed the long-term average of the stand (Fig. 3). If this is allowed to occur, then debits must be paid at harvest and the transaction costs and the other difficulties of real-time accounting (see above) have not been avoided. Payment of the credits must include a contractual agreement to manage a forest in such a way that it maintains the long-term average carbon density at a level agreed upon when the credits were issued.

Payment for credits can parallel the real growth of the stand (blue line in Fig. 3) up to the long-term sustainable level (asymptote of red line in Fig. 3). It may help to think of any temporary excess of carbon above this level as being notionally "banked" and then used to compensate for future periods where levels are below the long-term level.

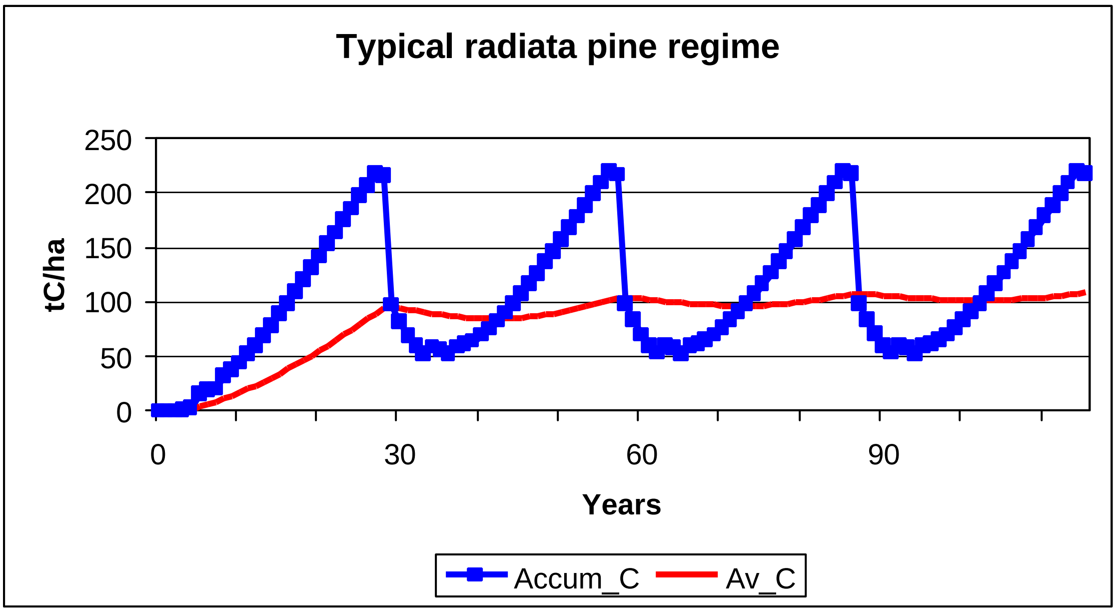


Figure 3:The long-term average carbon-density of a stand

2.3.2 Uncertainties associated with stocks-based accounting

A common difficulty in science is the estimation of small differences between two large numbers. For example, let us suppose that a country (or project) was estimated to possess 100 Mt of “Kyoto carbon” at the beginning of a commitment period, and 110 Mt at the end of the end of the period. In view of the large errors in the values of the stocks, how much reliance can be placed on the 10 Mt difference?

To overcome this problem it is essential to use identical techniques for each assessment. A useful analogy is a set of scales that is precise, but not accurate. The scales are biased in that they consistently record weights that are too high (or too low). Despite the bias, such scales can be used to observe subtle differences in weight changes. The error is almost the same as for each weighing separately. Major difficulties arise only if different scales are used for each measurement. Unfortunately, over a 5-year interval in forest inventory, there is likely to be a change in the quality of data and methods, and there may be complications arising from the changing characteristics of the forest estate. In other words, the techniques for carbon assessment are likely to change, analogous to switching from one inaccurate set of scales to another.

Another problem is that it is patently unfeasible to assess carbon stocks over a large area on the exact dates of 1 January 2008 or 31 December 2012. Data must be collected over a protracted period and must be standardised by modelling of some sort. Inventory techniques are essential to ensure that stock changes are transparent and verifiable (Article 3.3), but are by themselves insufficient.

2.3.3 Permanence of the carbon reservoir

It is often stated that once credits have been received by a forester, the carbon must continue to be retained as biomass in perpetuity. This may require new legislation in many countries. Some sort of legal device, such as a mortgage or easement, which is recorded against the title deed, would guarantee permanence. If a future holder of the carbon credit (which may be the Inland Revenue Department of some country) discovers that their certificate no longer corresponds to carbon held on a particular title, they would be able to claim recompense: equivalent credits from elsewhere or else the land itself in compensation. It may soon be possible to check, from satellite imagery on the internet, if any particular location is in forest cover or if it has been converted to a low carbon-density land use.

Many land owners are wary of locking up their land ‘in perpetuity’. An alternative perspective might be that if the land owner wants to deforest, for whatever reason, he must inform the national registry administrator. Similarly a change in management might affect the long-term average carbon stocks. In such cases appropriate action can be taken eg to buy an equivalent amount of credits on the open market, or to invest in other sinks.

In either approach there will need to be an effective auditing scheme conducted by an independent agency. This could take the form of regular remote sensing, combined with random ground-based monitoring of stocks and land owner intentions.

