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# THE SEARCH FOR CARBON SINKS IN THE TROPICS

Ariel E. Lugo
Institute of Tropical Forestry
USDA Forest Service
Southern Forest Experiment Station
Call Box 25000
Rio Piedras, P.R. 00928-2500 USA

ABSTRACT. The study and modeling of the global C cycle have been dominated by the assumption that the atmosphere and the biota were in C steady state prior to the industrial revolution. This view led to the perception that most of the terrestrial biota was neutral with regards to the C concentration of the atmosphere. Recent evidence suggests that neither the atmosphere nor the biota were in C steady state prior to, or since, the industrial revolution. Therefore, it is now necessary to re-visit the role of natural processes in the global C cycle, study the C cycle in its totality, and focus attention on the magnitude of potential C sinks in ecosystems previously thought to be neutral with respect to atmospheric C.

"An improved understanding of the $CO_2$ cycle is essential to predict the future rate of any atmospheric $CO_2$ increase and to plan eventually for an international $CO_2$ management strategy" Tans et al. (1990).

## 1. Introduction

Most of the recent scientific activity concerning the global C cycle has focused on the anthropological sources of $CO_2$ (Melillo et al., 1990; Watson et al., 1990). Concern with the sources of atmospheric C is based on the fact that human activities such as burning of fossil fuels, put in circulation about 6 Pg $yr^{-1}$ of which 3.4 Pg $yr^{-1}$ accumulates in the atmosphere. This rate of C accumulation is sufficient to eventually cause global warming and other environmental changes (Houghton et al., 1990). While many of the future consequences of increased atmospheric $CO_2$ concentration are hard to predict, no one can argue the fact that people have changed the gaseous composition of the atmosphere (Watson et al., 1990).

Intensive study of atmospheric C sources has not led to a comprehensive understanding of the global C cycle. In fact, scientists are still unable to balance the global C budget. For example, the ocean and terrestrial biota must sequester the difference between the accumulation of C in the atmosphere (3.4 Pg $yr^{-1}$) and the C produced by the combustion of fossil fuels (6 Pg $yr^{-1}$). Models suggest a C uptake by oceans of about 1.6 Pg $yr^{-1}$ which means that about 1.0 Pg $yr^{-1}$ must be sequestered in the terrestrial biota. However, models of the C flux in terrestrial systems suggest they are a **net source** of C to the atmosphere of an additional 0.3 to 2.5 Pg $yr^{-1}$ (Houghton et al., 1990;

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Tans et al., 1990). This causes an imbalance in the C budget and explains the euphemism of the "missing carbon" or that fraction of the anthropologically produced C that cannot be accounted for in C budgets.

The time has come to focus substantial scientific attention on the identification and quantification of global C sinks. Moreover, all aspects of the C cycle require study to balance the global C budget. I will review some of the historical obstacles to progress in the understanding of the terrestrial aspects of the global C cycle with emphasis on tropical forests (c.f., Lugo and Brown, 1980).

## 2. Identification of Carbon Sinks in Tropical Forests

### 2.1 CONCEPTUAL ISSUES

The perception that the only C fluxes deserving study are those that have "changed drastically in recent times" (Houghton et al., 1983) underscores most of the research effort since the 1970's when the Carbon Dioxide Program of the U.S. Department of Energy began to support research in the C cycle. The concept that has guided this important research program is that the global C cycle has been modified by human activity, particularly since the industrial revolution (about 1860). Before this time, it was assumed that the world was in C steady state and the atmosphere maintained homeostasis of its gaseous composition because the inputs of the various gases were balanced by their respective outputs. Scientists reasoned that to facilitate the analysis of the problem, it was best to ignore all C fluxes and storages that had not changed since 1860, no matter how large they were. This decision basically limited the study of C to a small fraction of its global cycle because it considered only changes in land use (Detwiler and Hall, 1988; Houghton et al., 1983; Post et al., 1990).

Moreover, if the world was in steady state, it was possible to divide any C pool by its estimated age to obtain its annual flux and thus an idea of its potential importance. For example, Woodwell et al. (1983) divided the C storage in soil, muskeg, and forests of the boreal and tundra zones by the elapsed time since the retreat of the ice some 5,000 to 15,000 yr ago, to estimate the annual C flux of this part of the world. They concluded that this region was not relevant as a C sink because it was such a small flux that it could be assumed to be at steady state.

