2.0 Summary of LBA–Ecology

INPE will lead the overall coordination and integration of LBA. LBA–Ecology will be responsible for its own project and Science Team management, but will work closely with the LBA Project Office at INPE and the other component research programs under the sponsorship of Brazilian, other South American, European, U.S., and international organizations. Research will be conducted across all components of LBA concurrently and integrated through joint sharing of field sites, equipment, and logistical support; exchange of data; collaborative modeling; and training and education activities. The Scientific Steering Committee (SSC) of LBA guides scientific collaboration among the independently funded components.

2.1 LBA–Ecology Science Question

LBA-Ecology research is focused on the following question.

> **How do tropical forest conversion, regrowth, and selective logging influence carbon storage, nutrient dynamics, trace gas fluxes and the prospect for sustainable land use in the Amazon region?**

"Forest conversion" refers to forest clearing and conversion to agricultural uses, especially cattle pasture, and "forest re–growth" refers to forest growth following the abandonment of agricultural lands. The science question calls for an explicit consideration of the effects of these land–cover and land–use changes on terrestrial carbon and nutrient budgets, the fluxes of trace gases between the land and the atmosphere, and the exchange of materials between the land and river systems. Implicitly, the question also calls for an understanding of these budgets, fluxes and exchanges in "primary" or pre–disturbance forest ecosystems.

The full LBA experiment addresses six different science topics: the physical climate system; atmospheric chemistry, carbon storage and exchange, biogeochemistry, land surface hydrology and water chemistry, and land use/land cover. LBA–Ecology research emphasizes carbon storage and exchange, trace gas, nutrient dynamics and land use/land cover, and contributes to some aspects of the other LBA areas (Figure 2.0).

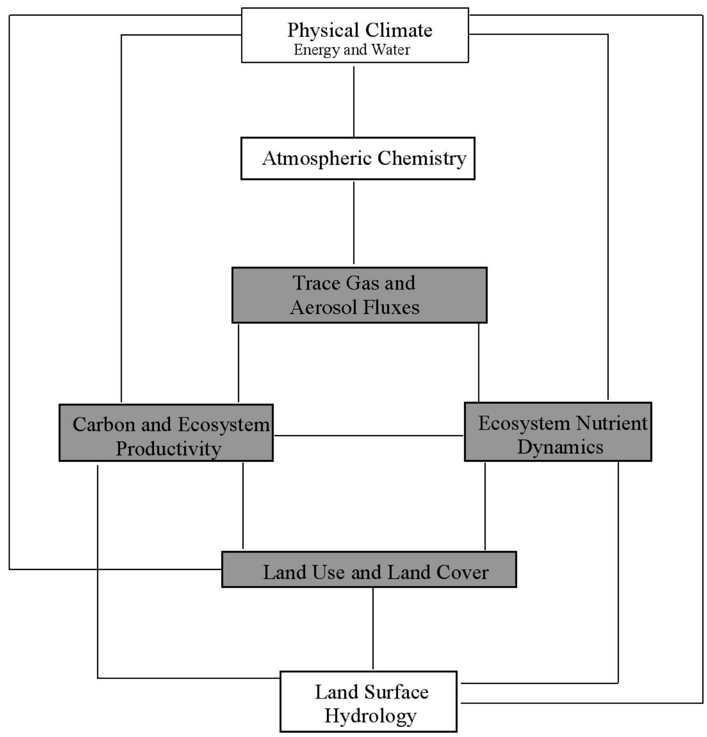

Figure 2.0 Linkages between components of LBA. LBA–Ecology Draft Science Plan, 1998. The shaded boxes indicate emphasis in LBA–Ecology.

2.2 Science Themes, Questions, and Tasks for LBA–Ecology

The LBA–Ecology Science Team will pursue an integrated approach to the broad LBA–Ecology science question. This approach will involve synthesis of past results and data sets, modeling, remote sensing, Geographic Information System (GIS)–based analyses, new field observations and process studies, training and education, and synthesis and integration of existing data and new results in order to respond effectively to the research goals.

The results produced by the LBA–Ecology Science Team will provide a new understanding of environmental controls on flows of carbon, nutrients, and trace gases among the atmosphere, hydrosphere, and biosphere of Amazonia. Efforts are grouped into four science themes. Under each thematic area intact forests and savannas, pastures, cultivated lands, and second growth and selectively logged forests will be examined.

The Land–Cover and Land–Use Change studies will focus on the documentation of past and current land–cover and land–use changes throughout Amazonia and development of a capability to predict the location and magnitude of future land–cover and land–use changes in the region. The Carbon Dynamics studies will involve the quantification of the carbon pools in vegetation and soils and the rates of carbon exchange among the atmosphere, vegetation, and soils, and the ways in which these rates are altered by natural and human disturbances. The Nutrient Dynamics and Surface Water Chemistry theme studies will focus on the quantification of nutrient pools and fluxes. In addition, studies will quantify the changes in surface water chemistry resulting from land–cover and land–use change.

Nitrogen and phosphorus are the nutrients of major interest. The Trace Gas and Aerosol Fluxes theme studies will focus on the quantification of the fluxes of trace gases between the surface and the atmosphere and the determination of the biological and physical factors that control these fluxes. Studies will compare natural systems with managed land uses and systems recovering from human management.

For each of the thematic areas of our study, we pose scientific questions that motivate research tasks. There is not a 1:1 correspondence of questions and tasks, as certain tasks are necessary to answer more than one question.

