Global Land Cover: The need for a dynamic, long-term database

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Summary

The global change research community needs to understand how the Earth's land cover is changing on an ongoing and long term basis. Land-use/cover change is important for global change because of its direct effects on the terrestrial biosphere (e.g., degradation, erosion, biodiversity), its impacts on atmospheric composition, and its direct effects on climate. Several issues are crucial to the development of appropriate land-cover/use databases for global change research:

- dynamic databases, with 5 or 10 year 'time slices';
- common land-cover classification schemes between data and models;
- linkage between land use and land cover; and
- development of an historic land-cover database.

In recognition of these issues, the International Geosphere-Biosphere Programme (IGBP) has initiated a project to build an historic land-cover database. The main components of such a database are described, as well as methodologies for developing the database and problems and uncertainties associated with those methodologies.

Background

Understanding how and why the Earth's land cover is changing is essential knowledge for global environmental change programmes such as the International Geosphere-Biosphere Programme (IGBP). IGBP is an international, interdisciplinary research programme whose overall goal is to describe and predict the interactive physical, chemical and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions. IGBP's research effort is structured around eight core projects. One of the eight is the Land-Use/Cover Change (LUCC) Core Project, which is jointly sponsored by the International Human Dimensions of Global Environmental Change Programme (IHDP). LUCC's objectives are to record the rates and trajectories of land-use and land-cover change, understand the driving forces – both proximate and ultimate – for these changes, and project these changes into the future (Turner et al. 1995).

It is important to note at the outset the difference between land cover and land use. Land cover is the assemblage of vegetation, animals and soils, as well as human structures, that actually occupy a place on the Earth's surface. Land use refers to the use or uses to which human societies put a particular land cover. For example, temperate forest is a land cover. But that forest may have a number of land uses, such as timber production, watershed protection, recreation, biodiversity conservation, or combinations of these.

Why is land-use and land-cover research so important in global change research? There are at least three main areas.

First , and probably most important, land-use and land-cover changes have direct and profound impacts on the structure and functioning of the terrestrial biosphere in its own right, independent of any effects of climate or atmospheric composition. These impacts can be seen in the following:

- Degradation/fertility – the long term sustainability of agriculture and other human activities dependent on the land are critically dependent on soil fertility and structure. These characteristics are, in turn, largely a function of the technologies and management practices which human societies adopt – that is, on land use.
- Erosion – in addition to the direct impacts of land use on the land's fertility, such use often has knock-on effects elsewhere in the biosphere, often termed 'off-site impacts'. Perhaps the best example of this is the transport of sediments and nutrients into the coastal zone from upstream areas subject to deforestation and conversion to agriculture.
- Biodiversity – a growing concern is the effect of habitat loss and fragmentation on biological diversity. Most estimates suggest that current rates of species loss are at least 10 times about background levels, and much of this loss can be traced to land-use and land-cover change. The effects of large-scale changes in biological diversity of the functioning of the Earth system are still largely unknown.

Second, changes in land-use and land-cover can directly affect the composition of the atmosphere.

- Carbon dioxide – historically land-use and land-cover change has been an important source of CO_2 to the atmosphere. Much of the emissions come during the deforestation process, but the subsequent agricultural practices are also important in affecting the emission rate from soils. Even in the present era of high intensity fossil fuel usage, emissions of CO_2 from land-use/cover change are still a significant source.
- Other trace gases – in addition to CO_2, land-use/cover change are a globally significant source of a number of other trace gases which are of importance for atmospheric composition and chemistry, and for climate. Principal amongst these are N_2O, which is connected to the use of fertilisers, and CH_4, which is emitted during rice production and by ruminants.

Third, changes in the Earth's land cover can have direct effects on climate, in addition to influencing climate through effects on the composition of the atmosphere. At a regional level, changing land cover affects climate through changes in albedo (the reflectivity of the Earth's surface and hence the energy balance), and through changes in evapotranspiration due to changes in vegetation. It is more difficult to quantify the direct effects of land-cover change on climate at the global level, but there are some hypotheses that this effect can be significant globally also (R. Pielke Sr, personal communication).

