Terrestrial Ecosystem Research Network National Centre Proposal

Expression of Interest – Assoc. Prof. Jason Beringer (Monash University)

Vision:
This group will provide a national capacity to monitor, understand and give early warning of changes in the sustainability of Australian ecosystems and their capacity to provide essential ecosystem services (carbon, water, air, biodiversity, and forest products) to sustain human welfare. The focus will be on key ecosystem cycles (water, carbon, nitrogen) and flora and fauna composition and structure as a basis for understanding changes in ecosystem services and the impacts of climate change and disturbance. The group will provide information on key indicators of sustainable forest and land management required for state, national and international reporting. The group will support research to develop new methods for monitoring ecosystem change and new modelling approaches for efficient data integration and reporting on ecosystem condition and health. We will aid policy and management to ensure viable water resources, carbon sequestration and biodiversity. There will be a strong focus on knowledge building, analysis and synthesis and presentation of information to policy makers, land managers and the public. There will be a strong education and research training component with linkages to coursework and research training programs. The group will be integrated with national and international networks that provide consistent approaches for data collection, storage and reporting.

This proposal is submitted as an alternative to a regional hubs based TERN. It provides a national strategic approach and priorities and allocates resources independent of state boundaries. It is a community based proposal with a common vision facilitating unique and multidisciplinary science. If a regional hub remains the preferred model then this EOI remains a powerful national coordinating framework, under which regional hubs could easily be developed. Appendix 1 outlines a scientific case for this EOI

National Themes and questions:

1. Climate change, variability and extremes – What is the impact of climate change on our natural resources and their ecosystem services such as water and sources and sinks of greenhouse gases and biodiversity? What are the key points of vulnerability and how do we manage these?
2. Management for multiple benefits – What is the impact of different types of management on eco hydrology, ground water interactions, water yield and quality, carbon sequestration and biodiversity and how do we manage these for multiple benefits?
3. Forest to farm – How do ecosystem services and processes change across the transition from forest to managed land and streams, with a whole of cycle approach? Regional hotspots will form the focus of research (i.e. Murray Darling region, south west Western Australia, Northern Australia agricultural development regions, Daintree rainforest).
4. Forest to pipe – Whole of cycle approach to water from catchment to urban piped supply network with focus on impact of climate and change and disturbance (fire, urban development, salinity and unanticipated drivers of change). Focus on major capital cities and the transition from catchment to peri-urban to urban areas.
5. Elements to ecosystem – We face a huge challenge to integrate individual ecosystem elements (biodiversity) research with ecosystem ecology and landscape scale exchanges of
water and carbon. This will be addressed within the national centre. We proposed a framework to link species to functional types to vegetation groups that can then be linked to processes and models through a range of scales including ACCESS.

**Infrastructure and network features:**
The national TERN would include an integrated monitoring and research framework that encompasses plot (10 to 100m²), ecosystem (100m to 1km²), regional (10 to 100km²) and continental scales. We propose a network of ‘super-sites’ and an indicative selection of sites has been made on a national strategic basis. The case is given in Appendix 4. The main features are:

- Concentration measurements of CO2 from tall towers to be used in inverse modelling for regional and continental carbon balance.
- Remote sensing at coarse (e.g. MODIS, Landsat) and fine (e.g. Aircraft and Spot) scales than can be used to extrapolate plot measurements to regional and continental scales.
- Historical ground measurements and observations across the landscape. These would build on historical measurement sites (e.g. long-term ecosystem plots established and measured by state agencies and universities, historical photo point collections).
- Comprehensive LTER ‘supersites’ to gain process understanding of ecosystem dynamics, for interdisciplinary studies and to provide a focal point for future research. Centres of investment for improved instrumentation. Keystones for model development and evaluation. These would be piggy backed off current sites, but add capacity to bring all sites to a common standard. Plot and ecosystem scales. Facilities and studies would include:
  - Biodiversity - Smithsonian style 25-50 ha plots for flora and fauna
  - Carbon, water and other exchanges from the ecosystem using Flux towers located centrally. Gives Carbon and Water Balance over short and long term.
  - Nutrients – Interactions between nutrients and ecosystem health and diversity
  - Isotopes – vertical profiles at sites using FTIR to examine isotopes of C and H₂O to partition water use and carbon budget. National and regional measurement using ANSTO facilities.
  - Soils – stocks of elements, microbial processes, heterotrophic respiration, fluxes CO₂, CH₄ and N₂O.
  - Phenology observations to link with the National Ecological Meta Database (BoM).
  - Remote laboratory and accommodation centres at SuperSites where feasible.
- Distributed wireless network comprising regional transects from forest to farm/urban regions that encompasses other existing sites where stocks, flows, ecological and biodiversity measurements are made. Soils and water monitoring networks will be key. Ecosystem to continental scale.

2. Development of methods for near realtime monitoring for operational NRM and Bureau of Meteorology assimilation.
3. Standardised protocols for measurement (see Appendix 6)
4. Long-term standardised survey locations for biodiversity using World Heritage areas as foci
5. Access to various models and modelling techniques which will provide a way to integrate these datasets so as to produce model simulation results based on measured data, and interpolation. National scale.
6. Visualisation facilities for researchers to visualise the information and results of simulations
7. Coordination with national (LTER, OzFlux, phenological and biodiversity networks) and international networks (ILTER, NEON, Fluxnet, GEOSS, GTOS, GEMS, GCP, IGBP, IHDP, ESSP, Diversitas, BASIN, etc.) to ensure cross compatibility and links with Australian research networks and associations (i.e. ESA) to ensure uptake of TERN by the community.
8. Priority locations for new projects (ARC, NWC, etc.) and locations for PhD projects
The concept of an integrated facility centred on a ‘supersite’ is illustrated in Figure 1. The focus is on linking scales from site based species data to continental scale satellite budgets. The supersites will be centred on existing OzFlux and LTER sites but are extended upon by a number of transects that deal with changing land use and also the forest catchment to urban pipe. Across the region the transects will capture key historical and new sites including biodiversity plots, hydrological monitoring, ecological research sites, etc.