3. SUMMARY —IMPLICATIONS OF CARBON TRADING IN FOREST SINKS

In order to compensate fully for human-induced emissions, there would need to be the equivalent quantity of human-induced sinks. Ongoing combustion of fossil fuels requires an ongoing contribution of sinks. As forests[1] are sinks only in their establishment phase, there would need to be an ongoing program of afforestation. Obviously, this cannot continue in perpetuity, as the global plantable area is limited. Even if 500 million hectares of land were afforested worldwide, and resulted in a one-off increase in carbon-density of 100 tonnes/ha, this amounts to only 50 Gt C. The IPCC Second Assessment Report examined scenarios of carbon accumulation from 1991-2100 of 630-1410 Gt C, so it can be seen that the contribution of afforestation to the overall scheme of things is very small. Forest sinks are a popular topic in the current decade because they are seen as being a relatively low-cost first step.

Nevertheless, active trading in carbon credits would stimulate the planting of large areas of the world in forests. While this might saturate the world with wood, and thereby reduce timber prices, it may presage the way to an global economy based, in part, on bioenergy. Bio-fuels from sustainably harvested forests represent the current energy income of the planet (i.e., sunlight), just as fossil fuels represent the accumulated capital. It is unsustainable to live off one's capital, rather than one's income.

The long-term benefit of trading in carbon sinks, therefore, may be to stimulate planting and thereby permit the formation of a sustainable biomass resource. The current rationale for such trading—sequestration of carbon—is likely to prove ephemeral. Nevertheless, if carbon trading is going to occur, it must be on a rational and cost-effective basis. Real-time accounting is not cost-effective; tonne-year accounting is conceptually flawed; only accounting based on "permanent" and one-off changes in carbon-density meet the criteria, but even with this method the practical difficulties of measurement, calculation and record-keeping may prove to be beyond the scientific and administrative capabilities of many countries.

4. REFERENCES

Beets, P. N.; Robertson, K.A.; Ford-Robertson, J.B.; Gordon, J.; Maclaren, J.P., 1999. Description and validation of C_Change: A Model for Simulating Carbon content in Managed Radiata Pine Stands. New Zealand Journal of Forestry Science 29(3): 409-427.

Dobes, L; Enting, I.G.; Mitchell, C.; 1998. Accounting for carbon for carbon sinks: the problem of time. Chapter 13 in Dobes, L. (Ed.), Trading greenhouse emissions: some Australian perspectives. Occasional papers No 115, Bureau of Transport Economics, Dept of Transport (Australian Government), Canberra.

Chomitz, K.M., 1998. The performance and duration issue in carbon offsets based on sequestration. World Bank Development Research Group: 20.

1

Enting, I.G., 1998. Report on quantitative relationship between global warming potentials and carbon sequestered in vegetation. Report for Greenhouse Challenge Office, June 1998. CSIRO Atmospheric Research.

Fearnside, P., 1995. Global warming response options in Brazil's forest sector: a comparison of project-level costs and benefits. Biomass and Bioenergy 8: 309-322.

Fearnside, P.M.; Lashoff, D.A.; Moura-Costa, P.H., in press. Accounting for time in mitigating global warming.

Ford-Robertson, F.C. (Ed.), 1971. Terminology of forest science, technology practice and products. The multilingual forestry terminology series No 1. 1971. Society of American Foresters, Washington D.C.. Pp 349.

Greenhouse Challenge Office, 1997. Greenhouse Challenge Carbon Sinks Workbook: a Discussion Paper. Greenhouse Challenge Office, Canberra.

Kauppi, P.E.; Mielikäinen, K.; Kuusela, K., 1992. Biomass and carbon budget of European forests, 1971 to 1990. Science 256, 3 April 1992.

Maclaren, J.P., 1996. Environmental effects of planted forests in New Zealand. FRI Bulletin 198. NZ Forest Research Institute, Rotorua, New Zealand. 180 p.

Maclaren, J.P.; Wakelin, S.J.; Te Morenga, L., 1996. Plantation forestry in New Zealand; Concepts, methodologies and recent calculations. In Greenhouse Abatement Measures: No Regrets Action Now. Proc. Of 1995 Invitation Symposium, Australian Academy of Technological Science and Engineering.

Matthews, G., 1993. The carbon content of trees. Forestry Commission, Technical Paper 4. Forestry Commission, Edinburgh. 21 p.

Moura-Costa, P.H. 1996. Tropical forestry practices for carbon sequestration. In: Schulte, A. and Schone, D. (Eds.) Dipterocarp Forest Ecosystems—towards sustainable management. World Scientific, Singapore. Pp. 308-334.

Moura-Costa, P.H. and Wilson, C., in press. An equivalence factor between CO_2 avoided emissions and sequestration—description and applications in forestry. In Brown, S., Mitigation and Adaptation Strategies for Global Change. Kluwer Academic Publishers.

Tipper, R. and de Jong, B.H., 1998. Quantification and regulation of carbon offsets from forestry: comparison of alternative methodologies, with special reference to Chiapas, Mexico. Commonwealth Forestry Review 77: 219-228.

Watson, R.T.; Noble, I.R.; Bolin, B.; Ravindranath, N.H.; Verardo, D.J. and Dokken, D.J. 2000. Land Use, Land-Use Change, and Forestry. A Special Report of the IPCC. Cambridge University Press.

White, A.; Friend, A.; Cannell, M., 1998. Impacts of climate change on natural vegetation. In: Hadley Centre, Climate Change and its Impacts, Bracknell, UK Meteorological Office, November 1998.