2.2.1 Land Cover and Land Use Change

The changes in Amazonian vegetation associated with land–use practices exert a large influence on and global biogeochemical cycles (Crutzen and Andreae, 1990; Houghton, 1991; Houghton and Skole, 1990; Salati and Vose, 1984; Shukla et al., 1990; Nepstad et al., 1994). The most conspicuous form of land use in Amazonia is the conversion of closed–canopy forests to cattle pasture and agricultural fields. Estimates of the area and rate of this conversion vary, but have shown some convergence in recent years. INPE estimated a total deforested area of 280,000 km^2 as of 1988, and an average annual rate of 21,000 km^2 from 1978 to 1988 in the Brazilian Amazon (Fearnside, 1993; INPE 1992). Skole and Tucker (1993) estimated that the total deforested area was 230,000 km^2 in 1988, with the average rate from 1978 to 1988 being about 15,000 km^2 per year.

Some important forms of land–cover and land–use change are difficult to measure with satellite imagery. Selective logging can remove or destroy up to a fourth of the basal area and half of the canopy cover of Amazonian forests. This greatly increases forest flammability (Uhl and Vieira, 1989; Uhl and Kauffman, 1990). Logging scars become difficult to detect with satellite imagery shortly after log extraction (Lefebvre and Stone, 1994). C. Uhl and A. Veríssimo estimate that logging affects >4,000 km^2 of forest in Pará State each year. It is also difficult to measure the area that burns each year, especially those areas of forest that experience ground fires (Setzer and Pereira, 1991). Moreover, in the portion of the Amazon region that supports savanna vegetation, conversion to agriculture is more difficult to measure with satellite imagery. This vegetation has been excluded from regional deforestation estimates, even though Government census data indicate that it is being converted to cattle pasture and agriculture at a faster rate than the closed canopy forests (Klink et al., 1994; Nepstad et al., 1996).

Field studies in Amazonia have documented the high frequency of land abandonment following deforestation, and the generally vigorous regrowth of forests on abandoned pastures and agricultural sites (Saldarriaga et al., 1988; Uhl et al., 1988; Nepstad et al., 1991; Salomão, 1994). Region–wide estimates of the total area of abandoned land, the annual rate of abandonment, and the rate at which secondary forests are converted back to pasture and agriculture are not yet available. With substantial ground–truthing, it is possible to distinguish among primary forests, secondary forests, and shrub–infested fields, and among different ages of secondary forest using TM imagery (Brown et al., 1992; Skole et al., 1994; Moran et al., 1994; Lucas et al., 1993).

Amazonia is a region defined by its abundance of water evident in the extensive river system, which culminates in the world's largest river, and its associated areas of periodically inundated land. Sippel et al. (1992) estimated that the main stem floodplain covers about 100,000 km^2. Junk and Furch (1993) estimate that the floodplain of Amazonia main–stem and primary tributaries cover about 300,000 km^2, whereas riparian zones of small rivers may cover about 1,000,000 km^2. Savannas exposed to sheet flooding in Roraima, the Rupununi district, along the Río Araguaia, and in northeast Bolivia may account for another 200,000–250,000 km^2. These estimates suggest that as much as 15–30% of the area of the Amazon basin is subject to periodic saturation and inundation, however these values remain highly uncertain.

2.2.1.1 Land Cover and Land Use Change Science Questions

LC–Q1 What are the rates and mechanisms of forest conversion to agricultural land uses, and what is the relative importance of these land uses?

LC–Q2 At what rate are converted lands abandoned to secondary forests; what is the fate of these converted lands, and what are the overall dynamic patterns of land conversion and abandonment?

LC–Q3 What is the area of forest that is affected by selective logging each year? How does the intensity of selective logging influence forest ecosystem function, thus altering forest regrowth and flammability?

LC–Q4 What are plausible scenarios for future land–cover change in Amazonia?

2.2.1.2 Land Cover and Land Use Change Research Tasks

LC–Task1: Regional scale rate, location, and pattern of forest conversion

The rate, location, and spatial pattern of forest conversion to pasture and agricultural uses and the succession of pastoral and agricultural land to secondary forest will be determined for the Amazon region, using visible/infrared and radar satellite remote sensing, Government statistics, and survey data. A variety of time spans will be covered, dependent upon satellite and statistical data availability.

LC–Task2: Local dynamics of deforestation, abandonment, and second growth turnover

Case studies and field investigations will be carried out in conjunction with analysis of multitemporal, high–resolution satellite data at 1:50,000 to 1:100,000 scale to gain insight into local–scale dynamics of deforestation, abandonment, and second–growth turnover. These case–study analyses will use data from census documents and from new household and community surveys to define the parameters that control local land–use strategies and decision making by individual farmers and managers. Land use classification will be recorded in geographical information systems (GIS). These GIS will incorporate data from historical sources, maps, air photos, and light aircraft videography in addition to satellite remote sensing. External institutional and economic factors will also be considered when evaluating the causes of deforestation.

LC–Task2a: Fire occurrence, intensity, and fire susceptibility
The use of fire is a critical tool in land management, which has major effects on biogeochemistry and the sustainability of future land uses. Fire frequency will be determined using operational AVHRR techniques. Fire occurrences identified by these techniques will be ground validated in specific areas. The spread of fire outside of managed lands poses a threat to natural and managed ecosystems. The fire susceptibility of forest, logged forest, and savanna systems will be evaluated under normal and drought conditions.

