

Biomass and soil carbon: Major research needs for the coming decade

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Abstract

We have selected nine topics of particular importance for gaining a better understanding of the inter-relationship between vegetation, the global terrestrial carbon cycle and climate change. Four of these priorities have an Australia-specific focus. In priority order they are:

1) Reduce uncertainty in Australian continental net primary productivity.

A primary input to any terrestrial carbon cycle model is an estimate of the rate of annual uptake of CO₂ from the atmosphere. Ability to model the baseline is a prerequisite to convincing modelling of its response to climatic change. Review of 18 model estimates of the long-term average net primary productivity of the Australian continent (Roxburgh et al. 2005) reported an 8-fold range from 0.4 Gt C yr⁻¹ to 3.3 Gt C yr⁻¹. Whilst some of this variation is due to identified modelling differences (e.g. use of current actual land cover vs potential vegetation cover, or driven by the weather in specific years vs long-term climatic averages), the extent of this range of estimates does highlight that knowledge of national NPP is still inadequate for many applications.

A national stratified network of long-term field sites is needed to estimate NPP by an agreed methodology, linked with model development and satellite imagery for interpolation, and augmented with a small number of sites for intensive measurements and determination of component C fluxes including towers for eddy-covariance measurements. At some of the long-term sites, plots with treatments (water, minerals, CO₂ concentration) should be included to facilitate prediction of future NPP.

2) Determine how C-stocks in Australian natural ecosystems may change under increasing [CO₂] and temperature.

The magnitude of the global terrestrial C 'sink' has increased from zero around the beginning of the 20th century to around 2-3 Gt C yr⁻¹ at the end of the century, and it may still be increasing (Houghton 2007). While it is not known exactly what is driving this increasing terrestrial sink, the increasing atmospheric CO₂ concentration is one plausible driver via the CO₂ fertilising effect on plant productivity. Since such a sink must eventually saturate and could even become a source with continued global warming (Canadell et al. 2007), it is important to determine the respective roles of increasing CO₂ concentration, temperature and other climatic conditions, such as water availability, in changing ecosystem C stocks world wide. Each ecosystem type is likely to have a different response to increasing CO₂ concentration and temperature. There have been few investigations of the response of Australian ecosystems to changing conditions, or

evaluation of when, or whether, the response to some environmental drivers, especially CO₂ concentration, may saturate (Canadell et. al. 2007, Raison et. al., 2007a).

3) *Quantify & model the recovery of the C-cycle to disturbance events induced by changes in climate and/or management.*

Abrupt changes in ecosystem carbon stocks via episodic disturbance events are characteristic of Australian ecosystems. Wildfire, woody vegetation clearing, agricultural management events, forest clear-felling and widespread pest/disease outbreaks are major agents of such events. There is a need for improved knowledge of their immediate impact on C stocks and the subsequent dynamics of recovery before these factors can be incorporated into high resolution dynamic vegetation models within the next generation of GCMs.

4) *Better quantifying the formation and fate of black carbon (char)*

A substantial fraction of soil organic matter in many Australian soils is black carbon that was derived from wildfire during earlier times. Even though it is estimated that usually less than 3% of carbon consumed by fire remains as such char (Forbes *et al.* 2006), these small fractions can accumulate over many years and fire episodes. Black carbon is highly resistant to decomposition and hence represents a potentially very long-term sink for atmospheric C. For future long-term climate modelling, this small sink and the ultimate fate of this recalcitrant carbon need to be incorporated into dynamic vegetation subroutines. This requires improved knowledge of the determinants of the fraction of ecosystem converted to black carbon, the routes of black carbon for subsequent gradual oxidation and quantification of the pathways to alternative long-term storage, such as ocean sediments.

