Atmosphere, Carbon Flow and CO_2 Fertilization

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1. PURPOSE

The purpose of this article is to discuss problems involving high CO_2 concentrations in the atmosphere. Since this is a concern to the scientific community, we felt it would be useful to prepare a detailed paper on this complex issue. The subject might have been approached from several angles. However, we chose to provide a brief discussion of the function and significance of CO_2 in nature from the standpoint of its role and flow patterns in the atmosphere. The target of our research is more specifically associated to the role played by the Earth's biomass — tropical forests — in terms of the high concentrations of CO_2 (part 2 of the article, under item 6). Are tropical forests a depository for excess CO_2 in the atmosphere?

2. INTRODUCTION

Each year, approximately 10 Gt of carbon in the form of carbon dioxide (CO_2) and other gases are released into the atmosphere by human activities. Along the past 200 years, carbon dioxide concentrations increased by 27% as a result of fossil fuels burned since the start of the industrial era and of deforestation. Half this increase took place in the last 30 years alone. CO_2 in the atmosphere rose from 272 ppm in preindustrial days to 346 ppm in 1986 (HALL, 1989, p. 175).

The rising CO_2 content is a major concern to scientists because of its potential impact on climate. Climate changes would tip the planet's current environmental equilibrium. In fact, higher concentrations of carbon dioxide in the air may indeed harm the balance between oceans and the biosphere, which exchange carbon through the atmosphere. In normal concentrations, CO_2 is anything but harmful. It is rather a vital element for two important reasons: *plant metabolism and the global climate balance.*

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3. CO_2 IN THE ATMOSPHERE

The Earth was formed without a surrounding atmosphere. Contemporary theories assume that the planet was resulted from the slow accumulation of solid and cold particles of all sizes originating from solar debris and waste. The gases and water that now constitute our air and oceans were chemical compounds from the same original blend (DONN, 1978, p. 4).

In time, the heat released by radioactive processes and by the heavier elements settling toward the Earth's core raised the temperature of primitive Earth. The elements that shaped the primeval atmosphere and oceans were discharged from inside the Earth's crust and gradually built up until they became the water and air that surrounds our planet now. Before life first appeared there were only traces of molecular oxygen. The atmosphere was made up primarily of CO_2 and water vapor released by the massive volcanic activity. Only later, when the earliest green plants capable of photosynthesis appeared did free oxygen materialize (DONN, 1978, p. 4).

In the early phases of our Earth CO_2 concentrations in the atmosphere were extremely elevated, chiefly due to the intensity of volcanic eruptions. The amount of carbon dioxide began to decline when algae transformed it into limestone deposits. This process occurred in two different phases: first, when Protozoa and Foraminifera proliferated in limestone deposits over 600 million years ago; and second through the proliferation of Pteridophytes 350 million years ago. However, a hundred million years ago when dinosaurs roamed the Earth During the mid-Cretacean, the concentration of CO_2 was still high, roughly 10 times what it is today. As volcanoes subsided, CO_2 levels fell to approximately current levels (POSTEL, 1986, p.22). After this reduction, atmospheric CO_2 concentrations went through successive ups and downs. This phenomenon still has no explanation, but many scientists believe there is some connection with the alternating glacial and interglacial periods of the Pleistocene.

As indicated above, CO_2 concentration increased 27% during the past 200 years as a result of fossil fuel burning, deforestation, and changes in land use.

When fossil fuels burn, stored carbon is oxidized and released into the atmosphere as CO_2. This energy source accounts for approximately 75% of world's primary energy in the following ratios:

1. Oil — 32%
2. Charcoal — 26%
3. Gas — 17%

The balance of primary energy comes from:

4. Biomass — 14%
5. Hydro power — 6%
6. Nuclear fission 5%

Total global CO_2 emissions resulting from fossil fuel burning (including cement production) amounted to approximately 5.65 Gt in 1987. The United States is the main source of CO_2 released by fossil fuels, averaging 1.202 Gt in 1986 (HALL and CALLE, 1989, p. 517).