Figure 1. Example of supersite concept with transects and scaling from point to region. The case uses the existing Ozflux/LTER site at Wallaby Creek in Old growth Mountain Ash.
**Integration, analysis and synthesis:**

A major outcome for this EOI will be the scaling from plot to continental scales. The approach to scaling is given in Appendix 2 and involves a suite of tools and collaborations detailed in Appendix 5. Note that data management, integration, storage and synthesis are critical components of this EOI. Our proposed national centre will coordinate within and between hubs as well as with 5.16 Platforms for collaboration. We have a design for the data requirements which could be hosted within the Hub (below). The following are features of the data integration, analysis and synthesis:

- **a)** Data will be obtained from wireless sensors located in remote areas and will automatically send information to a central point, or a number of central points and then to AARnet.
- **b)** Legacy data, like weather datasets, climate simulation outputs like from general circulation models, water catchment measurements, forest growth, etc. will be core information.
- **c)** Various models will be archived and available including land surface models, forest growth models, ecosystem models, bioclimate models, hydrological models etc. These models will require various inputs from (a) and (b) (like rainfall, soil moisture, sunlight, temperature, humidity, and vegetation characteristics like leaf area and structure etc.) and will be made available in a consistent framework.
- **d)** Various models for policy scenario modelling will be generated using simulations (c).
- **e)** Current international standards for the Ecological Meta Data Language would be adhered to.
- **f)** The Australian Greenhouse Office (NCAS) system and/or the Bureau of Meteorology could be used as a basis for spatial data handling.
- **g)** A conceptual framework for regional and national integration and modelling is identified below (Figure 2).
- **h)** Direct injection of data and research into the Australian Community Climate and Earth System Simulator (ACCESS) used for improved climate prediction and Weather forecasts. Provides data back to community through climate change simulations and impacts.
- **i)** Proposed integration through central TERN hub which could be run through the community based ARC network for Earth System Science.
- **j)** A centre for analysis and synthesis that uses long-term data sets and other knowledge to analyse critical questions for ecosystem management such as long-term fire management strategies, sustainable timber harvesting regimes or future water resource availability. Hosted at the current ARC network for Vegetation Function and Futures (Appendix 5).

---

**National System for Data Integration & Predictive Modeling**

![Diagram](image)

Figure 2: Integration across scales from point to continental to provide real time products for end users (courtesy of Dr. Cleugh CSIRO)
We will need the following system to deal with the TERN data requirements (from Prof. Ah Chung Tsoi – Monash University):

1. TERN will need a data management system to manage the data and will need to provide the following functionalities:
   a. ways to ingest data from existing databases
   b. ways to provide metadata to describe the data, based on some agreed nomenclature, and vocabularies.
   c. Ways for researchers to annotate the data if necessary, e.g. if a measurement is obviously wrong and you do not wish to delete the measurement, but instead you wish to annotate it so that others using the data will know.
   d. Ways to publish the metadata to a federated service (which houses the metadata and provide a metadata registry so that others can search and discover your data set).
   e. Ways for the researcher to access the data, may be through a web interface (web portal).
   f. Physical storage of TERN data across a distributed network.

2. A catalogue of TERN related models and what they can do (metadata on these models), and how to run them (including what inputs and what outputs that they will provide).

3. Catalogue of TERN policy scenario models and what they can do and what inputs and outputs that they will need.

4. A way to run the suite of TERN related models (including ACCESS) and to access the required data for simulation.

5. A way to run policy scenarios and to access the needed data.

6. Steps (4) and (5) would require workflow management procedures – to manage the sequence of events which require access to datasets, run models, collect results, and should allow users to visualise the results and re-run models by scanning some parameters.

At present there are no ready made systems available to do all these. The nearest you could have for step (1) would be the DART/ARCHER project undertaken in Monash in collaboration with other partners (JCU, UQ). DART/ARCHER could be extended to include steps (2) and (3) – this would be quite easy. However, DART/ARCHER would not be able to easily run the models for TERN. It is possible to run them by providing wrappers around them so that they can run on different systems. This will take more work though but it is possible (Monash has well known software which can do this, though it will require some work). Steps (4) and (5) could also be handled, though it will need customisation to TERNs special needs.

We will integrate with NCRIS 5.16 but it will not provide all the capabilities required for TERN but it would provide common elements. While the TERN requirements are generic, it will require significant customisation. We suggest that TERN provides co-investment to generate the system needed. We estimate that $2M - $4M total would produce a workable system on top of NCRIS 5.16 provision (dependent on the detailed requirements).

We would like to work closely with DART/ARCHER team so and we will work toward articulating the TERN requirements and what system architecture would be suitable to implement for TERN.
Outcomes:
1. Rescue of historical data for forest plots and photo points and re-measurement to gather powerful new data and salvage past investments.
2. Long term monitoring of ecosystem services and health that will capture ecosystem responses at a range of time scales from hourly (physiological) to interannual variability (e.g. El Niño) and climate change.
3. Examine variability in carbon, water and biodiversity dynamics due to environmental changes (vegetation structure and phenology, droughts, heat spells, El Niño, growing season length) along with the role of disturbance (fire, agriculture and urbanisation).
4. Comprehensive and fundamental datasets as a legacy for future generations
5. Key advice on strategies for sustainable management for multiple benefits including increased water yield, enhanced carbon sequestration, and maintaining biodiversity
6. Assessments of the impacts of land use change on forest ecosystem services and processes.
7. New ways to include Australian ecosystems in land surface, hydrological, ecological, bioclimatic, productivity, etc. models with a view to improving their simulation of temporal dynamics and our ability to predict carbon and water balances in the future. New national modelling capability via ACCESS along with model evaluation & data fusion.
8. Evaluate a range of ecological methods such as flux tower, inventory and other biometric techniques.
9. Combine TERN observations with existing land-use, aircraft, satellite, atmospheric concentration data and along with state-of-the-art data assimilation and multiple constraint methods to provide regional and national estimates of the carbon and water cycling in Australian ecosystems on various time scales.
10. Build expertise and collaborations in global change science with a focus on multidisciplinary research across biology, ecology, atmospheric science, hydrology, geosciences, IT at supersites. Provide resources and training to meet increasing demand for these multidisciplinary skills.