The remaining five topics are of generic global relevance for modelling the terrestrial carbon cycle. In priority order they are:

5) *Coupling the C cycle with N & P cycles*

Ecosystem carbon cycles are tightly coupled with nutrient cycles that drive both plant growth and litter decomposition processes. Any long-term changes in productivity and carbon stocks due to CO₂ fertilisation, or changes in temperature or rainfall are modulated by constraints imposed by the N-cycle. Rastetter et al. (1992) postulated that ecosystem carbon stocks can change only if nitrogen stocks can change through some mechanism, if C:N ratios of key ecosystem pools change, or if carbon is shifted between pools with different C:N ratios, such as between the soil and woody stems. These considerations limit the response of productivity or ecosystem carbon stocks of nutrient-limited systems to changing CO₂ concentration or other aspects of a changing climate (Kirschbaum 2004).

This hypothesis contrasts with the “carbon cycle leads the nitrogen cycle” hypothesis of Gifford (1992) who postulated that over the gradual time scale of changes in atmospheric CO₂ concentration or temperature, any increased photosynthetic assimilate supply could provide the energy resources for ecosystems to acquire additional N. This could derive from symbiotic & non symbiotic N-fixation, or from retaining a greater proportion of

circulating N in N-turnover and atmospheric deposition processes. N-fixation is in turn constrained by P-cycling, and a key question here is the flexibility of C:P ratios in soil organic matter and the relationship between P in organically versus inorganically bound forms. Disturbance by fire is known to be important in inducing pulses in P availability and consequent increases in rates of N fixation (Raison et.al., 2007b).

For vegetation modelling under global climate change, it is essential to determine to what extent carbon stocks and fluxes are constrained by mineral nutrient cycles. More emphasis is needed on the study of system responses to changing environmental conditions under a range of different co-limitations.

6) Acclimated temperature response of SOM decomposition rates

Some GCMs predict a very strong positive feedback of global warming onto modelled atmospheric CO₂ concentration via oxidation of soil organic matter to CO₂. This result should be viewed with caution as it may be largely due to the simple model-structures for soil pools in GCMs that fail to distinguish between pools having very different residence times, and to the absence of negative modelled-feedback loops, especially in relation to nutrient cycles. The importance of any temperature sensitivity of soil organic matter protection mechanisms, and of acclimation of soil microbial populations, are further unknowns.

While this is a key area of uncertainty that requires further work for resolution, it is not yet clear how further configure further basic experiments for real progress. We feel that more can be gained by first analysing the large amount of existing soil respiration and decomposition data to help resolve the conflicting interpretations.

7) Understanding the temperature-dependence of NPP

To model the effects of global warming on vegetation dynamics, it is necessary to understand how warming affects NPP. For that, it is important to distinguish:

- short-term growth responses to temperature from physiologically acclimated responses.
- physiologically-acclimated responses to temperature from genetically adapted ecosystem responses.
- partially acclimated/adapted responses from fully genetically adapted community responses.

Kerkhoff et al. (2005) conducted an analysis of NPP of the major biomes of the world and found that the growth rate of all biomes was independent of temperature if annual NPP was expressed as above ground growth per month of growing season (ie above 0°C). Differences in the annual productivity of different regions could be fully accounted for through differences in the length of the growing season. The authors hypothesised that this was attributable to compensatory increases in the N-productivity of ecosystem growth. The result and explanatory hypothesis need further investigation.

8) Fraction of above ground litter taken into soil

Terrestrial carbon cycle models have routines to decompose plant litter but do not always distinguish between above-ground litter and root litter. It has not yet been adequately

established to what extent above-ground litter is transferred to the soil in different ecosystems and contributes to organic matter formation, or whether surface litter is largely oxidized (either by microbes or fire) above ground and makes little contribution to organic matter formation. Long-term decomposition field experiments in a variety of environments including Australian ones are needed to be able to adequately distinguish between the decomposition pathways of above and below-ground litter.

9) *Understanding and modelling the capacity of the soil to store additional C inputs*

One of the factors that might contribute to saturation of the terrestrial carbon sink is an upper limit of soil organic matter stocks. It is commonly believed that soil organic matter concentration in a given soil reaches a saturation level at which the concentration stabilises despite further increases of litter input. Little is known about this process, how often it is of practical importance, or how to define it in models. Should it be represented in DGVMs?, and if so, how? There is a need for experimental evaluation for a range of soil and litter types.

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