NCESS Carbon sub-committee's recommendations on research priorities for the next decade relating to vegetation dynamics and global climate change.

Summary

At the national level, carbon fluxes in and out of the biosphere resulting from human activities will soon have an economic reward or penalty depending on its impact on atmospheric CO_2. Globally, the natural CO_2 sinks on land and in the oceans can be seen as a subsidy to our global economy worth hundreds of billions of dollars every year if we had to remove the same amount of carbon through mitigation activities. Understanding how carbon flows through our natural and human-changed systems is essential to successful climate mitigation and adaptation programs. Specifically, this information will inform and guide:

- the protection of ecosystem services via an understanding of terrestrial ecosystem functioning;
- more efficient and reliable greenhouse gas accounting as a means of managing net greenhouse gas emissions; and
- a predictive capacity of how terrestrial ecosystems will respond to climate change.

Each of these themes is ultimately informed by modeling. All approaches to modeling are informed critically by developments in process-based understanding. There can be no long-term improvement in our understanding of processes without a systematic observational program. Long-term observations are also key to tracking the response of the earth system, especially atmospheric CO_2, to whatever mitigation measures are implemented – how else will we know if they are being effective? The integration of these three themes provides the science-basis for sound decision making and policy development and minimizes the chances of large economic and social investment in flawed adaptation and mitigation strategies.

Background

The Blueprint for Australian Terrestrial Carbon Research (2005) provided clear guidance on the key role of carbon to Australia and the priority areas for research. Patterns of sinks and sources of carbon, how these may change in time, and how and where Australian terrestrial carbon sinks might be vulnerable now and in the future were highlighted as research priorities. Carbon cycling underpins our natural systems, and our socio-economic health. Developing the means to monitor and model carbon dynamics, in the past, present and future presents a major challenge. However, it is a challenge that must be overcome to inform emissions trading. It must also be overcome to help identify regional vulnerabilities to climate change, identify sound land-based mitigation strategies and highlight appropriate adaptation strategies to minimize regional vulnerability.

This document has been informed by the Blueprint for Australian Terrestrial Carbon Research (2005) and by the report by Dr Roger Gifford following the August 2007 workshop on "Vegetation and climate change". This summary revises some of the recommendations reached at that workshop and draws these recommendations together within the broad framework of the blueprint. Specific recommendations are made on research priorities and how to implement these priorities.

The detailed case supporting each recommendation is made in the Blueprint and in the Gifford report and is not reproduced here, although we do cross-reference to the Gifford report. Gifford establishes the rationale for this research including demonstrating the economic and national

reporting imperatives to tracking GHG uptake and emission from Australia's vegetation and soils annually. We note again that Australian ecosystems *are different*. They reflect the ancient nature of the Australian continent, the nutrient limitation, the role of fire and the relative lack of water in a highly variable climate. Thus, Australian ecosystems have evolved within fundamentally different constraints from northern hemisphere systems. To understand how Australian ecosystems will respond to climate change and increasing atmospheric carbon dioxide will require significant local studies to supplement the global research effort. Without this we will be disadvantaged in managing and assessing risks to our carbon stocks and sinks, and associated ecosystems services that support the wellbeing of Australian society.

This report does not attempt to be all encompassing. It does not consider other research priorities including a better understanding of socio-economic drivers of land use change and its full radiative forcing consequences for climate and the provision of ecosystem services. Rather we focus on informing policy and decision making through achieving four carbon-related fundamental goals:

1. Ecosystem Services

Ecosystem services are the functions of managed and unmanaged ecosystems which provide benefits to the wellbeing of society. Examples of these services are the capacity to remove carbon emissions from human activities, providing clean water and fertile soils, buffering capacity for flooding and coastal surges, recreational opportunities and a myriad of other services outside of our current economic evaluation. Quantifying ecosystem goods and services underpinning Australia's well being in light of environmental and policy changes provides an enhanced capacity to deal with multiple tradeoffs.