Current Partners based on initial southern hub proposal:
- University consortium
  - Monash University (Lead) – A. Prof. Jason Beringer, Prof. Ralph MacNally, Prof. Graeme Pearman, Prof. John Langford, Dr. Mike Grace
  - Australian National University – Prof. Will Stefan, Mackey?, Lindenmayer?, Farquhar?
  - Flinders University – A. Prof. Jorg Hacker
  - Macquarie University – Prof. Mark Westoby
  - The Melbourne University – Prof. Rod Keenan, Prof. Snow Barlow, Prof. Nigel Stork
  - University of Adelaide - Dr. John Jennings?
  - University of Tasmania – Prof. David Bowman
  - University of Wollongong – Prof. David Griffith
- Australian Community Climate and Earth System Simulator (ACCESS) (CSIRO, Bureau of Meteorology, universities)
- Airborne Research Australia (A. Prof. Hacker)
- Australian Research Council Network for Earth System Science (Prof. Pitman)
- Australian Research Council Network for Vegetation Function and Futures (Prof. Westoby)
- ANSTO (Dr. Williams?)
- Bureau of Meteorology (National Ecological Meta Database) (Dr. Chambers)
- CSIRO – Land and Water AND Marine and atmospheric research (Dr. Wang)
- Department of Sustainability and Environment
- Department of Primary Industries
- Federal agencies (AGO, DEH, BRS)
- Forestry Tasmania
- WARA LTER
- Other state agencies, CMAs etc.

**Steering Group (tentative)**
- National Centre Director – Beringer
- DEH representative (McFadden?)
- TERN science chair and/or facilitator?
- CSIRO representative (Cleugh / Raupach)
- BRS /LTER representative (Clancy?)
- NRM member representative
- Bureau of Meteorology representative (Chambers/Puri?)
- Australian Greenhouse Office representative (Richards?)
- State government representatives
- Community representative
- ARC network for Vegetation Function and futures representative
- ARC network for Earth System Science representative

**Science Reference Group**
- National Centre director
- Others TBA

**Hub management structure**
The case is given here for 11 sites across Australia. It is envisaged that their will be a combination of regional and site directors depending on the preferred national model.
- National centre director
- Regional/state hub directors from existing agencies and institutions (up to 6)
- Site science directors from existing agencies and institutions (up to 11)
- Site manager – logistics, planning and operations, facilitator of research. (11)
- Site technical officer - assistance to enable research, long term ongoing measurements, laboratory assistance (11)
- Regional technical officer – Integration across the region. Facilitate transects (6)
- Data manager and web (4)
- Development/education outreach person (1)
We feel that the network requires an integrated management structure in order to maximise the national benefits of the integrated facility. As such we will establish a TERN Steering Committee (TERNSC) that will initially include representative from major agencies and stakeholders. The TERNSC will provide overarching strategic and national advice. In addition a science reference group will be established to provide guidance on cross network issues (data management, data processing standards, calibration and equipment standards, data archiving) as well as research issues (Isotope, satellite, modelling). They will also provide guidance to individual sites in the network. The science committee members will communicate with GEOSS, Fluxnet and other international networks. Importantly, we will establish working groups that will report to the TERNSC for 1) measurement and data standards and protocols, 2) Data management 3) integration, synthesis and modelling.

We would hope that TERN could support the day to day management and operation of each station in the network through positions of site manager, technical officer (site and region). The day to day operation would be the responsibility of the site manager. The technical officer (site) would be responsible for ongoing calibration and maintenance of equipment, ancillary annual and seasonal measurements (e.g. Leaf area index), raw data download, archiving and transfer. The technical officer (site) would be responsible for facilitating the transects and encompassing research within the regions.

Free and open access will be given to persons wishing to undertake research activities at individual sites or across the network. We encourage the open use of the physical facilities especially for interdisciplinary research, and inter-site comparisons (e.g. soil decomposition studies). Unlimited time will be available at each site.
Indicative budget

- Startup to align all supersites with common infrastructure ($500k per site average but some more and some less) ($5.5 million).
- Startup for Community Ecosystem Ecology Lab ($1.5 million once off)
- Data framework integration with NCRIS 5.16 ($2-4 million).
- TERN Centre management (including hub director salary) and administration ($350,000 pa) ($3.0 million) through the ARC network for Earth System Science
- Site Management (including site manager and technical officer salary), calibration, maintenance, OHSE compliance, data collection, routine sampling, etc. ($180,000 pa per site) ($9.9 million)
- Regional distributed network calibration, data collection, routine sampling, etc ($150,000 pa per site). Includes integration across the region and transects from forest to farm and forest to pipe. Includes salary for technical officer (region) ($8.25 million)
- Laboratory analysis costs for plant and soil including isotopes ($150,000 pa) ($750,000)
- Aircraft capability across regional hub ($1.5 million)
- Integrated Isotope capability across network ($200,000 pa) ($1 million)
- Remote sensing integration, prioritise and develop products for plot, ecosystem, regional, and national scaling ($2.5 million)
- Synthesis program linked to ARC Vegetation Function and Futures network. ($350k pa)

Total over 5 years $39.65 million
Appendix 1: Additional information for science case.

Australia is unique because it has a large land base with a small population, but has one of the highest per capita emissions of greenhouse gases and water usages in the world. It also has a range of important natural ecosystems, many of which are vulnerable to climate change and disturbance. Given our reliance on carbon-based fuels, vulnerability of our water supplies and natural ecosystems, Australia needs to develop a strategy for the sustainable use and management of its critical natural resources. This must be underpinned by a research infrastructure and sound knowledge base of the carbon and water cycles and biodiversity. However, there is a paucity of long term continuous measurements of water, carbon and biodiversity resources at the ecosystem scale in Australian ecosystems, many of which are unique. We support the establishment of a TERN that will allow us to examine how economically and ecologically important ecosystems respond to climate change and other disturbances. This will aid the mitigation of carbon emissions, allow sustainable management of water resources and biodiversity. The TERN will support a world leading network of researchers across multiple disciplines to address problems of national significance in relation to carbon, water and biodiversity and its management.

The major dynamic components of the Australian environment includes a suite of interlinked physical, chemical and biological components and processes that cycle water, carbon and energy in complex ways within the total system. Ecosystem processes and services are an integral part of the functioning of the Australian landscape, and respond to changes within the dynamic system, such as impacts of climate change and disturbance (land use change, fire, agriculture, urbanisation, etc.). However, our ecosystems are active participants in the cycles of water, carbon and energy and interact strongly with the atmosphere, lithosphere and hydrosphere forming complex interactions at both the local and global scales. These interactions are the core of Earth System Science. As an example, ground-breaking advances by Friedlingstein et al. (1999) and Cox et al. (1999) predict that net ecosystem uptake of carbon globally will peak this century and then decline to zero, leading to no further carbon sequestration, or even a release of carbon from the terrestrial biosphere. Cox et al. [1999] project that atmospheric CO$_2$ levels will increase by an extra 300 ppmv due to the release of stored terrestrial carbon, 30-100% more than estimates from the IPCC [2001], thereby generating about 2.0 °C extra warming between 1860 and 2100 compared to earlier projections. If these projections are correct, then the decline and possible reversal of the terrestrial biosphere sink for CO$_2$ has enormous implications for climate and carbon and water resources. Such predictions need to be confirmed by global and regional observation networks consisting of flux stations, concentration monitoring and remote sensing that will provide an understanding of the future changes in our water and carbon resources.

