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RESEARCH REPORT

Mapping carbon in tropical Australia: Estimates of carbon stocks and fluxes in the Northern Territory using the national carbon accounting toolbox

By Rob Law and Stephen T. Garnett

*This work was carried out while **Rob Law** was a Research Officer at Charles Darwin University, working with **Stephen Garnett**, Director, School for Environmental Research, Charles Darwin University (Ellengowan Drive, Darwin, NT 0909, Australia; Tel: +61 8 8946 7115; Email: Stephen.garnett@cdu.edu.au). **Rob** is now a LandCarbon Policy Officer with the Victorian Department of Sustainability and Environment (8 Nicholson Street, East Melbourne, Vic. 3002, Australia; Tel: +613 9637 9196; Email: robert.law@dse.vic.gov.au) The study was carried out for the Tropical Savannas Cooperative Research Centre in Darwin, and with the guidance of a steering committee of representatives from the Northern Territory Government, CSIRO and Charles Darwin University.*

Summary The Northern Territory (NT) in Australia has been perceived by many as a frontier for future agricultural development that could serve as a future food bowl for Australia. However, such development is likely to require the conversion of large areas of relatively intact savanna forests, woodlands and grasslands into other land uses, resulting in the release of large amounts of greenhouse gases. With the evolution of international carbon markets, new livelihood opportunities are arising from the management of carbon in landscapes, to enhance sequestration as a means of combating climate change. In order for land owners and governments to realise these opportunities, it is necessary to gain a better understanding of the potential carbon stocks that can occur across different ecosystems throughout the NT. This article assesses the utility of the National Carbon Accounting Toolbox (NCAT) for estimating and mapping carbon stocks in the NT. The NCAT modelling estimates that the NT environments hold approximately 21.5 billion tonnes of carbon dioxide equivalents. The estimates of carbon vary from 5 to 235 tonnes of carbon per ha, decreasing from the north, where the highest estimates are for north-east Arnhem Land and the Tiwi Islands, to the arid lands of the south. They are thought to be the lowest in the Spinifex grasslands east of Alice Springs and west of Tennant Creek. Estimates of potential emissions from clearing and burning of native vegetation range from 27 to 439 tonnes of carbon dioxide per ha, depending on the initial vegetation type. The NCAT estimates are already being used for land-clearing assessments in the NT and demonstrate that Indigenous lands hold high levels of carbon. The performance of NCAT will depend strongly on the quality of the data on which predictions are based and the robustness of model parameterisation. We suggest that further work on soils, fire, grasslands, wetlands and woody debris is needed to improve the validity of the NCAT estimates for carbon in north Australian environments.

Key words: *carbon map, FullCAM, NCAS, NCAT, Savannas.*

Introduction

Two seemingly disparate policy directions have emerged in the Australian national agenda over recent years; (i) the reduction of greenhouse gas emissions through the development of new national standards for land clearing, and (ii) investigations into opportunities for agricultural development in Northern Australia. At the 2008 national 2020 summit it was recognised that, for 'productivity for 2020 sustainability' to occur, natural resource management and agricultural policies cannot be implemented in isolation from one another (Australian Government 2008). Therefore to avoid serious conflict between these policy goals, it will be increasingly necessary for government agencies to understand the greenhouse gas implications of different development options. It will be important to address how greenhouse gas mitigation goals will influence agricultural development policy, how the social and environmental costs of agricultural development vary across the landscape and among different forms of agriculture, and how regulatory constraints based on management of greenhouse gases may impact on Indigenous and non-Indigenous landowners.

The Australian Federal Government is required to report on its national greenhouse gas emissions as part of its obligations under the Kyoto Protocol and the United Nations Framework Convention on Climate Change (Department of Climate Change (DCC) 2009a). For the Land Use, Land Use Change and Forestry sector (LULUCF) the Department of Climate Change and Energy Efficiency (DCCEE) reports on CO_2 fluxes using the National Carbon Accounting System (NCAS) (DCC 2009b). Nationally in 2007 the LULUCF sector emitted 284.7 Mt CO_2e with emissions in the Northern Territory (NT), being 4.17 Mt CO_2e. Whilst the general national trend in LULUCF is negative, reflecting land clearing control, land clearing in the NT is still contributing substantially to the jurisdiction's emission profile, with a peak in land clearing emissions in 2006 (DCC 2009a). Expanding agriculture in the NT through the clearing of existing native savannas has the potential to produce large volumes of greenhouse gases. In fact CO_2e emissions from land clearing may be much higher than that recorded because only forest clearance is included in the National Greenhouse Gas Accounts and much of the woody vegetation in north Australia does not constitute a forest under the Kyoto definition (MacIntosh 2007).