Calculations such as the one by Woodwell et al. (1983) ignored two alternative considerations. (1) If the systems were not in steady state, what appeared to be a small sink could in fact have been a very large one if the C accumulated in a shorter time interval that was assumed, and (2) many small C sinks can add up to a single large one. For example, Brown et al. (1986) found that tropical tree plantations constituted a small sink of C (0.1 Pg $yr^{-1}$ or similar to the upper level of the estimate of Woodwell et al. [1983] for the boreal and tundra region) which nevertheless was sufficient to offset the C source associated with deforestation rate in the temperate zone. In fact, should tropical forests not be in C steady state, it would only take a small C sink of 20 to 30 g C $m^{-2}$ $yr^{-1}$ to add up to 1 Pg $yr^{-1}$, or the same order of magnitude of the missing C (Lugo and Brown, 1986)

The hypotheses that guided the early analysis of the global C cycle have been identified by Lugo and Brown (1992) as the steady state atmosphere (SSA) and the steady state forest (SSF) assumptions. Steady state assumptions are very convenient because they simplify modeling and reduce the need for data, as large sectors of the C budget can be declared neutral in terms of their effect on the atmospheric $CO_2$ concentration.

When ice core and tree ring data were used to develop time series of $CO_2$ concentration in past atmospheres (Oeschger and Stauffer, 1986; Barnola et al., 1987), they showed oscillations in atmospheric $CO_2$. Even before the onset of the industrial revolution, atmospheric $CO_2$ concentrations were increasing (Fraser et al., 1986). Therefore, even though the recent increase in atmospheric $CO_2$ concentration has been steeper than "normal" and due to human activity, it is nevertheless very difficult to identify a period of atmospheric $CO_2$ steady state, unless one recognizes an oscillating steady state. Moreover, for the terminology to be consistently applied, it would be necessary that the period of time used in the simulations of C flux be in synchrony with the period of time required to establish a C steady state. The implication of the history of oscillation of atmospheric CO2 to the study of the C cycle is that one cannot ignore any of the C fluxes and pools, particularly those associated with "natural" biotic processes. For unlike physico-chemical processes, biotic processes are dynamic, respond to change, and are able to adapt.

Regarding the SSF assumption, recent research and analysis have shown that tropical forests cannot be assumed to be in C steady state either (Lugo and Brown, 1986; Brown and Lugo, 1990a). Biomass and rates of biomass production for tropical forests have been changing constantly over time as a result of past disturbances by people and natural factors (Flint and Richards, 1991; Brown et al., 1991, 1992; Brown and Lugo, 1992). It is unrealistic to assume steady state in the C cycle of tropical forests.

## 2.2 RESEARCH ORIENTATION ISSUES

The constraints imposed by the SSA and SSF assumptions not only assure that C models based on land-use change and steady state assumptions will always predict net releases of C to the atmosphere (because the predominant human activity is generally associated with sources of C), but they have also influenced research orientation. Research activity has focused almost exclusively on terrestrial and deep water oceanic ecosystems, and ignored the coastal interface where C metabolism is very active. In the tropics, coastal wetlands, coral reefs, sea grass beds, coastal shelf, coastal waters, and estuaries have high rates of C cycling and high C accumulation but are usually ignored in global C budgets (Twilley, this volume). They too are assumed to be in C steady state and neutral with regards to the C cycle of the world.

Today, geographically referenced data have become the preferred strategy for modeling the global C cycle (Dale, 1992). This is an important technological advance which should help overcome the initial breakdown of the large tropical biome into two forest types (rain and seasonal forests). One reason for using geographic references to model the C cycle is the wide diversity of tropical forest life zones (33 forested tropical life zones vs 19 in the rest of the world; Lugo and Brown, 1991), and the fact that each appears to have its own unique biodiversity (Lugo and Brown, 1991) and set of C fluxes and stocks (Brown and Lugo, 1982). The initial simplification of life zone diversity retarded progress because it lumped too much variety into two or at most six categories (Detwiler, 1986). The fewer the number of categories, the less precise are the estimates of C flux, because the subtleties of C dynamics are averaged out without proper weighting. The recent report by the Intergovernmental Panel on Climate Change (IPCC) used a two biome concept to represent all tropical forests (Melillo et al., 1990).

Finally, the research focus on the C enrichment question took a "potted plant" approach and ignored the response of whole ecosystems to C enrichment (Melillo et al., 1990). Only now are experiments under way to study whole ecosystem response to C enrichment (even if in small microcosms; Drake, this volume), and almost a decade has been lost in a species by species approach to study plant photosynthesis without sufficient attention to heterotrophic respiration and C cycling bc_iits_1992_lug0002