LC–Task3: Regional pattern of inundation
Passive and active microwave remote sensing combined with visible/infrared remote sensing and field recording of inundation and water levels will be used to determine the temporal and spatial extent of inundation across the Amazon region.

LC–Task4: Modeling driving factors of land use change
Models will be developed at a variety of scales to understand the driving factors of land use change and to predict future land use and land cover. Scales of modeling range from decision making at the level of the individual land owner/manager to larger scale analyses, which consider external factors, and conditions that influence deforestation in Amazonia. Existing empirical modeling techniques allow the prediction of when (Markov and logistic), why (regression), and where (spatial statistical) land–cover conversion processes operate. The empirical models can serve as a foundation upon which mechanistic and systems dynamics models can be built. Cost–benefit analyses and sectoral policy studies can provide insights into the trends of industries such as beef cattle, perennial agricultural products, timber, and minerals. When combined with projected changes in infrastructure (roads and energy sources), credit programs, regulatory policies, domestic and international markets, and land reform, predictions can be made about where and when land–use and land–cover change will take place.

2.2.2 Carbon Dynamics

Conversion of natural systems for logging, pasture, or agriculture and the fate of these converted lands cause large local transfers of carbon between atmosphere and ecosystems. Forest conversion analysis for Amazonia suggest it is a net source of carbon to the atmosphere, while recent net ecosystem exchange (NEE) measurements indicate that undisturbed forest systems may be a net carbon sink (Fan et al., 1990; Grace et al., 1995). The importance of carbon sequestration in regrowing forest on abandoned lands is uncertain. One approach that has been used to estimate the flux of carbon over large regions is to account for the aerial extent of land–use change and to multiply those changes by land–use–specific carbon stocks (Fearnside, 1992; Houghton et al., 1987; Houghton, 1991). A related method relies on comparison of biomass stocks obtained from regional surveys conducted at different points in time, as has been done in some forests of the temperate zone (Apps and Kurz, 1994; Birdsey et al., 1993; Kauppi et al., 1992).

A second approach to the regional carbon balance emphasizes the natural carbon cycle, including net primary production (NPP) and respiration. Fluxes in the natural vegetation reflect two processes. The first of these involves metabolic processes of photosynthesis, growth, and decay affecting individual trees, and very short time and spatial scales. The second process, over stand–to–kilometer scales, is succession, which affects the number, age and species composition of stems, as well as the amount, nature, and turnover rate of soil organic matter. At small scales, eddy–correlation measurement of CO_2 flux above canopy integrates both of these processes (metabolic and successional), while repeated measurements of carbon accumulation in living biomass, distribution, and decomposition of dead biomass, and the nature and turnover of soil organic matter, allows for partitioning of net flux.

Physiologically based models have been used to predict regional carbon balance on seasonal to decadal time scales. These models generally ignore the effects of natural disturbance in forest ecosystems. This approach is too crude at present to be able to resolve net changes in terrestrial carbon stocks. The changes might account for the imbalance in the global cycle, but the model presently predicts the variations in flux expected as a result of changes in climate and atmospheric carbon dioxide concentrations (Melillo et al., 1993; Potter et al., 1993).

While some initial attempts have been made to bring these two approaches (land–use change and physiologically based models) together, it is important to recognize that they require different types of data and assumptions and have different sources of error. Changes in carbon storage resulting from human management of the landscape (clearing forests, logging, cultivation, afforestation, etc.) often result in well–defined locations of change and large changes in carbon per hectare. In contrast, changes in carbon storage resulting from environmental changes in temperature, moisture, and, perhaps, carbon dioxide concentrations affect areas of undefined extent, and the accompanying changes in carbon stocks per hectare may be subtle. Natural disturbances may be considered small enough to be irrelevant compared to the carbon fluxes associated with land–use changes when considered on an annual basis. However, the integration of small fluxes over the larger total area that remains as natural vegetation implies that natural fluxes cannot be ignored in an Amazonian carbon balance.

Eddy covariance measurements of CO_2 flux above the forest canopy integrate stand–level and perhaps successional changes in carbon stocks on time scales from days to years. When combined with intensive measurements of the flows of C, these allow development and testing of process models of carbon flow and storage at the stand level. Aircraft measurements of CO_2 flux provide comparisons of carbon exchanges between stands and surrounding regions, providing information on both variability among similar stands and differences among land–cover types.

At larger scales, interpretation of CO_2 concentration can be used to determine sources and sinks of trace gases over very large regions (Enting and Mansbridge, 1991; Tans et al., 1990; Ciais et al., 1995). Applications of inverse model approaches may be used to derive a regional estimate of net CO_2 flux. Comparison of isotopes of carbon and oxygen in CO_2, tracers of biomass burning (CO), and other trace gases will provide additional confidence in such estimates, as well as Amazon–wide fluxes for other trace gas species. Assuming that sufficient data can be accumulated, this information will provide a basin–wide test of the ability to predict regional carbon fluxes from process models coupled to remote sensing and geographical data. In particular, estimates of the deliberate (land use) and inadvertent (undisturbed ecosystem) fluxes should sum to the measured total net flux. If they do, researchers can gain confidence in understanding the carbon cycle in a major region of the Earth. If they do not, scientists may be able to learn something about techniques and processes.

2.2.2.1 Carbon Dynamics Science Questions

CD–Q1 What is the (climatically driven) seasonal and interannual variability of the CO_2 flux between the atmosphere and different land cover/use types?