Tropical deforestation through slash-and-burning of biomass for agricultural purposes also contributes to elevation of CO_2 in the air. Forests contain 20 to 100 times more carbon per unit of area than crops or pastures. As they are felled, the carbon originally found in the tree cover and soil is released into the air in the form of CO_2. Only a relatively small portion goes back to the ground or into rivers.

Net global carbon release from 1860 to 1980 resulting from deforestation was somewhere between 135 and 228 Gt (WOODWELL et alii, 1983, p. 1082). Wilson suggests that in just three decades (1860 to 1890), 110 Gt were released into the atmosphere by the so-called pre-industrial farming practices (WILSON, 1978, p. 41). Some estimates indicate that the net global CO_2 emissions into the atmosphere due to changes in land use ranged between 1.0 and 2.6 Gt in 1980 (HOUSTON et alii, 1987, p. 128).

Marland and Boden (1989) figured an average of 1.8 Gt (between 0.8 and 2.6 Gt) almost entirely from the tropics (MARLAND and BODEN, 1989, quoted in HALL and CALLE, 1989, p. 521). These discrepancies are due to the uncertainty about the actual carbon stored in plants and soils, the size of different forest types, deforestation rates, and the use made of cleared lands.

4. CLIMATIC CHANGES AND CO_2

The transparent and thin atmosphere we know represents a balance of its component parts.

The nitrogen, oxygen, and argon molecules which make up most of our air are transparent to both infrared radiation and the visible solar spectrum. Its absorption power is almost nil. On the other hand, there are certain molecules in the air that are just a minor portion of the atmosphere. They are mainly water vapor (11_20) and carbon dioxide, and, to a lesser extent, methane (CH_4) and other compounds. However, they reflect infrared rays scattered from the soil into space and thus heat the lower layers of the atmosphere. Thanks to this, the air temperature around us favors existing forms of life on Earth. This natural process is called the "greenhouse effect." It is an analogy to buildings used to protect plants sensitive to cold weather, where glass windows allow the visible solar radiation spectrum to shine in while preventing the flight of infrared radiation.

We have found that, along with water vapor, carbon dioxide absorbs large amounts of the solar radiation that heats the atmosphere. The more water vapor and CO_2, the hotter the air will be. Scientists, however, are concerned with the risk of global warming due to high CO_2 concentrations that might exacerbate something that is essentially a natural occurrence: the "greenhouse effect". These concerns are quite pertinent because CO_2 is an important factor in the global warming. On the other hand, *there is no definite evidence of causality between* CO_2 *content and temperature levels.* We know that the Earth went through extremely hot periods when CO_2 content was greatly elevated. But water vapor concentrations — the main contributor to the "greenhouse effect" — were probably much higher.

Systematic studies have traced back developments 150,000 years, comparing the volume of glaciers, sea levels, and CO_2 contents (these were computed by measuring carbon isotopes in shells of Foraminifera fossils). CO_2 concentrations in the atmosphere reached a maximum 350 ppm before the start of the last interglacial period, and a minimum 225 ppm just before the last peak glacial age. The correlation between high and low CO_2 concentrations in the atmosphere and hot and cold eras, respectively, was very accurate in these studies. *The question now is whether* CO_2 *contents that seem to signal cooling and heating cycles are effectively the source of these variations or a reflection of much more complex causes.* Carbon isotope tests performed in the growth rings of tree trunks have indicated substantial variations in CO_2 content in the atmosphere in Europe over the last 15 centuries. Between the years 1000 and 1010, CO_2 contents went from 230 ppm to 310 ppm, an increase of the same magnitude as we see today. The 310 ppm mark is associated to the hot age of the Viking civilization. Whether this hot age came before or after CO_2 elevation is yet to be determined. On the other hand, the 230 ppm figure — close to the maximum value found for the last glacial era 18,000 years ago — was not matched by a glacial period (POSTEL, 1986, p. 26). This goes to show that any connection between climate changes and increased atmospheric CO_2 concentrations is still mere speculation.