An integral component of the NCAS is the National Carbon Accounting Toolbox (NCAT), particularly its Full Carbon

Accounting Model (FullCAM). The NCAT integrates a range of carbon cycle models of changes to emissions and removals of carbon dioxide in the major carbon pools – soil, litter and debris, above and below ground biomass – from agriculture and forest systems on a spatial scale of 1 ha. The tool is capable of carbon accounting for different land activities such as afforestation, reforestation and deforestation, and estimates carbon exchanges, uptake and loss between the terrestrial biological system and the atmosphere. Although current national carbon policy is uncertain, the NCAT will probably be the model recognised formally under any Emissions Trading Scheme introduced to Australia. The NCAT models and the NCAS have also been selected by the Clinton Climate Initiative as the basis for a Global Carbon Monitoring System, and the modelling approach is already being trialled in other parts of the world (CSIRO 2009). In 2009 the government announced that it is investing $16 million over 4 years to develop a new NCAT that focuses on improving the capabilities of the system to account for non-carbon dioxide emissions such as methane and nitrous oxide, as well as updating the underlying datasets (DCC 2010). This article provides estimates of the carbon stocks in the NT using the existing NCAT and comments on ways in which the underlying datasets can be improved for the Australian tropics.

Methods

The NCAT was used to generate estimates of carbon stocks and flows using plot and spatial simulations (Richards *et al.* 2005). Plot simulation models were used to estimate tonnes of carbon per ha at individual point coordinates, assuming uniform characteristics at that location. A spatial simulation, consisting of many plot files modelled cumulatively to derive estimates for larger areas, was then used to estimate stocks across contiguous areas of land where there was geographically-coded biophysical information available. During the spatial simulation, individual plot files were generated at a set frequency to check and verify the estimates that the NCAT generates for the entire surface. Point-based carbon estimates had to be generated individually so a sampling regime across the NT was designed to generate a sufficient number of estimates from which to interpolate a surface in ArcGIS.

Estimates of carbon within the NCAT are largely driven by the maximum above-ground biomass estimate determined from the Forest Productivity Index (FPI) input layer. This was augmented by the choice of one of 30 broad floristic formations that include the dominant growth form, canopy cover, tree height and the usually dominant land cover Genus for the uppermost stratum native vegetation group [Level III National Vegetation Information System Major Vegetation Groups (MVG) described and mapped within the National Vegetation Information System (Fig. 1; DCC 2009b)]. The data associated with each vegetation group, such as allocations of carbon to different portions of the tree selected in the NCAT, including the roots, coarse woody debris and fine litter values, was then downloaded as a 100 × 100 m ArcInfo grid from Department of