Currently Australia’s carbon inventory shows that managed native forests and plantations were a net sink of 75.8 Mt Carbon in 1999 [AGO 2001]. Less certain is the role of native ecosystems, which comprise 88% of the landscape [Graetz et al. 1995]. Such a large area of native vegetation has a great potential to increase or decrease carbon sequestration due to climate change, land management and/or natural disturbance [RAC 1992]. Any potential sink/source is likely to be significant in comparison to our emissions. Yet, unmanaged native ecosystems are at present outside the scope of the National Greenhouse Gas Inventory and National Carbon Accounting System. Estimates and predictions of carbon balances from the TERN, across Australian ecosystems and how they may change with disturbance will be vital for understanding potential carbon sinks/sources. This is especially important given the fluidity of possible future versions of the Kyoto Protocol.

An understanding of carbon and water balances is crucial for the sustainable management of our Australian landscapes, which include ecosystems that are economically important for our forestry industry and are significant in providing recreation areas and maintaining ecosystem health and biodiversity. Native vegetation also occupies water catchments that are crucial in sustaining the amount and quality of drinking water. The cycle of water within Australian ecosystems is also important for ecosystem sustainability and is determined largely by vegetation water use, canopy
and soil evaporation and runoff. Understanding the ecohydrology of catchments is critical given their role in the provision of potable water.

To date, a number of approaches have been taken to determine carbon and water budgets in Australian ecosystems. Current accounting of Australia’s carbon balance relevant to the National Greenhouse Gas Inventory under the Framework Convention on Climate Change come from the Australian Greenhouse Office’s National Carbon Accounting System, using integrated observations (carbon inventories) and modelling. Scientific underpinning has come from the CRC for Greenhouse Accounting and other sources but, significantly, does not include long term biosphere observations. Moreover, current methods give estimates but at limited spatial and temporal resolution, making it difficult to scale up point-based measurements both spatially and temporally. For instance, ecosystem processes are strongly dependent on seasonal changes (phenology) or changes in climate extremes [Grelle et al. 1999]. These dynamics are not often captured during short-term field measurements or integrative assessments, yet these non-average conditions have a strong impact on the hydrological and carbon cycles of terrestrial ecosystems [Baldocchi et al. 1997].

To date, there have been few detailed studies of carbon exchange and balance of native Australian vegetation. Recently, carbon fluxes [Beringer, et al. 2003; 2007, Eamus et al. 2001] and carbon balance [Chen et al. 2003] have been determined for tropical savanna ecosystems of northern Australia. Burrows et al. [2002] used long term biomass inventory plots to estimate carbon sink strength of grazed northern Queensland savanna. Keith et al. [1997] examined carbon balance and stand-scale nutrient dynamics of temperate eucalypt forests. These studies demonstrate the utility of carbon and water cycling measurements but provide only a limited level of understanding for a small number of ecosystems which span a narrow range of bioclimatic space. Hence, we still have a limited understanding of these biologically complex systems [Nikolov and Fox 1994] and a paucity of quantitative information on the carbon, water and biodiversity resources at scales of national relevance.

This EOI describes a national strategic approach for TERN to measure carbon, water and biodiversity in key Australian ecosystems using a coordinated national research infrastructure, which substantially expands the small number of existing Australian study sites (known as OzFlux and LTER), and complements the growing international network of measurement stations (Over 300). At the core of the proposed TERN will be a combination of LTER and Ozflux sites that form a network of ‘supersites’ that will include tower based flux measurements of carbon dioxide, water and energy coupled with various layers of biodiversity information.

Carbon, water and biodiversity will be quantified and the variability of these ecosystem services across different temporal (hourly to decadal) and spatial (canopy to continental) scales will be examined. TERN will enhance our current understanding of short-term (hourly to seasonal) ecosystem processes, how they respond to changes over longer periods (seasons to decades) and how ecosystems as a whole will respond to changes in climate, climate extremes, ecological succession and human disturbance. Our short-term (hourly to seasonal) measurements will provide a vital link to the current seasonal to centennial carbon balance estimates from the CRC for Greenhouse Accounting and will allow their estimates to be validated using our longer term measurements. TERN will support the data and knowledge requirements for scaling up from ecosystem to catchment, regional and national budgets of carbon and water using complementary aircraft measurements, remote sensing, CO₂ concentrations and atmospheric inversion models. We will use data assimilation and multiple constraint methods to reduce the uncertainty of our measurements [Rayner and O’Brien 2001]. It may not be feasible or ecologically relevant to attempt to scale biodiversity information to a national scale, however, a working group will be formed to address this issue.

Information from TERN will underpin the development and improvement of hydrological, climate, ecophysiological, ecological, and productivity models that will reduce uncertainties in Australian carbon and water budgets. This will be achieved by including Australian specific ecosystem information across a suite of models and develop new model parameterisations to
capture ecosystem processes. In particular this EOI aims to directly inject outcomes from TERN into the new Australian Community Climate and Earth System Simulator (ACCESS) initiative (a joint venture by the Bureau of Meteorology, CSIRO and universities). ACCESS will underpin climate change simulations as well as weather forecasting and the contribution from TERN into this framework will be significant. It will result in improved climate and weather simulations. The TERN will provide a direct means of validation for ACCESS and other models that will be in turn used to predict large-scale and long-term responses of Australian landscapes to changing environmental conditions (e.g. drought). This will ultimately aid in the sustainable management of these resources within Australian ecosystems.

In addition, the TERN supports a level of scientific integration and synthesis that has not been previously attempted in Australia amongst the meteorological, biological, remote sensing, and modelling disciplines. The TERN will make new and complementary contributions to inventory methods, historical records, remotely sensed data and anthropogenic inputs used at present for carbon accounting and water balance studies.
Appendix 2: Integration and Scaling from Canopy to Continental Scales

Estimation of carbon and water budgets requires measurements of carbon and water fluxes that include ecological variables, such as vegetation biodiversity, as well as net atmospheric fluxes at a range of scales. Spatial scaling requires a combination of point measurements that characterise variability, average site estimates and regional inventory data. The measurement plan and protocols for this EOI will provide the necessary information for robust modelling and national integration of carbon and water cycles. Modelling activities will be conducted at leaf, canopy, regional and national scales using a suite of models including ACCESS. Modelling groups around the country such as Macquarie University (Westoby), UNSW (Adams, McMurtrie, Pitman), Monash University (Beringer, Lynch, McNally), CSIRO Atmospheric Research (Leuning, Wang, Barrett) will guide the measurement protocols and collaborate with the TERN data acquisition team to optimise their modelling efforts and in turn provide advice on data collection needs. Members from the community will form a modelling and synthesis working group. A library of TERN related models will be made available to the community. TERN will provide the pivotal observational database and fundamental processed-based knowledge that will allow a strong modelling/measurement synergy to be developed.