Nevertheless, if climate changes do occur because of carbon dioxide elevation in the atmosphere, some terrestrial ecosystems will certainly be affected. Effects will be felt in the distribution and make-up of wildlife in our ecosystems because of the numerous variables currently sustaining the biological equilibrium. There will be changes in temperature and consequently in rainfall patterns, water runoff, river flow rates, soil moisture, evapotranspiration. In short, *all the variables involved in the vital balance of nature will be involved.*

In spite of so many uncertainties, there is agreement on one point: humans are the number one source of CO_2 release into the atmosphere in vat amounts. How the Earth — a long-time partner of CO_2 — will react to the impact of too much of this gas is an open issue.

The rising CO_2 content is a major concern to scientists because of its potential impact on climate.

5. CARBON FLOWS

Carbon exists in nature as follows: 0.06% in the atmosphere, oceans, plants, and animals; 99.94% in rocks and ocean sediments (BERNER and LASAGA, 1989, p. 58).

Notice that most of the carbon on Earth is stored in geological layers and in ocean sediments, in the form of fossil coal and oil carbonates.

However, the three main sources of carbon exchange and key components of the biological, geologic, and chemical carbon cycle are: *the atmosphere, oceans, and the Earth's biosphere.*

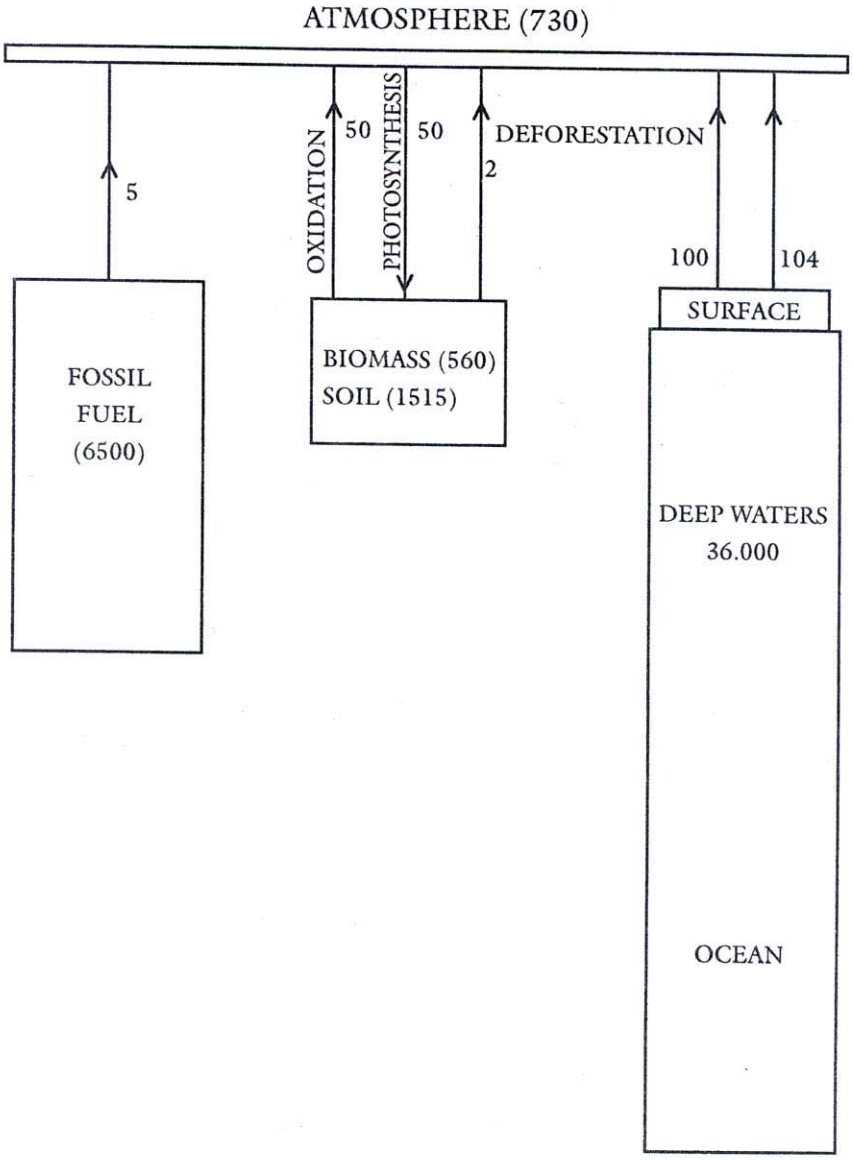
These sinks are internally compartmentalized and their boundary exchange mechanisms are highly complex. The biogeochemical cycle of carbon is the name given to a set of processes whereby carbon is removed from a certain sink, bound into compounds and reacted in other sinks, and finally returned to the original sink. Carbon stored in fossil fuels is not exchanged naturally without human assistance.