Important issues

The global change research community requires data to address the scientific questions raised above. The data question has been discussed at length within this community, and the following issues have been raised as crucial to the development of appropriate databases:

- **Dynamic databases.** Single 'time slices' of global land cover are interesting but of rather limited value in global change research. Rather, we need to track changes in land cover on an ongoing basis to discern long term trends over broad areas (i.e., continental scale). What is required are 5 or 10 year time slices in the past (see below), beginning perhaps from the time of intensive agriculture, and, in addition, continuing maintenance of the database into the future. Remotely sensed data should help in the future development of dynamic land-cover databases.
- **Common classification schemes.** One of the major problems facing global change researchers is the plethora of classification schemes for vegetation or land cover. A recent attempt to synthesise our current understanding of global change interactions with terrestrial ecosystems had difficulty in comparing model outputs with map (in situ) derived land-cover databases (Walker et al. 1999). Many disparate classification schemes exist. A rationalisation of these schemes amongst remotely sensed data, in situ data (maps) and global model outputs, or at least translation algorithms between the most common classification schemes, is urgently needed.
- **Linkage of land-use to land-cover.** Dynamic databases of land cover will be useful to track changes in land cover over time and, for example, estimate their effects of carbon emissions. But to understand the patterns of land-cover change over time, it is essential that databases of land-use also be developed, and that the two be linked in a geographically explicit way.
- **Historic land-cover database.** As noted above, to build a dynamic global land-cover database requires that we look back in time as well as forward. Much can be learned by understanding how land cover and land use have changed over the last 200 – 300 years.

Historic land-cover database

Given the emphasis on the need to understand the evolving changes in land use and land cover over long periods of time, the IGBP has initiated, as a high priority, a project to build an historic land-cover database.

The main components of the database are land use and land cover. More specifically, information on agricultural activities are essential; these include crop production in both area and yield, animal production in terms of types and numbers of livestock, and fertiliser usage. In addition, some environmental parameters associated with land cover, such as carbon storage, are also important and need to be included in the database.

Current estimates of land use and land cover can be derived in a number of ways. For example, databases of vegetation distribution (Olson et al. 1985) can be used as a basis, and then modified using statistics on agricultural activity (FAO 1991) to modify the ‘potential vegetation’ to give actual land cover. Another method is to simulate natural or potential vegetation with a global vegetation model (BIOME, Prentice et al. 1992), and then ’stamp’ the map with agricultural areas estimated from a soils map, crop suitability, population density and a map of methane emissions as a proxy for grazing activity (IMAGE, Alcamo et al. 1996).

Deriving land-use and land-cover maps for the past is more problematical. Again, statistics from organisations like FAO can be used to develop the ‘time slices’, but these only go back to about 1960. For earlier periods, estimates of land-cover conversion rates can be used to ‘backcast’ what land-cover might have been, or proxy methods, such as estimation of agricultural areas from population density maps, can be used.

It must be recognised that any historic land-cover database will be subject to considerable uncertainties. The most important of these are:

- lack of reliable statistical data before 1960;
- lack of sub-national data and documentation (which is important for matching socio-economic data based on political boundaries to biophysical land cover presented on a spatially explicit geographical grid system); and
- for most recent periods, the choice of using map-based data or remotely sensed data as the basis for the database.

The use of proxy methods carry with them fundamental uncertainties. For example, is population density a reasonable proxy for agricultural activity? Can pasture allocations be made by inverse calculations from methane emissions data?

Conclusions

There is broad consensus that global databases of land cover are crucial for global change research. Map-derived databases can play an important role in this effort. To be most effective, however, global maps of land cover should:

- be available in digital formats;
- be constructed over at 5 or 10 year intervals back in time (i.e., not a single ‘time slice’) but an historic database as well; and
- adopt common land cover classification schemes in collaboration with the remote sensing and global modelling communities.

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