CD–Q2 How do biological processes such as mortality and recruitment or succession following land use change influence the net annual C balance for different land–cover/land use types?

CD–Q3 What are the relative contributions of fluxes from natural and disturbed ecosystems to the net Amazonia–wide flux? This question can be approached through a number of subsidiary questions:

CD–Q3a How do pools and fluxes of C and nutrients (in soils) of pasture/cropland change over time and what factors determine C gain or loss?

CD–Q3b How does selective logging change the storage and cycling of C in forests?

CD–Q3c What factors (biologically mediated, land–use history, soil properties, etc.) control the rate of C sequestration in biomass and soils of regrowing forest?

CD–Q3d What portion of the Amazonia–wide C flux is from fire? How do ecosystems recover from fire? What are the relations between land management and fire occurrence/frequency?

2.2.2.2 Carbon Dynamics Research Tasks

CD–Task1: Quantifying carbon pools in soils and vegetation
The project aims to improve estimates of the carbon pools in soils and vegetation, both above ground and below ground (including deep roots) in natural and managed ecosystems in the Amazon region. While recognizing that improving estimates of old–growth forest biomass is an incremental task, investigators hope to make progress by augmenting traditional forest surveys of trees with estimates of vine biomass and the quantity of coarse woody debris. Forest survey data will be interpreted with existing allometric equations. In recent years, researchers have made significant advances in quantifying the biomass of second growth in areas of abandoned pastures and agriculture. This study will conduct extensive biomass surveys in a range of second growth areas using harvest. Ground surveys will be linked to light aircraft and satellite remote sensing (both visible/infrared and radar) in order to

determine relations useful for extrapolation of results to wider areas. Soil carbon pools will be quantified in surface soils and in deep soils across the LBA transects under a range of land uses.

CD–Task2: Quantifying seasonal and interannual variability in carbon budgets
Ecosystem–atmosphere carbon dioxide fluxes for natural and managed land uses will be studied, complemented by a suite of measurements designed to elucidate the causes of seasonal and interannual variability in carbon budgets. Continuous flux measurements using the eddy covariance technique will be performed over several years at sites run by the LBA–Ecology Science Team (including old growth forest, logged forest, and pasture) and by collaborators in other LBA modules. These flux measurements will be complemented by a wide variety of measurement and modeling approaches.

CD–Task2a: Eddy covariance of net ecosystem CO_2 exchange
Eddy covariance fluxes of CO_2, H_2O, and sensible heat measured from towers will be complemented by a suite of continuous meteorological and soil moisture and temperature measurements necessary to quantify energy and water budgets. In forests, the study will supplement the flux measurements with semi–continuous CO_2 concentration profile measurements to estimate the in–canopy CO_2 storage. Automated and manual soil and stem CO_2 flux measurements will quantify the major respiration components of carbon exchange. Stable isotopes of oxygen and carbon will be used to partition the below–ground and above–ground respiration components of canopy layer CO_2 exchange.

CD–Task2b: Carbon cycling and controls on photosynthesis and decomposition
A wide variety of techniques will be used to study the cycling of carbon within natural and managed systems and to understand controls on productivity, respiration, and decomposition. Stand level models will be used to diagnose carbon exchange and gain insight into the relative importance of the processes controlling photosynthesis and autotrophic and heterotrophic respiration. Investigations will measure components of productivity, including leaf area, litterfall, growth increment of trees using band dendrometers, and fine root turnover using sequential coring. Decomposition rates will be measured for litter, roots, and coarse woody debris, using traditional approaches and ^{14}C measurements. Past growth histories of trees and stand demography will also be approached using ^{14}C. Decomposition and productivity in forest–pasture transitions will be studied with $^{13}C/^{12}C$ ratios in organic mater. Controls on decomposition will be studied in natural and managed systems through carbon–nutrient interactions and other measures, including density fractionations of organic matter, lignin/cellulose ratios, microbial biomass, and biomarker compounds for specific identification of the agents of the decomposition process.

CD–Task2c: Testing the reliability of the eddy covariance method
Various tests of the reliability of the eddy covariance method for determination of carbon fluxes will be used. These tests include comparison of nocturnal flux measurements to continuous automated measurements of respiration; sap flow and soil moisture compared to moisture fluxes; and routine checks on the closure of site energy budgets. More intensive investigations using radon as a tracer for gas exchange and eddy covariance and other meteorological measurements at multiple levels within and above the canopy will be conducted.

CD–Task3: Dynamics of carbon turnover with land management
An improved understanding of the dynamics of carbon change with land–use/management will be generated using measurements discussed in Tasks 1 and 2 across a range of land use types and on specific chronosequences of management and succession. In particular, the study will link to nutrient studies (see Nutrient Tasks 1–3) and land use studies (see LUCC Tasks 1 and 2) to understand the mechanisms of land use turnover and biomass accumulation in secondary growth.

CD–Task4: Regional estimates of net carbon exchange
Two approaches will be used for scaling up to Amazon region–wide estimates of net carbon exchange. The first approach is bottom–up. A hierarchy of models will be developed for stand scale to regional scale application. Models will use a range of inputs, including meteorological data, soils data, vegetation characterization with physiological parameters, and satellite data for broader scale models. A GIS framework can be used to link models for prediction of Amazon regional carbon exchange. A top–down approach will include inversion of CO_2 fluxes based upon surface and aircraft measurements of CO_2 concentrations and carbon and oxygen isotopes. These may be applied on local scales and possibly on Amazon–wide scales if investigators can make sufficient measurements.