The amounts of carbon transferred from one storage sink to another per unit of time via physical-biogeochemical processes are known as carbon FLOWS. These flows occur between the three main sinks with the atmosphere as mediator. At a first approximation, direct exchanges between continental biomass and oceans are negligible and all exchanges between these two sinks are mediated by the atmosphere.

Figure 1 shows carbon sinks and the flows between them.

Figure 1

CARBON SINKS AND FLOWS
(IN BILLION TONS)
(Houghton and Woodwell, 1989, p. 20)



Carbon sources in the atmosphere are well known. Some result from human activities which burn fossil fuels and release billions of tons of carbon into the atmosphere each year. Others involve natural sources such as volcanoes and the balance of exchanges between atmosphere and the planet's biomes and oceans. Carbon dioxide concentrations in the atmosphere fluctuate depending on the time of day, season, latitude, and longitude. CO_2 can only be removed from the air by absorption in either of its two other sinks: the oceans and biomass.

Plants build their tissues thanks to the uptake of atmospheric CO_2 by leaves. This operation known as PHOTOSYNTHESIS removes around 100 Gt of carbon in the form of carbon dioxide from the air each year by a natural process. At night, plants release carbon dioxide into the atmosphere in a process called RESPIRATION. Together with the soil, plants return approximately 100 Gt of CO_2 per year to the atmosphere (HOUGHTON and WOODWELL, 1989, p. 20). Plant activity levels depend on light, temperature, moisture, and other factors. The seasons illustrate this quite remarkably: the warmer temperatures of spring and summer assist in plant production and therefore boost CO_2 uptake, while in the fall when plants die and bacteria attack, more CO_2 is released. In short, photosynthesis and respiration in both plants and soils are the two key processes whereby carbon flows are exchanged between atmosphere and biosphere.

Evaluating the role of oceans as sinks is a complex issue. Since the ocean's surface is in direct contact with atmospheric gases, these gases are diluted in sea water. Carbon dioxide is found at a 33 to 56 m1/1 concentration (HARARI, 1989, p. 8).

Local carbon flows exchanged between the atmosphere and oceans per unit of surface and time seems to be function of the solubility of CO_2, water temperature, and the difference between the partial pressures of the gas in water and the atmosphere. The ocean's global capacity vis-a-vis exchanges with the atmosphere involves complex tidal dynamics. A given ocean area may both release and take up CO_2 depending on the partial pressure of carbon dioxide in water and air. The amount of CO_2 dissolved in the water depends on climatologic variables as well as on the seasonal life cycle of sea organisms. The physical/chemical processes occurring at sea surface levels release approximately 100 Gt of carbon dioxide per year, while the uptake is roughly 104 Gt (HOUGHTON and WOODWELL, 1989, p. 20).

The atmosphere is not the only source of CO_2 for the oceans. A massive chemical system — the carbonate system — provides oceans with a greater and steadier flow of carbon dioxide than the atmosphere. The carbonate system, usually in the form of sodium bicarbonate, potassium bicarbonate, and calcium carbonate is carried by rivers to the oceans where it undergoes chemical reactions to become carbon dioxide (HARARI, 1989, p. 9).

Any change in these natural flows could have major implications for the atmosphere. Changes are already taking place as the burning of fossil fuels and deforestation release carbon dioxide in great quantities into the atmosphere. Estimations made in 1980 indicate that fuel emissions delivered around 5.2 Gt of carbon in the form of CO_2 to the atmosphere and deforestation in tropical forests contributed with another 1.8 Gt on average, a total of 7 Gt of carbon annually. Half of it stays in the air — a net annual increase of around 3.5 Gt. The balance is stored by oceans, biomass and other unknown sinks (MEYERS, 1989, p. 74). This finding has led to studies on the role of biomass as a depository of excess CO_2 in the atmosphere. This issue is discussed in the next section.

