

FINAL REPORT

**Spatial and Temporal Patterns of Biotic Exchanges
of CO2 Between the Atmosphere and Tropical
Landscapes
and Their Role in the Global Carbon Cycle**

(#DE-FG02-90ER61083)

We have no objection from a patent
standpoint to the publication or
dissemination of this material.
Richard Fisher 4/4/96
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OVERVIEW

This document is a final report to the Department of Energy for work done at the University of New Hampshire (DE-FG02-90ER61083). The aim of the research is to determine the net annual flux of carbon between terrestrial ecosystems and atmosphere. The approach we take couples remote sensing, geographic information systems (GIS), in-situ measurements, and modeling.

The general objectives of the overall research are:

(1) The quantification and mapping of the rate of deforestation in the tropics, primarily through GIS-based analysis of tabular datasets and with remote sensing data.

(2) A calculation and analysis of the net annual exchange of carbon between tropical ecosystems and the atmosphere from deforestation, reforestation, and degradation using a large-scale, geographically-referenced carbon model.

The results from the first objective are reported in the form of two published, peer reviewed articles, which can be referenced as follows:

- Skole, D.L. 1994. Data on global land cover change: acquisition, assessment, and analysis. In, Meyer, W.B. and B.L. Turner, (eds.), *Global Land Cover and Land Use Change*, Cambridge University Press, Cambridge.
- Skole, D.L., W.H. Chomentowski, W.A. Salas, and A.D. Nobre, 1994. Physical and human dimensions of tropical deforestation in the Brazilian Amazon, *Bioscience* 44(5): 314 - 322.

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The results from the second objective are reported the form of a peer review paper which can be referencec as follows:

- Skole, D.L., B. Moore, and W.H. Chomentowski. 1994. Spatial analysis of land-cover change and carbon flux associated with biomass bunnring in Brazil, 1970-1980. In, R. Zepp (ed.) *Climate and Biopshere Interactions*, John Wiley, New York.

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SUMMARY

Land cover change is one of the most important components of global change. It might be argued that over the next 20 to 50 years the global effects on ecosystems and human habitability from land cover conversion will be much larger than any estimated to arise from climate change. Only a few datasets exist, and these suffer from a number of technical and interpretive problems. There are three areas of uncertainty which need much better documentation and analysis: (1) the state (ie information on biomass, net primary production, etc.) and distribution of existing land cover, (2) the rate and distribution of land cover conversion, both historically and currently, and (3) the underlying driving forces which determine the rate and extent of land cover conversion. Some combination of historical reconstruction and remote sensing are needed to refine the first two areas.

Future research can be developed around three general areas: (a) acquisition and analysis of new data on existing and pre-disturbance land cover, using a combination of satellite data, historical reconstructions, and maps, (b) acquisition and analysis of mapped data on the distribution of primary agents of land cover change, such as deforestation or agricultural expansion using satellite data for the contemporary period (since 1978), and tabular census data for historical periods, (c) development of models, both explanatory and numerical, which are based on simple extrapolation for short term analyses and socio-economic factors for long term analyses.

EXTENDED SUMMARY

Coarse resolution remote sensing data could provide the basis for defining the distribution of current land cover. The advantages to this over existing maps is temporal consistency and an explicit definition of actual, rather than estimated, boundaries between cover types. The most straightforward approach would be to derive maps of current land cover types from remote sensing measurements along pre-defined classification system. It seems unlikely that a single classification will suite all needs, however. But much could be gained by initiating international efforts to collect the necessary datasets from existing satellite sensors, such as AVHRR, from which various classifications could be made on a case by case basis. A remote sensing-based map of current land cover could form the base from which a pre-disturbance land cover map could be created by correlating existing natural land cover with physical variables (eg. temperature, precipitation, edaphic conditions), or through approximation based on simple assumptions of contiguity and spatial clustering. Having such maps of both current and pre-disturbance land cover, it might then be possible to reconstruct the history of land cover change with the addition of geographically-referenced time series of human use and conversion, such as maps of the expansion of deforestation. Since much of the analysis is spatial, a GIS would be used to organize the data and analysis.