2.2.3 Nutrient Dynamics and Surface Water Chemistry

The flows of energy, water, and carbon within ecosystems of Amazonia are linked with the cycles of essential nutrients. The experimental design for studying the effects of land conversions includes consideration of natural distributions of stocks of nutrients within forest ecosystems, processes that determine flows of nutrients, and how land conversion affects those stocks and flows.

Human alteration of natural ecosystems and their conversion to different agricultural uses change the storage of nutrients and rates of organic matter and nutrient cycling. Some important examples of how these actions alter carbon and nutrient flows include:

- Direct volatilization of carbon and nitrogen stocks formerly in the vegetation caused by biomass burning (Ewel et al., 1981; Fearnside, 1993).
- Increases of soil stocks of elements such as P, K, Ca and Mg after burning as these elements are transferred from pools formerly in the vegetation (Nye and Greenland, 1964; Sanchez, 1976; Uhl and Jordan, 1984).
- Removal of stocks of nutrients such as Ca, Mg, P and N in logging operations.

Other changes include alterations to the amount of carbon and nutrients stored in the soils converted to pasture or other agricultural uses and changes to nutrient cycling rates (Montagnini and Buschbacher, 1989; Choné et al., 1991; Nepstad et al., 1995; and Neill et al., 1995). These changes are linked to soil fertility, which in turn affects future changes to land use and land cover. Further modifications to nutrient cycling patterns can occur over time under altered land use, such as when pastures age or degrade (Buschbacher et al., 1988; Robertson and Tiedje, 1988). These changes can influence ecosystem responses, such as the rate at which forests regrow.

Study of the effects of land–cover and land–use change on nutrient cycling will focus on the changes that are spatially dominant in terms of area in Amazonia. The dominant land use conversions that affect nutrient cycling are:

- Direct conversion of forest to pasture, which is typically practiced on large ranches (>1000 ha).
- Selective logging, which often occurs on lands held by large–holders, although small–holders also sell logs.
- Slash and burn agriculture, which is typically conducted by small land–holders (<100 ha). The sequence of management phases varies regionally. One common pattern is forest conversion by slash and burn followed by a crop, then fallow, a second slash and burn, a second crop, and ultimately pasture.
- Pasture degradation and abandonment, which occurs on small farms and large ranches.
- Conversion of savanna to pasture and row crop agriculture, which is an increasingly important change, and is concentrated in the southern portion of the study region.

Land–use changes result in significant alterations in the flow of water through the affected drainage basins, with consequent feedback on the sediment transport and biogeochemistry of the region's river systems. The river corridors of a region express the interaction of hydrologic processes and the land surface. The Project plans to relate the river signals to the land use changes within a basin by monitoring the rates of carbon and nutrient movement through the overall plant/soil/river system environments in response to changing hydrologic regimes using river basin models. The central premise of a river basin model is that the constituents of river water provide a continuous, integrated record of upstream processes. These processes vary systematically, depending upon changing interactions of flowing water with the landscape and the interplay of biological and physical processes (Karlsson et al., 1988; Billen et al., 1991). The chemical signatures of riverine materials can be used to identify different drainage basin source regions, reaches, or stages, and can be tied to landscape–related processes such as chemical weathering and nutrient retention by local vegetation (Meyer et al., 1988). Rivers should respond with differing magnitudes and lags to natural or anthropogenic perturbations, depending on the processes involved and the downstream transfer rates of their characteristic products.

2.2.3.1 Nutrient Dynamics and Surface Water Chemistry Science Questions

ND–Q1 How do stocks, cycling rates and budgets of carbon and important elements N, P, K, Ca, Mg, and Al change under different land covers and land uses?

ND–Q2 Are nutrients major factors that control the rates of re–growth and carbon accumulation in abandoned pastures and re–growing secondary forests?

ND–Q3 How does the capability of native vegetation to extract nutrients from soil differ from capabilities of exotic pasture grasses?

ND–Q4 What are the changes in the inputs, pathways and fluxes of dissolved organic matter, nutrients, and associated elements through river corridors?

ND–Q5 How will the composition and quantity of nutrients and organic matter entering and being processed within streams be altered under different land–use change scenarios? Are there unique signatures that can be traced downstream?

ND–Q6 To what extent do intact riparian zones buffer streams against changes due to anthropogenic activities in surrounding uplands?

2.2.3.2 Nutrient Dynamics and Surface Water Chemistry Research Tasks

ND–Task1: Review and synthesis of existing studies
The task will review and synthesize existing studies of nutrient cycling and nutrient controls on ecosystem function in the Amazon region. A great deal of local literature has been produced, particularly in agricultural studies. This high–quality work has not been adequately disseminated in the international scientific literature, partly because of the languages of publication (Portuguese and Spanish) and partly because of the inaccessibility of the journals and unpublished technical reports. Information gathered from the synthesis activity will be applied to other tasks listed below.

ND–Task2: Quantifying nutrient pools in soils and vegetation
The study will use standard techniques to quantify nutrient pools in soils and vegetation. Nutrient availability will be assessed through techniques such as phosphorous fractionation and nitrogen mineralization assays. Measurements of nutrient pools will be closely linked to measurements of carbon pools (Carbon Task 1).