6. THE EARTH'S BIOMASS AND CO_2 INCREASE

Oceans and land-based biomass are assumed to absorb part of the CO_2 emissions from human activities. For this reason, both sinks have been extensively studied and investigated regarding their present and future role as depositories of excess CO_2 in the air.

Plants can turn inorganic matter involved in chemical cycles directly into biomass by a natural process (e.g. carbon, hydrogen, oxygen, etc.). Thanks to photosynthesis, plants use the sunlight trapped by leaf chloroplasts to chemically change atmospheric CO_2 stored in stomata into energy-rich substances such as sugars. Sugars are vital for food metabolism and therefore for plant growth. The elevation of CO_2 concentrations in the atmosphere raises a number of issues, since CO_2 is a crucial element in plant development:

What are the current and future impacts of higher concentrations of atmospheric CO_2 on the Earth's biomass? How does CO_2 act on individual plants and on the community as a whole?

Laboratory research findings have evidenced that plants stimulated with high concentrations of CO_2 respond positively with higher yields. Some controlled experiments have shown that raising CO_2 content from 300 ppm to 600 ppm on average causes a 30% increase in plant yield (IDSO et alii, 1989, p. 8). Based on the above figures, considering that CO2 concentrations in the atmosphere have increased by 74 ppm over the last 200 years and *assuming* a linear correlation between elevation of CO_2 and increases in yield (BAZZAZ et alii, p. 9), it follows that plant growth has increased by 7.4%. Taking this same line of thought one step further: since the world's plant cover stores 560 Gt of carbon (HOUGHTON and WOODWELL, p.20), biomass must have increased by 41 Gt. This could be described as a "missing sink" (a sink for the uptake of excess carbon). If this sink

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is not an actual "missing sink", how did ecosystems manage to dissipate this enormous amount of carbon generated by the 41-Gt increase in productivity?

Total dissipation of this biomass would take these ecosystems back to their original carbon levels. Partial or no dissipation would bring a different balance to the ecosystems. Since species within an ecosystem compete with one another, this second state of balance might involve, for example, different increases in fixed biomass for plants with distinct photosynthesis rates (C_3 and C_4). This does not take into account the climatic effects of CO_2 increase, such as changes in water balance or temperature variations.

Plant productivity increases resulting from higher CO_2 concentrations are known as the *CO_2 fertilization effect.*

Controlled experimental findings on the direct impact of CO_2 elevation have shown that leaf response to carbon dioxide uptake rates is linked to two factors:

1. sensitivity of stomata to CO_2; and
2. The activity of photosynthetic enzymes.

Plant response to assimilation will depend on the sensitivity of stomata (microscopic pores on the surface of plant leaves where gas exchanges occur, including carbon dioxide) to CO_2 levels. Some experiments have shown that in the presence of high CO_2 concentrations the diameter of plant stomata tends to shrink, resulting in decreased water losses. The lower rate of transpiration or water loss improves photosynthetic efficiency, and probably increases plant yield (SHUGART et alii, 1986, p. 476).

In regard to photosynthesis, certain plants respond better than others to high CO_2 concentrations, depending on their particular photosynthetic process. There have been several classification systems to catalogue plants according to physiologic and morphologic criteria. However, in the late sixties a new form of classification emerged, based on the triggering mechanism of CO_2 assimilation during photosynthesis. The explanation for the phenomenon of photosynthetic efficiency differences resides in the biochemical mechanisms of photosynthesis. Two main classes of plants were determined from the standpoint of photosynthesis: C_3 and C_4.

In the majority of plants, CO_2 is fixed through a pentose phosphate cycle known as C_3 or Calvin cycle. For many years this was the accepted explanation for the photosynthesis pathway. In other plants, known as C_4, CO_2 reduction (redox process) follows the dicarboxylic acid cycle. C_3 plants account for 95% of the world's plant biomass; C_4, though with fewer representative species, are particularly numerous among the grasses but are also found in several other plant families.