2. GHG accounting and reporting to meet national and international requirements

The land sector has a significant effect on the GHG signature of Australia, and there are international obligations to report on this under the UNFCCC. The recent signing of the Kyoto Protocol, and the need to support GHG accounting as part of the proposed ETS are additional drivers. Significant and on-going research is required to strengthen the capacity of the NCAS to account for GHG emissions and uptake from Australia's large and heterogeneous land systems. This research will underpin new technologies and models that can increase the efficiency and certainty of estimates of GHG emissions relating to:

- Climate variability, climate change, and related disturbances such as fire
- The GHG benefits of a wide range of mitigation activities

3. Continental-scale monitoring

Terrestrial observations are essential for each of the following goals

- *Monitoring the state of the system (land surface and atmosphere)*: to detect trends, episodic events and abrupt changes; to evaluate the effect of management strategies; and to assess and manage carbon resources. Long-term and continuous observations; high quality data; and effective data analysis, quality control, storage and distribution systems are all essential.

- *Model development and testing*: to better understand processes and represent these in models; to parameterise models and quantify model biases, and to provide rigorous and independent verification (benchmarking) of model predictions.

- *Fusing observations with models*: to improve predictions by data assimilation (as done with success in numerical weather prediction); and to diagnose trends and variability in terrestrial energy, water and carbon budgets.

As there is no single terrestrial observing sensor that can provide the resolution, quality and representativeness across the continent needed to achieve these goals, what is required is an integrated observing framework that combines in situ, remotely-sensed and targeted experimental and field observations. To be sustained and transformed from *data* to *understanding* requires that these observations are closely aligned to the science drivers and priorities described in this paper and the underpinning Blueprint and Gifford report.

4. **Predictive capacity of carbon at local, regional and global scales.**
   The building of a dynamic global vegetation model enriched by Australian science is one priority, but this is best informed by regional and local modeling initiatives that build process-based understanding into the global models based on observations. This underpins adaptation initiatives as the improved projections allow a clearer determination of adaptation priorities.

Overall, to inform these four goals, in a cost effective and reliable way requires fundamental and sustained developments in the science of carbon dynamics. It requires long-term observations, process-focused science to improve our understanding and then the incorporation of this understanding into Earth System models. Our recommendations therefore focus on these three, but these build over time to a gradual enhancement of our knowledge of, and capacity to manage, our environment in ways that directly contribute to our socio-economic well-being.

Overarching goal

To underpin strategic planning and decision making for Australia's land resources through the development and maintenance of a research and monitoring program involving theory, experiment, observation and integrative system-modeling.

To achieve this goal we must develop;

- *a coordinated network of fixed, long term (multi-decadal) terrestrial ecological, eco-physiological and eco-hydrological observation areas, integrated with remote sensing data. These should be established by governments as national reference stations*

and because models can spatially and temporally integrate observations and underpin our capacity to project these systems into the future we must develop;

- *ecosystem models configured for local, regional and global applications. These inform each other and can be used to inform experimental and observational research. They can be developed now, and later be improved using data from the coordinated network.*

To achieve the overall goal and the two enabling recommendations, a series of specific recommendations on research directions and priorities can be made. These are prioritized based on their significance in achieving the goal, their cost and their potential for success.

Fundamental observational needs

R1 *A national network of long term terrestrial observing and research sites should be established by governments as basic infrastructure for national reference stations for multiple time-series measurement and analysis. This network should meet the following criteria:*

- The sites should encompass key Australian ecosystem types, a variety of climate zones, and varying levels of management.
- Observations should be long-term to incorporate several climate cycles and disturbance events.
- The network should include a hierarchy of ground-truthing sites with varying levels of observation intensity. Base level sites, for example, might require only decadal measures of vegetation condition, grading up to high-level sites with intensive measurements of carbon, water and nutrient fluxes.
- At the highest level of the network, multi-temporal remote sensing would provide a continental coverage of vegetation cover and some elements of vegetation "condition", and a basis for interpolation from site observations.

A detailed design and implementation plan should be prepared in liaison with the Terrestrial Ecological Research Network (TERN). The plan should recognize that this more extensive terrestrial observing program builds upon TERN. The above framework and network of field sites can be used to guide the nature and deployment of the research agenda encompassed by the set of recommendations that follow. (RG11, RG#17, RG#6, RG#10, RG#20).