Scaling to continental levels will be aided by the use of recent satellite data products such as MODIS [Rayner and O’Brien 2001] and new satellite products coming on line in the next few years such as daily CO2 mapping by the Orbiting Carbon Observatory (OCO, www.oco.jpl.nasa.gov). Advances in multi-resolution and hyperspectral techniques will also be important. In addition, satellite derived soil moisture, soil temperature, and heat and moisture fluxes are of considerable interest for carbon and water balance studies. For example, soil moisture is important in determining evaporation and plays a crucial role in the water balance. Such studies are being undertaken by Western (Melbourne University) as part of the international GEWEX program and will be integrated with the TERN measurements in the Murrumbidgee region. Current research (Leuning, Cleugh – CSIRO AR) is using flux data and remote sensing to validate water use and net primary productivity algorithms and to scale from local through regional to global scales. In addition, eddy covariance systems have been installed on aircraft platforms for measuring CO2, water and energy fluxes at landscape scales (Hacker – Airborne Research Australia (ARA)). Hacker (ARA) and complementary aircraft measurements will be undertaken on a regular basis over TERN stations. These measurements do not capture temporal dynamics like the towers, but they are powerful in elucidating the spatial variability in fluxes at a landscape/bioregional scales. Airborne site surveys of the new and existing sites will also be carried out to assist in the calibration of satellite NDVI (Normalised Difference Vegetation Index), multispectral imagery and canopy lidar. The ground based towers of the Biosphere Observing Facility will provide important reference and calibration data required to correct aircraft and satellite fluxes [Isaac et al. 2003].

Our EOI would also provide support to Prof. David Griffith’s group, which will enhance the facility across all sites through the investigation of other trace gases and their atmosphere-biosphere exchanges (methane, nitrous oxide, carbon monoxide, etc.) as well as in situ measurements of isotopic fractionation in water vapour using an Fourier Transform Infra Red (FTIR) instrument. This group also provides a link to the OCO satellite products through an independently planned group validation station for CO2 measurements near Darwin. Dr. Roger Francey, David Etheridge and Ray Leuning (CSIRO AR) will contribute by operating high accuracy (LOFLO) CO2 analysers at several sites to estimate regional CO2 fluxes using an atmospheric inversion modelling approach. The TERN will provide shared field infrastructure (towers, power, communications, and field technical staff). In addition, the towers will provide greatly enhanced information on surface processes and fluxes, initially to be used as prior constraints on surface fluxes in inverting concentration data and later as key inputs to the multiple-constraint framework.

Finally, we will examine stable isotope fractionation during terrestrial carbon cycling to link physiological and ecological processes on the ground with large-scale atmospheric measurements [Styles et al. 2003]. The TERN will make stable isotope measurements ($^{13}$C, and $^{18}$O in CO2)
across the network in conjunction with ANSTO and Universities to provide: (1) an independent estimate of the partitioning of net ecosystem carbon exchange into its major component processes, i.e., gross photosynthesis and ecosystem respiration [Farquhar et al. 1993]); (2) average ecosystem discrimination which can be input to large-scale studies that partition the net uptake of anthropogenic carbon emissions between ocean and terrestrial ecosystems.
Appendix 3: Demand for a Network Approach

Systematic global observations are an essential underpinning of research to improve our understanding of ecosystems and climate/earth systems [IPCC,2001]. Modeling of these systems is limited by our process based understanding and observational data. Observing networks have been developing in many countries since 1995 and have provided a major contribution to understanding carbon and water cycling, particularly in the northern hemisphere, where the majority are located [Baldocchi et al. 2001]. Major flux networks include Ameriflux (America – 71 towers), Europe (CarboEurope – 39), Canada (Fluxnet-Canada – 21), Asia (AsiaFlux – 41) and Africa (AfriFlux – 6) and major ecological networks include the ILTER and NEON.

Australia has distinctly different geology, soils, climate and biota from the Northern Hemisphere and therefore an independent Australian network is required to study our unique ecosystems. The utility of an Australian network was recognised some years ago by CSIRO and University partners. This led to a strategic investment in 2000 by CSIRO and the AGO (through the Australian Greenhouse Science Plan) in two long-term flux stations: (a) a temperate wet sclerophyll forest near Tumbarumba NSW (CSIRO Land and Water; Forestry and Forest Products); (b) a tropical (wet/dry), grazed savanna in Northern Queensland (Virginia Park). Funding from the ARC has enabled the establishment of: (c) a tropical savanna site at Howard Springs (Monash University/Charles Darwin University), and (d) a lowland rainforest site near Cairns (James Cook University). These have been running since 2001.

Worldwide there is a lack of LTER and Flux sites in the Southern Hemisphere and within Australia, the four current ongoing long term measurement sites do not encompass the range of ecosystems and bioclimates that influence carbon, water and biodiversity resources. Moreover, current sites are run by individual investigators and there is no co-ordinated approach to building a national facility with a high level of data quality control. The limited sites cannot, alone, meet our national objectives of developing a complete understanding of carbon, water and biodiversity resources for Australia’s unique landscapes. We propose a powerful merger of LTER and OzFlux sites for our EOI, which confers cost efficiency and the advantage that there is a wealth of experience amongst the partners in running LTER and Flux stations and in developing measurement and analytic techniques (e.g. Webb et al. [1980]; Finnigan et al. [2003]).

The TERN will provide a long-term scientific heritage for Australia through a comprehensive database system and web portal. This will permit synthesis and modelling by the scientific community, enable temporal analysis, permit inter-site comparisons, and facilitate spatial comparisons across environmental gradients and across biomes. It will also entrain colleagues from the ecological, remote sensing, meteorological, hydrological and modelling communities by providing data for biospheric observations and providing common integrative science questions. A national facility will ensure cross-site standardisation and inter-calibration of measurements so that TERN activities can be realised (e.g. integration, modelling, stable isotope analyses, etc.).