These two kinds of photosynthetic plants show different growth responses depending on 4 variables: *light, relative concentrations of* O_2 *and* CO_2*, temperature, and moisture.*

The C_3 plants tend to reach maximum photosynthesis rates under moderate light and temperature, and are inhibited by high temperatures and full sunlight. On the other hand, C_4 plants are adapted to intense luminosity and high temperatures, by far exceeding the output of C_3 plants under the same conditions. The reason why C_4 plants are efficient under these conditions is that photorespiration does not increase as light intensity rises (ODUM, 1985, p. 20). CO_2 lost during photorespiration partially offsets the fixation of CO_2 by photosynthesis. Depending on the plant species, photorespiration can reduce photosynthetic yield by 30 to 50%. Photorespiration rates may affect C_3 plants. However, C_4 plants have different metabolic pathways mediated by special anatomic structures that reduce the strength of photorespiration (SOMERVILLE and SOMERVILLE, 1984, p. 494).

C_4 plants have another very important morphological property: large chloroplasts on the sheath of bundles surrounding leaf ribs. They make more efficient use of water — 400 grams of water to produce 1 gram of dry matter, while C_3 plants need 400 to 1,000 grams of water for the same output — and are not inhibited by high oxygen contents like C_3 plants. Although the photosynthetic potential of C_3 plant leaves is smaller than that of C_4 plants, under optimum conditions for both, C_3 plants are responsible for most of the world's photosynthesis production. This is probably because they are more competitive in mixed communities where shading plays a role, and where light, temperature and other factors are average rather than extreme (ODUM, 1985, p. 21). Another interesting fact is that experimentally C_3 plants respond better to higher CO_2 concentrations, and their yield is greater than that of C_4 plants. This has led some researchers to believe that high levels of atmospheric CO_2 might be a growth inhibiting factor for C_4 plants such as sugarcane crops.

Standard net forest productivity represents the sum of individual tree growth and the forest's overall dynamics.

Controlled experiments have been made on leaves and buds for short periods of time. The short-term response of leaf photosynthesis rates to high concentrations of CO_2 does not constitute any indication of the plant's short or long-term response in it native environment. *Despite the positive growth response found in laboratories, it cannot be stated that yields would keep increasing in a natural environment at high* CO_2 *contents or that standard growth rates would continue to improve with time.* Furthermore, experiments focusing on leaves still require a better understanding of plant physiology, leaf growth patterns, nutrition, etc. which are vital for plant response to external stimuli. Available field studies are few and refer only to crop lands. (SHUGART et alii, 1986, p. 494).

As indicated above, findings on individual plants obtained experimentally are insufficient to determine anything about the effects of atmospheric CO_2 increase in plants in their natural environment. The issue is much more sensitive in terms of entire ecosystems. *Ecosystems are a complex fabric of chemical, physical and biological interactions; they cannot be approached from a cause-and-effect angle in terms of plant yield growth and atmospheric CO_2 increase.*

Forest ecosystems pose a challenge to scientists. Problems are of great magnitude both due to the extent and complexity of interactions involved in ecosystem dynamics, and to the close association between plant life and the atmosphere. Standard net forest productivity represents the sum of individual tree growth and the forest's overall dynamics (death, tree recruitment?, regeneration, and competition) (SHUGART et alii, 1986, p.481).

Quantifying the net productivity of a forest with high CO_2 concentrations is a difficult task because of the complex interaction among the different species, of their particularities, and of the exchange between each ecosystem and external variables.

Climax forests are at a higher maturity stage on the ecological scale. "Theoretically, climax communities are self-perpetuating because they are in equilibrium both internally and with their physical habitat. In contrast with developing or transition communities, the annual output of climax forests plus imports are in balance with annual consumption by the community plus exports." (ODUM, 1985, p. 299). *Climax forests like the Amazon rain forest may see higher growth rates among their individuals as carbon dioxide concentrations rise, which does not mean the forest's total net yield will increase.* As forests stabilize, the annual average net CO_2 exchange is zero, although CO_2 uptake by some plant components may be occasionally high. Carbon dioxide uptake rates are offset by CO_2 losses in the plant through respiration of live biomass, losses of dead biomass, respiration exchanges in roots, leaves, branches, and the individual as a whole (SHUGART et alii, 1986, p. 495). In the Amazon basin, the CO_2 uptake rate (soil and canopy) around noon was estimated at 9(±4) $kgC.ha^{-1}.h^{-1}$, while the daily average uptake rate is 1.8(±0.2) $kgC.ha^{-1}.h^{-1}$ (WOFSY et alii, 1988, p. 1377).