Thematic classification of land cover from remote sensing data follows traditional cartographic approaches. For many aspects of global change research, in the fields of biogeochemistry and water/energy dynamics for instance, there is a need to parameterize land cover beyond basic classes such as forest, savanna, and the like. Here, the need is for parameters such as nitrogen status, biomass, primary productivity and other land cover-related parameters. Functional classifications, of the type mentioned in this paper, could be very important new approaches to classification of land cover. However, much more research must be conducted. Another approach would be to develop methods by which direct parameterization of the state of land cover could be derived from satellite data. Direct parameterization of canopy chemistry, albedo, surface roughness, NPP and other variables could be one feasible approach which circumvents the necessity for an a-priori system of nomenclature.

Land cover conversion rates are not well known. The comparison between current estimates of deforestation in the tropics presented in this paper demonstrate the need for new and objective information. One approach would be to couple historical reconstruction with remote sensing, as shown in Figures 3 through 6. Tabular data, national censuses, or historical documents in which data are reported geographically (eg. by administrative district) could be mapped in a geographic information system. Remote sensing provide direct observations of land cover change, while historical reconstruction generally relies on indirect estimation from changes in various human-use categories. Nonetheless, the coupling of these two approaches provides a way to "calibrate" the historical assessment, since the historical trend should overlap with remotely sensed data -- both in magnitude and space -- during the years where both historical and remotely sensed data exist.

The use of coarse resolution remotely sensed data (1km or greater) to map deforestation and other forms of land cover conversion has frequently been considered the optimal approach for monitoring land cover change since it requires fewer data than high resolution sensors (less than 100m). However, in cases where coarse resolution datasets have been used in the past, they tend to overestimate deforestation. This over estimation bias is partly related to the geometry of clearing, so a single conversion factor cannot readily be developed. Considerable work remains before mixture modeling and other techniques which could derive an accurate estimate from coarse sensors could be used. Meanwhile, the best approach appears to be one based on high resolution data from such satellite systems as Landsat. The use of photoproducts at scales ranging from 1:250,000 to 1:500,000 provides an efficient, low-cost alternative. These data can be interpreted for areas of deforestation and then encoded digitally in a geographic information system.

The fine-scale dynamics of clearing, abandonment, regrowth and re-clearing are completely unknown and understudied, yet could be important to analyses of the net flux of carbon. The use of high spatial resolution remote sensing data provides detailed information on regrowth and abandonment. There is very little quantitative information on the amount of secondary growth. Some preliminary results from on my own work and others suggests as much as 20% of the deforested land in the Amazon Basin is in some stage of regrowth at any point in time.

Documentation of land cover change is the first step toward understanding the underlying agents of land cover change. But is clear that documentation alone will not yield a complete explanation. Simple correlations between various factors are often facile but not fruitful, and may in fact be misleading or wrong. When it works, correlation between deforestation and some other social factor such as population might be useful for developing a sampling scheme or for making short term predictions, but such an approach lacks the ability to explain the phenomenon. In Brazil, for instance, the rapid increase in deforestation in the Amazon Basin in the late 1970s was more a response to changing social and economics conditions -- in fact conditions far outside the Amazon itself -- than population pressure. Other examples can be found; it could be reasonably argued that population growth in Sub-Saharan Africa is as much a response to land degradation as it is a driving factor. Population pressure has been frequently and been cited as the main driver of land cover change, yet there is little strong quantitative evidence to support this since there is paucity of hard data on land cover change.

It could be reasonably argued that if a correlation between population and land cover change exists, such a relationship could be used as a first-order, short term predictor of land cover change, both in terms of extent and spatial distribution. However it is not clear that for short term predictions, complex formulations based on population, economic variables, or social drivers are required to make reasonable predictions. In mapping studies of deforestation in the Amazon which we are developing now at the University of New Hampshire, it appears that the rate and spatial distribution of deforestation are somewhat persistent over short time periods (see for example Figure 14 which shows the spatial arrangement of deforestation as a function of distance from concentrated settlements at two dates, 1975 and 1978). The indication from these data are that spatial relationships are maintained from one date to the next in generally predictable ways. The conclusion one draws is that the best predictor of deforestation at time, $t=n$, is the deforestation at time, $t=n-1$. This, in turn, suggests that one of the highest priorities in deforestation prediction and analysis is an accurate base map of deforestation. Predictions on time horizons beyond one or two decades will require more sophisticated models which consider primary causal factors, and an understanding of the complex social and economic conditions which exist in a particular region.