R2 *Manipulative experiments are required at a subset of sites to complement the observational studies. Such experiments should include manipulations of CO_2, water and nutrient availability, disturbance regimes and temperature, either individually or factorially. The Gifford report prioritises:*

- One or more long term FACE (Free Air CO_2 Enrichment) experiments, with an initial forest FACE study being established in a eucalypt forest that is subject to both water and nutrient limitation, with water availability as an additional experimental factor.
- Experiments employing increased and decreased water input, to help understand whether the relationship between rainfall and net primary production is the same for Australian evergreen ecosystems as for northern hemisphere ones.
- Disturbance should be manipulated experimentally at selected sites to build scientific understanding and associated model development.
- Long-term experimentally elevated CO_2 and temperature studies are needed, which embrace both manipulative nutrient regimes and natural ecosystems having natural mineral cycles, to elucidate feedbacks through nutrient cycles.

R3 It is imperative that data from network sites be made easily available to operational agencies, government and the research community via a significant data archiving, and data serving initiative. A significant investment in a terrestrial observation system must be underpinned by a well-planned data archiving and data serving initiative.

R3 Research should be undertaken to improve the estimation for a grid-cell(or pixel of any particular size) a surface description across a range of plant functional and ecosystem types to inform a range of Australian Earth System modeling (RG#23, RG#5.

Fundamental process-based understanding

Research into understanding the distribution and functioning of vegetation types in Australia must be enhanced to support Earth System Modelling at local, regional and global scales. Resolving issues as fundamental as the sign of the terrestrial carbon feedback requires advances in process-based understanding. Key among these includes instantaneous transpiration, photosynthesis and photo-respiration, and autotrophic and heterotrophic respiration. Fundamental advances in all these areas are required to improve Australian Earth System models (RG#22).

R4 For modelling plant CO_2 & H_2O exchange, understanding of plant photosynthetic, respiration and stomatal acclimation to elevated CO_2 concentration and temperature remains problematic. It is necessary to continue evaluation of the alternative methods to represent autotrophic respiration in vegetation models in relation to environmental change. Progress is needed in the fundamental understanding of feedbacks that determine photosynthetic and stomatal acclimation to elevated CO_2 concentration and the expression of such feedbacks in Australian species under field conditions. (RG#7)

R5 New research and synthesis should be conducted to develop simplifying concepts for modelling the allocation of new growth between vegetation parts (leaf mass and area, root, stem, reproductive organs) and respiration for specified plant functional types on short (sub-year) and long (annual to decadal) timescales. RG#8

R6 undertake research and literature analysis to determine the relationship between decomposition of litter and heterotrophic respiration in relation to temperature over various timescales relevant to global warming. Use results to inform long term field experiments and modelling. RG#9

R7 Australia should lead research on the role of black carbon in all its forms as an important natural variable in the soil carbon and nutrient cycles and vegetation dynamics. This enhances our knowledge of carbon storage, sequestration and nutrient cycling (RG#18)

R8 Research to improve our understanding what controls recruitment and mortality rates of Australian vegetation and the responses to availabilities of carbon, water and nutrients.

Fundamental modeling needs

In modeling, the land surface has to be initialized and characterized in gridded-form, processes-based understanding must be described and key elements of a model must be identified. Most crucial, data collected and the improved process-based understanding that results must be systematically built into the models which must then be thoroughly and systematically evaluated.

R9 *A model infrastructure must be designed and implemented to effectively draw new and existing data, and new and existing process-based understanding of Australian ecosystems into the Australian Earth System models.* As these models build towards the full-complexity of nature, careful collective thought needs to be put into what natural, management and land use aspects need to be included. One outcome – a DGVM – would build capacity in the global-coupled modeling initiatives of ACCESS and would be evaluated using observations and compared openly with overseas models. (RG#19)
Some priorities require investment that would provide key advances in support of R9:

R 10 *Model studies, to explore hypotheses about climatic influences on the herbivory-effects of domestic stock, feral and native mammals, and insects on grass/tree balances, should be encouraged.* These would guide field observations and experiments that will build improved understanding of climate change/herbivory interactions in vegetation dynamics. (RG#14)

R11 *A sustained research program to address vegetation-fire-climate interactions is needed in Australia to support realistic fire regimes being implemented into Australian models. (RG#16)*

R12 *Research facilitating the incorporation of the role of humans on land use and land cover change is needed to ensure the correct representation of the surface in regional, continental and global models*