How can higher CO_2 levels in the environment affect the checks and balances of highly complex climax systems? There is no straightforward answer to this question.

"The findings do not provide a convincing enough argument to assume that the growth stimulation effect of CO_2 observed in controlled environment studies may or may not become manifest in the long run within natural communities of mixed species" (GIFFORD, 1989, as quoted by HALL and CALLE, 1989, p. 536).

6.1 Amazonian Ecosystems

To speak of Amazonian ecosystems involves a number of complex interactions between atmosphere, hydrosphere, lithosphere, and biosphere.

The exchanges between these four systems provide stability to all terrestrial ecosystems.

Although this natural domain generally presents an even relief and a seemingly homogeneous and extensive plant cover, it harbors a variety of ecological, pedological, hydrologic, and phytogeographic patterns (AB'SABER, 1984, p. 173). Forest ecosystems cover more than 90% of the Brazilian Amazon Region, or 3,500,000 km^2 (BRAGA, 1979, p. 54).

Species are heavily mixed, i.e., there are many different species per unit of area, none of them predominant over the others in terms of number of individuals. This is more clearly visualized in forests on dry ground, spanning 3,300,000 km2. As indicated in the previous section, this heterogeneity of species and of internal and external exchanges (with the atmosphere) makes it very hard to investigate the Amazon ecosystem, especially its forests, in terms of atmospheric CO_2 elevation and its impact on plant biomass.

Species heterogeneity is translated by morphologically and

physiologically distinct individuals that respond differently to growth limiting factors: water shortage, too much or too little sunlight, mineral shortages or surpluses, and temperature. The magnitude of the forest and its exchange with the atmosphere are also a delicate issue. For example, forest stratification does not allow all plants to have the same rate of exchange with atmospheric CO_2 and the CO_2 obtained from root respiration. The taller canopies, therefore, are in closer contact with carbon dioxide from the air than other layers of vegetation.

This is only the tip of the iceberg. The only way to determine the response of forest biomass to increased atmospheric CO_2 is by looking at individual or community variables, and at the interactions between those variables.

7. CONCLUSION

By burning fossil fuels and clearing forests, humans have caused the release of billions of tons of CO_2 into the atmosphere each year. The consequences of this massive release for the planet are still uncertain, considering the atmosphere's composition, carbon flows, and the reaction of Earth's biomass to the increase of CO_2.

Many scientists advocate the idea that substantial climate changes will be inevitable if carbon dioxide emissions continue to rise. Some are more conservative and say that research is still highly speculative, while others discard the concern altogether.

Part of these emissions is absorbed by our main carbon sink: the oceans. The rest is thought to be stored by terrestrial biomass through a process still under investigation: *the effect of plant fertilization by* CO_2.

If the Earth's vegetation is truly fertilized by CO_2, it will act as a sink for part of this excess gas in the atmosphere. Together with the oceans, it may then act as a buffer for possible climate changes. Researchers still do not have an answer to this question, they can only make educated guesses based on experimental data.

Tropical forest biomass plays an important role in this regard as a depository for part of the excess CO_2 in the atmosphere, both because of its sheer volume and for the diversity of plant species. Forest biomass is seen as a likely CO_2 sink for its exuberance and plant diversity. On the other hand, however, detailed studies are required to determine whether or not forests will indeed be able to perform this function. The complexity of tropical forest ecosystems is a stumbling block to hasty answers. The question now is: "what has to be researched in forest ecosystems to determine if they are indeed the "missing sink"? We hope to suggest some field studies on the subject.