There is a significant demand for a TERN capacity within the Australian and international science communities as demonstrated by the worldwide demand for flux and ecosystem data from the Carbon Dioxide Information and Analysis Center (CDIAC), an international data centre that houses the international Fluxnet data, currently contains worldwide flux data (including data from the existing Australian sites), which in a single year has had over 32,000 downloads from 24 countries. We will provide a data mirror to international organisations, which will further raise the profile of Australian flux researchers internationally and promote the use of our data by the international scientific community.
Appendix 4: National strategic approach to supersites for TERN

We propose to gain a critical mass for TERN by building on the limited and discrete network of LTER and Ozflux stations to a total of 11. We believe that the approach described in the current proposal represents the minimum necessary to make a serious attempt to address the carbon, water and biodiversity resources across major Australian ecosystems and across a range of bioclimates. A key criterion in selecting supersites is to study ecosystems representative of key bioclimatic regions of Australia. Such a sampling strategy is needed because it is impossible to sample adequately in physical space. We will need to undertake a network analysis to determine the exact locations that will deliver the best outcomes. However, the following stations are indicative (existing flux tower stations are shown in *italics* and * shows existing long term ecological data sites);

1. Dry sclerophyll forest (e.g. Wombat State Forest*)
2. Jarrah forest in WA – Important managed system for carbon sequestration, response of native vegetation through growth cycles. Includes transect through production landscapes (i.e. Kellerberrin*, WA)
3. Hummock grassland in Pilbra – Large important biome, functionally different to woody plants
5. Warra eucalypt forest (WARRA LTER*)
6. Floodplains forests (Gunbower Island* or Barmah-Millewa*). Dovetail with The Living Murray investments.
7. Savanna in Howard Springs (high rainfall)
8. Lowland Rainforest in Cape Tribulation
9. Cool temperate eucalypt forest at Tumbarumba
They aim to cover:

a) the range of bioclimates across the continent - wet/dry, tropical, semi-arid, arid, temperate, Mediterranean and cool;
b) major ecosystem types including a range of functional groups – Evergreen forest, woodland, savanna, grassland
c) a range of important anthropogenic landscapes (e.g. cropping, fire, grazing);
d) sites important in carbon sequestration activities;
e) an east-west transect from NSW coast inland across the Murray Darling region
f) a north-south transect from Darwin to Alice Springs along a rainfall gradient
g) and sites that link with international programs (GEWEX, Int Canopy Crane Network).

The TERN will be able to measure plot and ecosystem processes in great detail at high temporal frequency and for extended periods. However, TERN will be limited in its spatial coverage so we will measure at sites that are representative of key ecosystems and bioclimates (we will also use climatic transects North-south and East-west). On the other hand satellite measurements give us tremendous spatial coverage but do not directly measure the fluxes, reservoirs or key processes. The TERN will inform the models used in the satellite derived estimate of carbon and water balance.

The TERN will support a coordinated network of scientists to provide enhanced integrative and cross-cutting research that will strengthen Australia’s standing in this field. The TERN will provide important scientific benefits including the sharing of data, ability to scale up to national level, enhanced quality control and quality assured data collection. More importantly it provides a framework for the collaboration of researchers and synthesis of scientific ideas. The TERN will support a network of researchers to train highly-qualified personnel, inform policy-makers, and increase public understanding of carbon and water cycling science and issues.

**National Benefit**

Australian ecosystems, both disturbed and natural, are a critical natural resource and provide ecosystem services through the provision of potable water and the possible sequestration of carbon. In order to use these resources in a sustainable manner we must understand the current carbon, water and biodiversity resources and how these may change over time (seasons to centuries). We will provide a major contribution to the National Research Priority of ‘An environmentally sustainable Australia’ through four priority goals. 1) **Water – a critical resource**: We will assess the role of climate variability on water fluxes and the impact on water supplies in vegetated catchments for an understanding of sustainable water management; 2) **Reducing and capturing emissions in transport and energy generation**: We will determine the role of Australian ecosystems in sequestering carbon and their likely response to climate change, climate variability and disturbances; 3) **Sustainable use of Australia’s biodiversity**: We will provide a comprehensive understanding of the interplay between natural and human systems with regard to the provision of ecosystem services (water, carbon and biodiversity); 4) **Responding to climate change and variability**: We will address the response of ecosystems to change and the impact on water, carbon and biodiversity resources. We will address the national priorities through the provision of an advanced research facility that will ultimately provide considerable social benefit for Australia. The TERN will support measurements and models to provide robust future estimates of carbon, water and biodiversity resources that will aid our sustainable management of ecosystems to ensure viable water resources, carbon sequestration and maintainence of biodiversity.

The flux measurements described above, have been identified as extremely important by the National Land and Water Resources Audit [NLWRA 2000] who state that a characterisation of the linked carbon, water and energy exchanges between the Australian land surface and the atmosphere is needed. These exchanges play key roles in the terrestrial biospheric components of Australia's
greenhouse gas inventory and in the landscape budgets of carbon and water that are crucial measures of land use viability. Federal and state governments will be the primary policy users of the information from the TERN. This information will be crucial for the development of policies concerning carbon sequestration and greenhouse gas management, water management and biodiversity policy. Forestry companies will benefit from knowledge gained on the impacts of forest management on emissions and energy companies will have a much better idea of the potential of using the Australian biosphere for carbon offsets.

This EOI will be central in providing the research capability to build an Australian biosphere monitoring system. Our network will contribute to the Australian Climate Observing System that is part of the Global Terrestrial Observing System (GTOS) and will supply observational data for the improved understanding of Australian climate, prediction of the seasonal and inter-annual variations in Australia's climate and the detection and quantification of longer term climate change. The Bureau of Meteorology will be partner in this proposal and we will contribute radiation and flux data that will be used to drive (in stand-alone mode) and validate the operational land surface model of the Bureau of Meteorology. This will enhance their forecasting capability by developing methods to assimilate land surface observations from flux stations into schemes to help constrain forecasts (e.g. the diversity of the proposed flux tower sites will allow model testing of performance under varying soil and vegetation conditions).
Appendix 5: Collaborative arrangements and synthesis