ND–Task3: Quantification and modeling of internal nutrient fluxes
Internal nutrient fluxes within ecosystems will be studied, including the cycling of nutrients through litterfall (and retranslocation), fine root turnover, and throughfall. Nitrogen cycling will be studied, using assays of net mineralization and net nitrification. Controlled experiments using fertilizers will be conducted to ascertain nutrient limitations to productivity. Nutrient flows will be diagnosed with crop models and biogeochemical models adapted to incorporate both N and P cycling. Modeling efforts will be closely linked with Carbon Task 3.

ND–Task4: Quantification of external nutrient inputs
Investigations will measure external nutrient inputs from wet deposition, dry deposition of particles, and weathering of soils and geological parent material. Rainfall will be collected at several sites for routine nutrient analyses. Using measurements of particulate chemistry and models of particle deposition, particulate deposition of nutrients will be estimated. Quantitative determination of soil mineral composition and weathering models will allow estimation of the nutrient inputs from the "bottom" of the system. Weathering nutrient inputs will be constrained by measurements of strontium isotopes in soils, parent material, and vegetation.

ND–Task5: Effects of management on stream chemistry
Paired basins (natural vs. managed) will be studied in order to assess how management affects the fluxes of carbon and nutrients from the uplands to streams and how their controlling processes might change. Sampling transects of soil solution and trace gas fluxes from uplands through riparian zones into streams in which the partitioning of organic matter and nutrients into gaseous, liquid, and particulate phases is tracked will identify the sequence of substrate and oxidation/reduction conditions that control the partitioning and degradation pathways. Stream properties that will be measured, using manual sampling and automated sampling to catch high flow events include pH, conductivity, NH_4^+, NO^{3-}, P, Dissolved Organic Nitrogen (DON), Dissolved Organic Phosphorous (DOP), cations, silica, Sr, Cl^- and SO_4^{-2}, total suspended solids (C,N,P), chlorophyll, Dissolved Organic Carbon (DOC), Particulate Organic Carbon (POC) and ^{13}C of DOC and POC. The task will use manipulative studies to assay the controls of phosphorus and light on algal growth.

ND–Task6: Regional and mesoscale modeling of hydrology and stream water chemistry
Amazon region–scale and mesoscale modeling will be based on the hydrologic routing modeling from partners in LBA, and the process–level understanding derived from the Task 5 studies. These models will predict the output hydrographs of water and chemical constituents (versus the measured time series) under different conditions of land use. Distributed surveys of stream chemistry as a function of diverse local ambient conditions and land–use patterns will allow an extension of the models that would be developed in the more intensive study areas to a wider range of conditions.

2.2.4 Trace Gas and Aerosol Fluxes

Upland soils, wetlands soils/sediments, and vegetation of Amazonia all emit significant quantities of trace gases. These three functional sources have different controls that may be altered by the process of land–use change. Trace gases of interest include those that are primarily important to the radiative properties of the troposphere, such as nitrous oxide (N_2O), and those that regulate oxidant balance. Trace gases that regulate oxidant balance include carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2) ($NO + NO_2 = NO_x$), and volatile organic carbon compounds (VOC) (Fehsenfeld et al., 1992). Methane (CH_4) has both functions. The effects of natural ecosystems are included in this plan, which emphasizes the perturbations brought about by human development efforts.

Measurements in the Brazilian Amazon and in other tropical areas indicate that tropical forest soils are a major global source of N_2O (Matson et al., 1990; Keller and Matson, 1994) and probably a small sink for CH_4 (Keller et al., 1983; Keller et al., 1986; Steudler et al., 1996). The conversion of a forest to cattle pastures results in soil compaction and limited drainage. This in turn limits gas diffusion that may reduce the consumption of CH_4 or increase the production of N_2O by denitrification. Luizão et al. (1989) found that, on an annual basis, emissions of N_2O from pastures exceeded forest emissions by a factor of three. They suggested that conversion of tropical forest to pasture might account for as much as one Tg N_2O–N annually, about 25% of the current imbalance of N_2O sources over sinks. Subsequent work by Keller et al. (1993) in the Atlantic Lowlands of Costa Rica shows that this estimate is probably an upper bound because N_2O emissions decline with time following deforestation. Like N_2O, NO emissions appear to peak within a decade following deforestation and pasture conversion at the lowland Costa Rican wet forest site (Keller et al. 1993). Studies in Rondônia show that conversion of forest to cattle pasture can change a net methane sink to a small net CH_4 source (~1 mg m^{-2} d^{-1}) (Steudler et al., 1996).

Globally, natural wetlands produce approximately 110 Tg y^{-1} of CH_4, roughly 60% in the tropics (Fung et al., 1991; Bartlett and Harriss, 1993). Devol et al. (1990) estimate that the main–stem floodplain of the Amazon River alone may account for five to ten Tg y^{-1} CH_4. Amazon–wide estimates are hampered by a lack of knowledge regarding wetland areas and distribution of ecosystem types as well as a dearth of studies of wetlands off the main stem of the Amazon River.

One of the surprising results of the NASA and INPE sponsored Amazon Boundary Layer Expeditions (ABLE–2) of the 1980's was the inference of a strong CO source. A CO source of 4×10^{11} molecules cm^{-2} s^{-1} was discovered in tropical forests based on measurements of boundary layer CO concentrations in tropical forest (Kirchhoff and Marinho, 1990). Jacob and Wofsy (1990) concluded that the CO source could not be explained by hydrocarbon oxidation. They suggested that direct emissions of CO from vegetation account for at least part of the inferred source (Tarr et al., 1995).