Without neglecting the complexity of the ocean sink, the continental biomass is less amenable to modeling and to research that may conclusively prove that the Earth's vegetation is a sink for excess atmospheric CO_2 (LAMBERT, 1987, p. 784). In connection with this, it should be stressed how helpful *observation satellites* can be to clarify the CO_2 issue. However, correlating satellite imaging to surface density of carbon in plant material and deforestation is a time-consuming and detailed task. On the other hand, it should not be forgotten that much of the carbon in our ecosystems is out of sight, stored in the soil rather than in vegetation. The exceptions are tropical forest ecosystems, where carbon uptake by plants is greater (HALL and CALLE, 1989, p. 524).

BIBLIOGRAPHY

Aziz Nacib AB'SABER (1984), "Ecossistemas Continentais", Rqma — Relatório da qualidade do meio ambiente — SEMA, Brasília.

F.A.BAZZAR, K. GARBUTT e W.E. WILLIANS (1985), "The effect of elevated atmospheric CO_2 on plant communities", United States Department of Energy — DOE/EV/04329-5, July 1985.

Robert A. BERNER and Antonio C. LASAGA (1989), "Modeling the Geochemical Carbon Cycle", Scientific American, vol. 260, n° 3, March 1989.

Pedro Ivo Soares Braga (1979), "Subdivisão fitogeográfica, tipos de vegetação, conservação e inventário florístico da floresta Amazônica", Supl. Acta Amazônica, vol. 9; n° 4.

Willian DONN (1978), Meteorologia, Editora Reverte, Barcelona 1978.

David HALL (1989), "Carbon flows in the biosphere: present and future", Journal of the Geological Society, vol. 146.

David HALL and Rossillo CALLE (1989), "CO_2 cycling by biomass: global bioproductivity and problems of deforestation", Amazonia: Facts, Problems and Solutions, July-August, 1989, Sao Paulo.

Joseph HARARI (1989), Apostila do curso de Fundamentos de Oceanografia Instituto de Oceanografia — Universidade de São Paulo.

R.A. HOUGHTON, R.D. BOONE, J.R. FRUCI, J.E. HOBBIE, T.M. MELILLO, C.A. PALM, B.J. PETERSON, G.R. SHAVER and G.M. WOODWELL (1983), "The flow of carbon from terrestrial ecosystems to the atmosphere in 1980 due to changes in land use: geographic distribution of the global flow", Tellus, vol. 39B.

Richard A.HOUGHTON and George M. WOODWELL (1989); "Global climatic change", Scientific American, vol. 260; n° 4, April 1989.

S.B.IDSO, B.A. KIMBALL and M.G. ANDERSON (1989); "Greenhouse warming could magnify positive effects of CO_2 enrichment on plant growth," CDIAC Comunications. Oak Ridge, Winter, 1989.

Gerard LAMBERT (1987), "Le gaz carbonique", La Recherche, vol. 189, Juin 1987. N.MYERS (1989), "The Greenhouse Effect: A tropical forestry response", Biomass, vol. 18. Eugene P. ODUM (1985), Ecologia, Rio de Janeiro.

Olivier POSTEL (1986), "Les prophètes de Pete carbonique", Science et vie, Août 1986.

Christopher R. SOMMERVILLE and Shauna C. SOMERVILLE (1984), "Les photosynthèses des plantes". La Recherche, vol. 15; n° 154, Avril 1984.

H. H. SHUGART, M. ANTONOVSKY, P.G. JARVIS E.A.SANFORD (1986), "CO_2, climatic change and forest ecosystems", in Bolin, Doos, Warrick and Jager (ED.), The Greenhouse Effect climatic change and ecosystems — SCOPE 29.

A.T. WILSON (1978), "Pioneer agriculture explosion and CO_2 levels in the atmosphere", Nature, n^o 5657, May 1978.

G.M. WOODWELL, J.E. HOBBIE, R.A. HOUGHTON, J.M. MELILLO, B. MOORE, B.J. PETERSON and G.R. SHAVER (1983), "Global Deforestation: Contribution to Atmospheric Carbon Dioxide", Science, vol. 222, n^o 4628, December 1983.

Steven, C. WOFSY, Robert C. HARRIS and Warren A. KAPLAN (1988), "Carbon dioxide in the atmosphere over the Amazon basin". Journal of Geophysical Research, vol. 93, n^o D2, February 1988.