Communication and collaboration

Australia has world-leading expertise in micrometeorology, carbon and water cycling, biodiversity research and global change research but it is spread across the country in universities, CSIRO, ANSTO, BoM and other organisations. The proposed TERN will bring together scientists from various institutions to gain knowledge, collaborate, and share information, to allow us to address questions of national importance that were previously not possible. Networking of scientists fostered by the TERN will enable better training of graduate students and research fellows, thus providing valuable opportunities to teach new researchers the scientific importance and policy-relevance of their work. Specifically, the TERN will support a highly inter-disciplinary research network where researchers from universities, government agencies, and stakeholders have an opportunity to combine their talents and expertise to address a problem of great importance to Australia. Scientific integration of research partners will occur through a coordinated communications effort that will (1) link students and scientists working on a variety of flux and ecological research topics that cut across sites in the facility; (2) establish a cross-station stable isotope component that links the tower-based flux measurements to regional- and global-scale atmospheric measurements; (3) build an integrative modelling effort that optimises the use of site-based measurements to parameterise the different climate and ecosystem process models that will in turn be used to extrapolate to larger spatial and longer temporal scales; (4) foster further collaboration between with other Australian and international researchers and networks (e.g. Fluxnet, ILTER, NEON, etc.); (5) allow the sharing of ideas, data and research results with TERN partners (federal and state government agencies, NGO’s, other networks, industry sponsors), the broader scientific community, and interested parties (industry partners, forestry companies, etc.); and (6) inform decision-makers of policy-relevant results and their implications. Research networking will be promoted through joint research proposals, workshops, annual meetings, and educational outreach involving participants in all aspects of the TERN.

The above communication strategy will be achieved via the ARC network for Earth System Science which already has 300 members in disciplines related to TERN. The centre will be hosted via the ARC network.

Ecological synthesis (courtesy Westoby)

A characteristic of TERN is that it incorporates many different data types at multiple scales. A serious effort is needed to organize, interpret and synthesise data. If this effort is not committed, the data collected will not be converted into coherent outcomes of relevance to the policy and scientific community or the general public and the credibility of TERN in the research community will evaporate.

The model for successful data synthesis internationally is US-NSF NCEAS (National Center for Ecological Analysis and Synthesis, http://www.nceas.ucsb.edu/). This operates through a combination of working groups that gather together expertise, and in-house postdocs to give continuity to datasets and analyses.

In Australia, the ARC-NZ Research Network for Vegetation Function (www.vegfunction.net) similarly operates through working groups modelled on NCEAS. There is considerable synergy between the topics the Vegetation Function Network is funded by ARC to pursue and the topics that a TERN Synthesis and Analysis Program would want to pursue. The Vegetation Function Network also has strong international linkages. The network has established a Networks International Council that includes directors of NCEAS, of US-NSF National Evolution Synthesis Centre (http://www.nescent.org/), and of UK-NERC Quantifying and Understanding the Earth System (QUEST, http://quest.bris.ac.uk/). Given these established mechanisms and linkages, we suggest the natural way to develop synthesis and integration activity directed specifically to TERN data types is
through the apparatus already existing in the Vegetation Function Network but with an additional stream of funding available for competitive proposals (prioritised for TERN related synthesis).

Logistical arrangements

A major outcome of the network is a centralised data distribution system. Each station will be connected to the central network (using LoggerNet, Campbell Scientific) via mobile phone or satellite link providing near real time data and site status information according to an agreed Data Management (DM) policy. We aim to minimise data loss through real time DM that will notify partners of any measurement errors or equipment failures. The centralised national database of long-term carbon, water and biodiversity measurements will be of critical value for the research areas outlined previously, including local to national scale modelling of the Australian environment. To maximise the utility of the data the preliminary 30-minute processed data will be made freely available in on the WWW. The raw turbulence data (10-20 Hz) will be stored at each station where it will be downloaded regularly and transferred to the DM office. This data will then be finalised and made public according to the agreed DM policies.

The facility will be linked nationally through (1) standardised equipment levels across all sites, (2) a series of network protocols that will assure standardised and cross-calibrated measurements of flux, meteorological and ecological variables; (2) standardised data processing software and protocols; (3) a standardised policy for data documentation, submission, archiving and distribution that will be managed by a data manager.

These activities will be coordinated by a TERN Steering Committee (TERNSC) to ensure the network meets its stated objectives. We will utilise the existing research strengths of particular institutions whilst building the national capacity in higher education institutions.
Appendix 6: Example of consistent data collection guidelines and measurement protocols. These would be subject to advice from the ‘standards and protocols’ group. Tables a,b,c list the potential mandatory measurements for all stations. The mandatory measurements are suggested for inclusion in TERN. The ‘standards and protocols’ group will develop the optimal measurement and sampling strategy to be adopted by the network in collaboration with other groups. These measurements can be classified into three groupings:

i) Flux data. Continuous, largely meteorological and flux, data.

ii) Site characterisation data. The mandatory measurements that will be required to characterise the site in terms of its soil, vegetation, initial C stocks and their change. The stated frequency represents a recommended minimum requirement. The soil measurements are essential for the full characterisation of the physical and nutrient status of the profile. The specific levels of sampling will depend on the rooting depth of the vegetation but will never be less than 50 cm. The data for characterisation of the vegetation vary from simple, infrequent measures such as vegetation height to more complex measures such as clumping index. All of these data are important in the interpretation of the site’s carbon balance and for providing important parameters to modellers.

iii) Ecological data. Summarises a series of mandatory ecological variables to be collected at each site where there will be continuous eddy flux data collection and are based around biodiversity type measurements. For example vegetation surveys, species level data in Smithsonian style plots.

Note that individual ‘supersites’ may decide to make additional measurements (e.g., soil hydraulic conductivity, soil thermal conductivity, soil incubations for organic matter CO2 flux, etc.). Protocols for these measurements will be developed by a working group and made available to network participants so that they can be followed should other investigators decide to add these measurements.

Table A. Mandatory Continuous Measurements of Meteorology and Flux.

