2. Carbon Pools and Forestry Projects

2.1. Carbon Pools

Forest ecosystems can be compartmentalized into three main carbon pools: live biomass, detritus and soils (Fig. 3) (Apps and Price 1996). The exchanges of carbon among these pools and between them and the atmosphere form the basis of the forest carbon cycle. This type of typology is useful for monitoring and evaluation purposes because forestry projects have different carbon stocks: some store carbon in standing natural forest or new vegetation grown in the project (biomass), some of which may end up as detritus or in the soil (soil and peat); some accumulate carbon in harvested products (products) that enter long-term storage, some of which may end up in landfills; and some biomass energy farms and plantations and natural vegetation and wood waste store additional net carbon in unburned fossil fuel by preventing carbon emissions from fossil fuel use and wood grown unsustainably. The use of fossil energy in management, harvesting and wood processing results in the release of additional carbon from the fossil fuel pool. The carbon dynamics of the products, landfills, and fossil fuel pools are determined largely by socioeconomic and technological factors (the right side of the figure), as distinguished from the forest ecosystem (the left side of the figure).

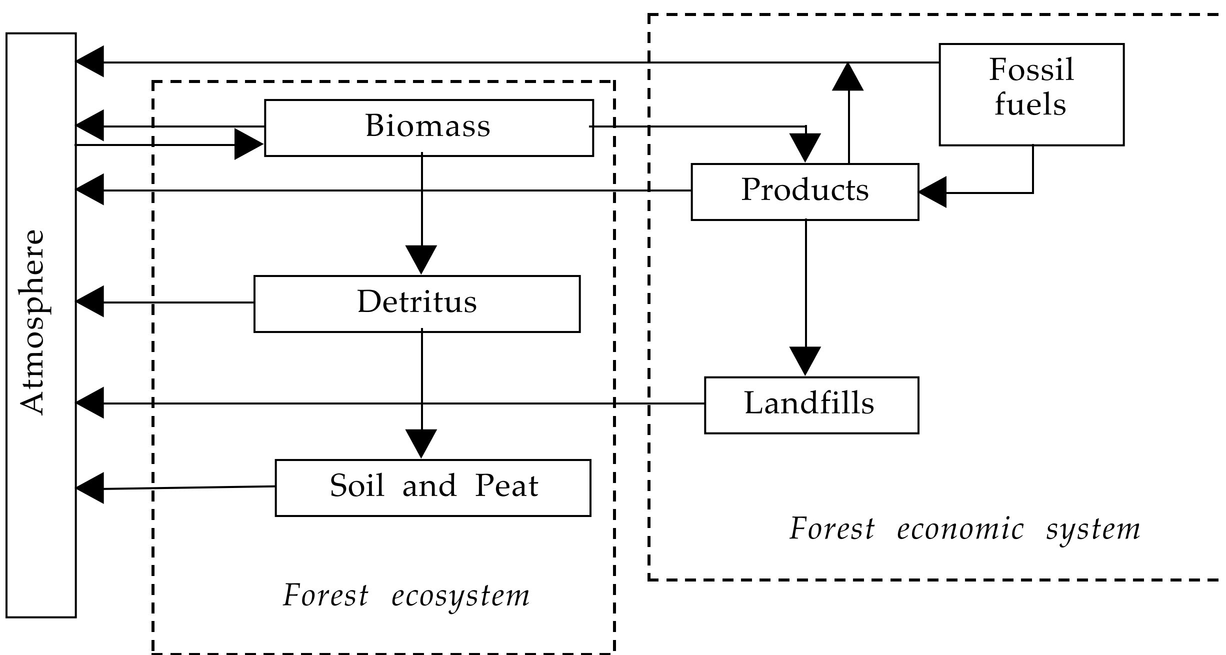

Figure 3. Forest System Carbon Cycle

Source: Apps and Price (1996)

The relative size of the carbon pools, and potential changes in the carbon pools from forestry projects, will determine the type of monitoring and evaluation that will be needed for a specific project. If the carbon pools are small, or if the potential changes to the carbon pool from a project are minor, then less resources will be needed for MERVC activities. Thus, one of the key monitoring and evaluation issues is determining which of the carbon pools are significant. The significance of a carbon pool may be defined by its relative size:

> "For example, in a forest preservation project, the carbon stored in trees may represent 70-80% of the total carbon stored on site, and consequently is a relatively significant pool. Leaf litter may contain as little as 1% of the carbon contained in the trees and, therefore, does not represent a significant pool in terms of relative size. Changes in pools that are directly attributed to project activities should be the focus of the monitoring program, but changes in all pools need to be evaluated for their relative significance to the project's carbon balance." (EcoSecurities 1998)

In addition to relative size, we believe it is useful to rank the carbon pools according to their vulnerability (rate of change) and direction of change (positive or negative). Pools that are relatively large and that are likely to change rapidly are very important to monitor. Pools that are relatively small and unlikely to change are not so important to monitor. A monitoring and evaluation program should adopt a conservative approach when deciding upon which pools to monitor and evaluate. Only pools that are monitored and evaluated should be considered in the calculation of GHG impacts. Some small pools may not justify the expense required to acquire reasonably reliable estimates of carbon contents (e.g., fine roots or fine litter); default values for carbon storage may be used in these cases (IPCC 1996; World Bank 1997). Nevertheless, it is important to ensure that the remaining pools are not depleted due to the activities being pursued. To avoid inaccurate accounting, it is important to conduct some evaluation to report on the increase and depletion of carbon stocks, or at a minimum, to demonstrate that carbon is not lost from pools for which no improvement is being made (UNFCCC 1998a).