Terrestrial vegetation is the largest global source of volatile organic carbon compounds (VOC) to the atmosphere, exceeding industrial processes by a factor of two to three (Müller, 1992). Investigation of the vegetation emissions of VOC's to the atmosphere in the Amazon region has been exceedingly limited. Results from the Brazilian–American Amazon Boundary Layer Expedition (ABLE–2A) in forest outside Manaus, Brazil, indicated that isoprene emissions ranged from 25 to 38 mg m^{-2} d^{-1} and monoterpene emissions were about 6 mg m^{-2} d^{-1} (Zimmerman et al., 1988; Jacob and Wofsy, 1988). No published data are available at the level of individual plant species from the Amazon region.

2.2.4.1 Trace Gas and Aerosol Flux Science Questions

TG–Q1 What is the magnitude of the annual flux of CH_4, N_2O, NO_x, CO, and VOC from Amazonia?

TG–Q2 How do the temporal and spatial patterns and controls of soil–atmosphere trace–gas fluxes resulting from conversion of forest to pasture vary across soils and climate in Amazonia?

TG–Q3 How does the magnitude of trace gas and aerosol flux in pastures vary through succession and with management practices?

TG–Q4 Do selective logging and related practices have a significant effect on soil–atmosphere exchange of trace gases, and how do these fluxes change as forest sites recover from logging impacts?

TG–Q5 What is the magnitude of CH_4 emissions from inundated areas, and what are the physical and ecosystem level controls? How do emissions of CO_2, N_2O, and CH_4 vary along a transect from uplands to the riparian zone and stream?

TG–Q6 What are the major controls on CO and VOC production and emissions? Can different VOC emission capacities be associated with specific land use types?

TG–Q7 What is the impact of aerosols on radiation (PAR, UV) fluxes and nutrient cycling, and what is the magnitude and composition of aerosol flux from different land use types in Amazonia?

TG–Q8 Are losses of carbon from forested systems in forms other that CO_2 (CO, CH_4, VOC, organic aerosol) of sufficient magnitude to influence ecosystem carbon balance estimates obtained from eddy covariance techniques?

2.2.4.2 Trace Gas and Aerosol Flux Research Tasks

TG–Task1: Quantify trace gas and particulate fluxes over natural and managed systems

The fluxes of N_2O, NO_x, CH_4, CO, VOC, O_3, and particulates will be quantified over natural and managed ecosystems. The fluxes can be estimated from sampling techniques such as eddy covariance (for isoprene), relaxed eddy accumulation (CO, VOC, NO_x), and profile measurements from towers or balloons (CO, VOC, NO_x, N_2O, CH_4, particulates). Automated and manually operated enclosures will be used for measurements over soil and vegetation surfaces (N_2O, NO_x, CH_4, CO, VOC). Measurements will cover a range of sites along the LBA transects, which will complement sites selected by the European Studies on Trace gases and Atmospheric Chemistry–LBA (EUSTACH–LBA) project. Both continuous and campaign measurements are planned. Multiple land uses will be sampled, including chronosequences of pastures and secondary forests. Logging sites will be studied prior to and following cutting. On local scales, sampling will be stratified according to soil types, drainage, and landscape position.

TG–Task2: Diagnosing controls on trace gas fluxes using measurements and models
Trace gas studies will be closely linked to studies of ecosystem productivity, decomposition, nutrient cycling, and hydrology. The controls on trace gas emissions will be diagnosed using statistical models and simulation models that incorporate key ecosystem processes (e.g. DeNitrification and DeComposition model (DNDC), Carnegie Ames Stanford Approach (CASA) Biosphere model).

TG–Task3: Estimation of regional biosphere–atmosphere trace gas
Background gas concentration measurement and models will be used to estimate trace gas fluxes from the region. The distribution of trace gas concentrations and particulate characteristics (using in situ and remotely sensed measurements) will be measured in the region at a number of ground points and through weekly aircraft sampling. Researchers hope to leverage their activities and those of partners in LBA to include a sufficient sampling frequency and number of sampling locations (including vertical distributions) to place constraints on fluxes of trace gases and particulates using inverse models. As in the case of carbon, regional extrapolation will be attempted using bottom–up approaches whereby ecosystem models will be implemented in a GIS framework with underlying soil, vegetation, hydrologic, and climatic forcing.

2.3 Field Measurement Strategy

Field measurements, remote sensing, and modeling will be integrated in order to answer the LBA–Ecology science questions. The use of existing environmental gradients and human–caused disturbances provides a powerful framework for experimental design without the logistical difficulty and expense of conducting large–scale manipulations. Studies of chronosequences of managed and successional sites will provide us with understanding of the temporal responses to land use changes. Two LBA transects have been identified (Figure 2.1) that cover a gradient of total annual precipitation. Rainfall is highest and the dry period is shortest in the northwest Amazon region, and rainfall is lowest, with a dry period lasting nearly half the year, in the southeast. The natural vegetation varies from wet forest at the northwest ends of the transects to savanna grassland and woodland at the southeast ends. Both transects cover a wide range of variability in soils, topography, and underlying geology. However, eutrophic soils are common on the southwestern transect (B), whereas dystrophic soils predominate on the northeastern transect (A).