<table>
<thead>
<tr>
<th>Eddy-covariance (EC) fluxes, above canopy</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>– Carbon dioxide flux</td>
</tr>
<tr>
<td></td>
<td>– Latent heat flux</td>
</tr>
<tr>
<td></td>
<td>– Sensible heat flux</td>
</tr>
<tr>
<td></td>
<td>– Momentum flux</td>
</tr>
<tr>
<td>Fluxes or storages below EC level</td>
<td>– CO2 air column storage (where appropriate)</td>
</tr>
<tr>
<td></td>
<td>– Sensible and latent heat air column storage (where appropriate)</td>
</tr>
<tr>
<td></td>
<td>– Aboveground biomass heat storage (where appropriate)</td>
</tr>
<tr>
<td></td>
<td>– Soil heat flux at the soil surface</td>
</tr>
<tr>
<td>Radiation</td>
<td>– Net above canopy (using a network standard 4-way radiometer set)</td>
</tr>
<tr>
<td></td>
<td>– Down- and up-welling photosynthetically active radiation (PAR), above canopy</td>
</tr>
<tr>
<td></td>
<td>– Net below canopy where a significant canopy exists</td>
</tr>
<tr>
<td></td>
<td>– Fraction of PAR absorbed by the vegetation (fPAR) using at least three ground-level PAR sensors where a significant canopy exists</td>
</tr>
<tr>
<td></td>
<td>– Diffuse and Direct beam PAR radiation</td>
</tr>
<tr>
<td>Meteorology, above canopy</td>
<td>– Air temperature and relative humidity (shielded)</td>
</tr>
<tr>
<td></td>
<td>– Wind speed and direction</td>
</tr>
<tr>
<td>Meteorology, within canopy</td>
<td>– Air temperature and relative humidity (shielded)</td>
</tr>
<tr>
<td>Meteorology,</td>
<td>– Barometric pressure</td>
</tr>
<tr>
<td>other</td>
<td>Rainfall</td>
</tr>
<tr>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td>Soil</td>
<td>Soil temperature profile (2, 5, 10, 20, 50, 100 cm, 2 replicate profiles)</td>
</tr>
<tr>
<td></td>
<td>Soil moisture profile (by depth to at least 50 cm, or, where the roots go deeper, to the rooting depth, 3-6 depths, 3 replicate profiles)</td>
</tr>
<tr>
<td></td>
<td>Water table depth (peatlands)</td>
</tr>
</tbody>
</table>

Table B. Mandatory Measurements of Site Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carbon stocks</strong></td>
<td></td>
</tr>
<tr>
<td>Aboveground biomass by species, including overstorey biomass (basal area, sapwood area, stem density) and understorey biomass (shrubs, herbs, moss).</td>
<td>- Biomass would be measured only once, and then combined with measurements of growth rate. Ecosystems with rapidly changing biomass may need additional measurements</td>
</tr>
<tr>
<td>Root biomass</td>
<td></td>
</tr>
<tr>
<td>Surface detrital C including standing dead trees, coarse and fine woody debris, and forest floor organic layers</td>
<td></td>
</tr>
<tr>
<td>Mineral soil C (to the depth of parent material)</td>
<td></td>
</tr>
<tr>
<td><strong>Vegetation</strong></td>
<td></td>
</tr>
<tr>
<td>Site history</td>
<td>- Once</td>
</tr>
<tr>
<td>Species composition</td>
<td>- At least at the start and end of the experiment, but annually for disturbed sites</td>
</tr>
<tr>
<td>Canopy height</td>
<td>- For mature sites at start and end of experiment, but more frequently for regrowth and deciduous.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Clumping index</td>
<td>- Annually (coniferous) or seasonally (deciduous)</td>
</tr>
<tr>
<td>Specific leaf area</td>
<td>- Once</td>
</tr>
<tr>
<td>Foliar element size</td>
<td>- Annually</td>
</tr>
<tr>
<td>Spatial variability in fPAR</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf area index</td>
<td></td>
</tr>
<tr>
<td>Rooting depth</td>
<td></td>
</tr>
<tr>
<td>Date of budbreak</td>
<td></td>
</tr>
<tr>
<td><strong>Soil</strong></td>
<td></td>
</tr>
<tr>
<td>Profiles (sampled by depth to at least 50 cm, but where the roots go deeper, to the rooting depth) of:</td>
<td>- Once as part of installation</td>
</tr>
<tr>
<td>soil texture</td>
<td></td>
</tr>
<tr>
<td>bulk density</td>
<td></td>
</tr>
<tr>
<td>soil coarse fragment fraction</td>
<td></td>
</tr>
<tr>
<td>water retention characteristics (field capacity, wilting point)</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
</tr>
<tr>
<td>Cation exchange capacity</td>
<td></td>
</tr>
<tr>
<td>N total, extractable P and K</td>
<td></td>
</tr>
<tr>
<td>% base saturation</td>
<td></td>
</tr>
<tr>
<td>$^{13}$C (where possible)</td>
<td>- Once per year</td>
</tr>
<tr>
<td>Mineralisable N (To be established)</td>
<td>- Annually</td>
</tr>
</tbody>
</table>
Table C. Suggested Measurements of Ecological Variables.

<table>
<thead>
<tr>
<th>Component Carbon Fluxes</th>
<th>Variable</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soil carbon dioxide efflux <em>(Methods to be developed by a working group to consider coverage of spatial and temporal variability)</em></td>
<td>Frequent (eg monthly) to cover seasonal variation.</td>
</tr>
<tr>
<td></td>
<td>Aboveground growth increment (dendrometers)</td>
<td>Seasonally with dendrometers or at end of experiment with increment cores</td>
</tr>
<tr>
<td></td>
<td>Fine root phenology/turnover (to be established)</td>
<td>Frequent (eg monthly) to monitor production and mortality of fine roots</td>
</tr>
<tr>
<td></td>
<td>Litterfall</td>
<td>Seasonally for sites with canopy</td>
</tr>
<tr>
<td></td>
<td>Overstory mortality</td>
<td>Annually or from re-measurement of C stocks</td>
</tr>
<tr>
<td></td>
<td>Decomposition (litter and roots)</td>
<td>Annually</td>
</tr>
<tr>
<td></td>
<td>$^{13}$C, $^{18}$O in CO$_2$ and $^2$H in water vapour</td>
<td>7 times per year</td>
</tr>
<tr>
<td>VEGETATION</td>
<td>Foliar nutrients (total N, P, K)</td>
<td>Annually or seasonally</td>
</tr>
<tr>
<td></td>
<td>$^{13}$C &amp; $^{18}$O in leaves and wood</td>
<td></td>
</tr>
<tr>
<td>ECOPHYSIOLOGY</td>
<td>Maximum stomatal conductance</td>
<td>Once</td>
</tr>
<tr>
<td></td>
<td><em>In situ</em> photosynthetic light response curves (i.e., quantum efficiency and $V_{max}$).</td>
<td>Once</td>
</tr>
<tr>
<td></td>
<td><em>In situ</em> A/C$_1$ curves</td>
<td>Once</td>
</tr>
<tr>
<td></td>
<td>Pre-dawn and mid-day water potential</td>
<td>During significant drought periods</td>
</tr>
</tbody>
</table>
References