2.2. Forestry Projects

The forestry sector affects a broad range of potential GHG sources, emissions reduction activities, and carbon sequestration activities. There are basically three categories of forest management practices that can be employed to curb the rate of increase in carbon dioxide in the atmosphere (Brown et al. 1996; Watson et al. 1996). These categories are: (1) management for carbon conservation, (2) management for carbon sequestration and storage, and (3) management for carbon substitution (Table 1).

Table 1. Types of Forestry Projects

Carbon conservation management	**Carbon sequestration and storage management**
Forest reserves /reduced deforestation	Afforestation
Modified forest management	Reforestation
Reduced degradation (e.g., from fires and pests)	Urban forestry
Carbon substitution management	Agroforestry
Biomass for energy generation	Natural regeneration
Substitution for fossil-fuel based products	Biomass enrichment
	Forest product management

Source: Adapted from Watson et al. (1996)

The goal of carbon conservation management is primarily to conserve existing carbon pools in forests as much as possible through options such as controlling deforestation, protecting forests (forest preservation), modified forest management (e.g., reduced impact logging, hardwood control, sound silvicultural practices, firewood harvests, more efficient use of wood, and fertilization), and controlling other anthropogenic disturbances such as fire and pest outbreaks ("reduced degradation").

The goal of carbon sequestration and storage management is to expand the storage of carbon in forest ecosystems by increasing the area or carbon density of natural and plantation forests and increasing storage in durable wood products. Thus, this includes afforestation (i.e., the planting of trees in areas absent of trees in recent times), reforestation (i.e., the planting of trees where trees had recently been before, but currently are absent), urban forestry (i.e., the planting of trees in urban or suburban settings), and agroforestry (i.e., planting and managing trees in conjunction with agricultural crops). Other activities include natural regeneration, biomass enrichment, and forest product management.

Finally, carbon substitution management aims at increasing the transfer of forest biomass carbon into products (e.g., construction materials and biofuels) that can replace fossil-fuel-based energy and products, cement-based products, and other building materials. This type of management includes short-rotation woody biomass energy plantations (Section 2.3).

2.3. Biomass Energy Plantations

The conventional view of forest management assumes that initial forest establishment is followed by a relatively extensive period of growth (and carbon accumulation). With short-rotation forests for bioenergy, harvesting occurs approximately every 5-12 years, and regeneration is accomplished through replanting or coppicing (USDOE 1994). Longer rotation plantations and natural forests can also be used for producing biomass for power generation (Carpentieri et al. 1993; Hall 1997; McLain 1998; Perlack et al. 1991; Russell et al. 1992; Swisher 1994; Swisher and Renner 1996). Thus, the cultivation of bioenergy resources, such as short-rotation forestry, can mitigate climate change, not only by replacing fossil fuels in the energy system, but also by storing additional terrestrial carbon in trees. Furthermore, to the extent that harvests are sustainable, the biomass fuel supplied from the same land can continue to prevent carbon emissions indefinitely in the future.

In the analysis of these projects, associated carbon sequestration in soils, detritus and growing vegetation has to be accounted (Swisher 1992). The carbon capture resulting from woody biomass plantations can be analyzed in conventional forestry sector terms (Sathaye and Meyers 1995). Analysis of these projects also depends upon information regarding how energy would have been supplied in the absence of the project (McLain 1998; Swisher and Renner 1996). The release of carbon from the combustion of biomass fuel and the displacement of emissions from fossil fuels relates more closely to activities in the energy supply sector. Thus, the monitoring and evaluation of the impacts of biomass energy projects will rely on the methods described in this report as well as methods used in monitoring and evaluating energy-efficiency projects (Vine and Sathaye 1999). The MERVC of the two components of biomass projects is important because the use of biomass on a renewable basis as a substitute for fossil fuels typically yields greater GHG abatement benefits than sequestration alone (World Bank 1994a).

2.4. Unique Features of Carbon Pools and Forestry Projects

Several unique features of carbon pools and forestry projects make the MERVC of forestry projects challenging. First, temporal changes in the carbon pools of forested ecosystems are driven mainly by the dynamics of the living biomass: accumulations of organic carbon in litter and soil reservoirs change significantly as forest stands develop or decay, and whenever disturbances to the ecosystem occur (Apps and Price 1996). Some of these changes do occur relatively more quickly in some carbon pools than others (see Section 4.1.2). Keeping track of ecosystem processes is a necessary part of forest carbon assessment.

Second, although carbon storage in forest products typically represents a very small fraction of the total forest stores, these products can play an important role in the net forest-atmosphere exchange over the short term by delaying the return of photosynthetically fixed carbon to the atmosphere (Apps and Price 1996). Of the carbon that reaches wood products, some remains only for a short time (1-5 years), but a significant amount remains stored in the wood products for long periods (on the order of decades) before returning to the atmosphere (Winjum et al. 1998; USDOE 1994).

Third, the monitoring domain (see Section 3.1.1) of the carbon pool will be different, depending on the carbon pool: e.g., a larger monitoring domain is needed for tracking the fate of wood products. Fourth, the fate of some of these products is difficult to track and, therefore, adds to the level of uncertainty in impact measurement. The most conservative approach is to treat carbon destined for wood products as if it is released immediately after the harvest (IPCC 1996; USDOE 1994). Fifth, forestry activities can have a wide range of effects: e.g., reforestation may increase fertilizer use in forests, which can increase nitrous oxide emissions, and fossil fuel use in harvesting and transporting timber. And sixth, forestry activities may have indirect impacts on GHG emissions (e.g., urban tree planting can decrease the extent and severity of urban heat islands (Rosenfeld et al. 1998), potentially reducing the consumption of electricity to cool buildings, thereby reducing GHG emissions).