Human modifications of natural ecosystems add a critical dimension to the experimental design. Some degree of human activity is found in all habitats. However, not all areas are equally affected. Eutrophic soils are more likely to be farmed than dystrophic soils. The relatively dry areas of the savanna in the southeastern portion of Amazonia are generally more heavily affected by human management than the wet forests of the northwest Amazon for a variety of geographical reasons (e.g., proximity to markets, transportation networks, soil associations). Historical, political, and social dimensions have also influenced the extent and the pattern of development in different regions. LBA–Ecology has selected two intensive sites near the towns of Santarém, Pará (extending to nearby areas of the Trans–Amazon Highway) and Ji–Paraná, Rondônia for intensive study of land use and cover change and the effects of multiple land uses on ecosystem function. Researchers from Brazil, Europe, and the U.S. will be involved at studies at both of these sites.

In addition to Santarém, Pará, the northeastern transect (A) includes a number of distributed sites where one or more major land uses will be studied. These include Manaus, Amazonas, a long–term focus for research led by the Instituto Nacional de Pesquisas da Amazonia (INPA), where studies will emphasize old growth forest, logged forest, and secondary succession in abandoned agricultural areas; the Zona Bragantina, near Belém, Pará, which has a long history of small–holder agricultural activity; and the area surrounding Brasília where natural savannas and savanna areas have been exploited for cattle ranching or converted to row crop agriculture. In addition to these sites, the Science Team plans to collaborate with EUSTACH–LBA to study the undisturbed forest at the Caxiuanã Research Station. This site provides access to both upland and wetland ecosystems and the logistical support of the station operated by the Museo Paraense Emilio Goeldi. In the future, it is hoped that collaboration with South American and European groups will extend the northeastern transect to São Gabriel de Cachoiera in wet forest in the state of Amazonas, an area with relatively little human influence.

Fewer distributed sites are currently located along the southwestern transect. In addition to the study sites in Rondônia, sites in Acre will anchor the northeastern end of this transect. Additional sites have not been selected along the southwestern transect.

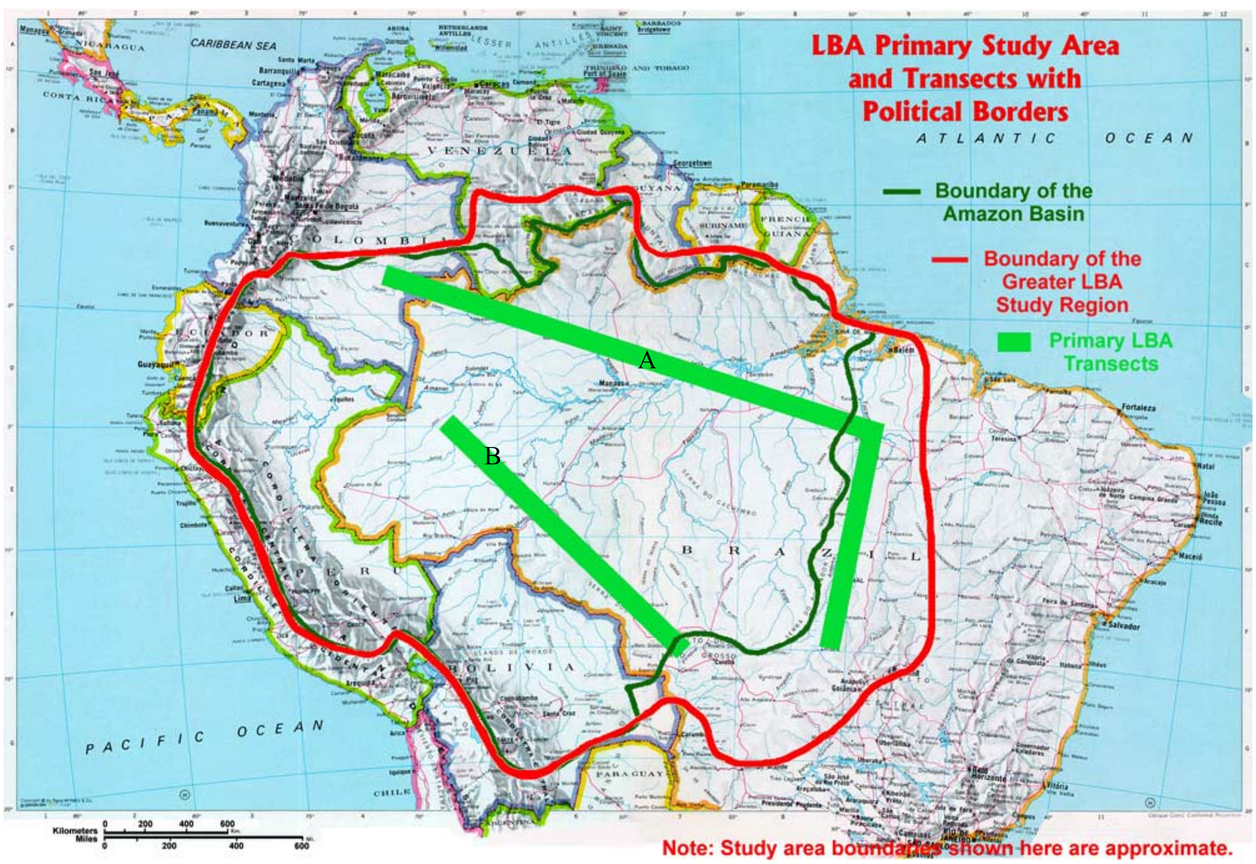

Figure 2.1 Transect Map