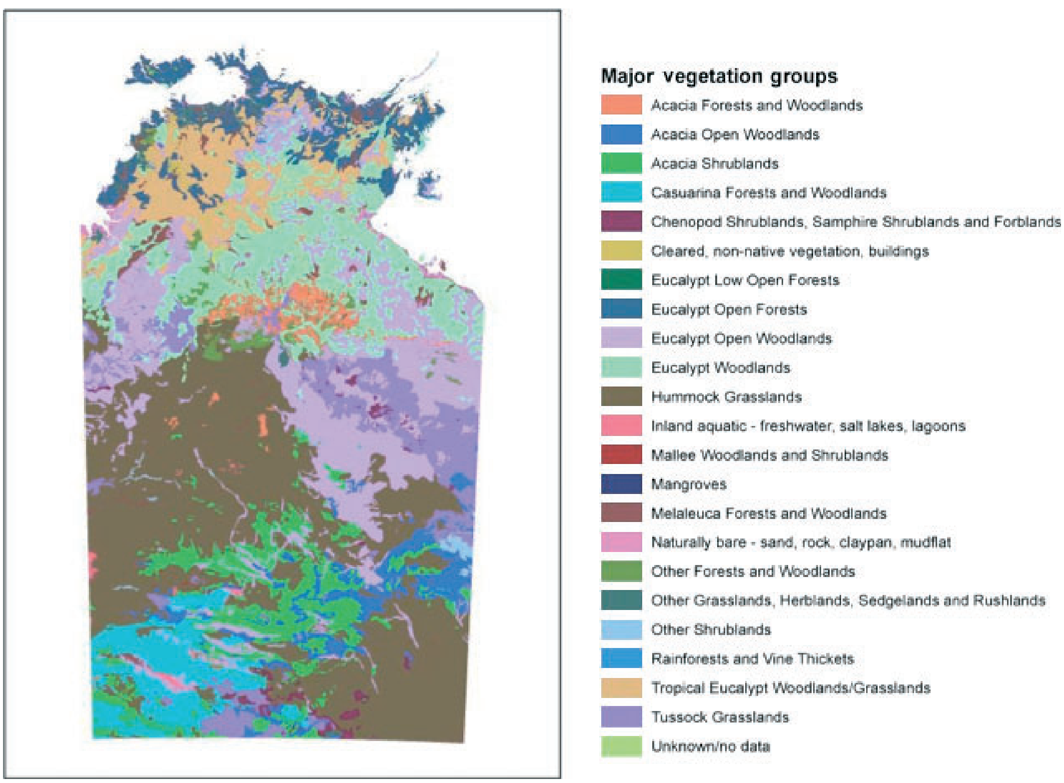

Figure 1. Major Vegetation Groups across the Northern Territory from which the National Carbon Accounting Toolbox vegetation types are derived (developed from DEHWA 2009a,b).

Environment, Water, Heritage and the Arts (DEHWA) (2009a). This dataset was considered appropriate for use at the broad state scale or for regional analyses, and was then used in ArcMap to design a sampling scheme that would cover the extent of the NT. Vegetation group categories that were not possible to model in the NCAT, such as inland aquatic, were excluded in the analysis, leaving a total of 18 MVG (Table 1). Although native grasslands are not available within the NCAT as a downloadable vegetation type, these were modelled using the agricultural model within the NCAT. About 20 000 sample points were generated using the Hawth's Analysis Tool (Spatial Ecology 2009) in ArcMap, stratified based on MVG and proportional to the area of each MVG. This approach does not include local disturbance history and assumes that the MVG selected is the vegetation type growing at the location being modelled. While this ignores the spatial and temporal variability of disturbance across the NT, the sampled point approach was still considered adequate to provide an indicative estimate of carbon across the landscape based on the MVG dataset.

Table 1. Number of sample points per vegetation type modelled in the National Carbon Accounting Tool estimation

Major vegetation group name	*n*
Rainforests and vine thickets	35
Eucalypt open forests	835
Eucalypt woodlands	2388
Acacia forests and woodlands	385
Casuarina forests and woodlands	995
Melaleuca forests and woodlands	365
Other forests and woodlands	288
Eucalypt open woodlands	3316
Tropical eucalypt woodlands/grasslands	1198
Acacia open woodlands	736
Mallee woodlands and shrublands	18
Acacia shrublands	1413
Other shrublands	69
Tussock grasslands	1321
Hummock grasslands	6190
Other Grasslands, Herblands, Sedgelands and Rushlands	138
Chenopod shrublands, Samphire shrublands and forblands	181
Mangroves	40

Once the modelling had been performed on each of the 20 000 sample points, the outputs were combined into a single point layer in ArcMap containing the NCAT estimates for each individual location. In addition to carbon stocks, the NCAT was also used to model the impacts of land clearing events followed by burning. Geostatistical analysis was then used to interpolate a surface from the points using the Inverse Distance Weighted method, and masking the areas excluded for analysis. Maps were also generated for the above-ground carbon, which includes the above-ground tree components as well as the debris pool, and a soil map was generated using the same method. The total amount of carbon was estimated by determining the mean for each vegetation type within each Interim Bioregional Area (IBRA region; version 6.1, DEHWA 2009b) and then multiplying this by the area of each vegetation type within each IBRA region.

Results

National Carbon Accounting Toolbox estimates were used in ArcMap to provide maps of the NT estimating total carbon mass (Fig. 2), which includes the above and belowground carbon pools, debris pool and soil carbon pool down to 30 cm, above-ground carbon only (Fig. 3) and the soil carbon pool (Fig. 4), which excludes belowground tree components of root biomass. The total carbon stocks across the entire NT were estimated to be 5.85 billion tC, or 21.47 billion tCO_2-e. The NCAT estimates of total carbon across the NT ranged from <5 through to 235 tC/ha. Carbon stocks were estimated to be the highest in the northern part of the NT and to decrease steadily south and away from the coast into the arid interior. The highest estimates of C for the NT (150–235 tC/ha) were in north east Arnhem land, the northern coastline including Kakadu National Park and Adelaide and Mary River region, the Tiwi Islands and other offshore islands, and some parts of the Daly River region. Medium levels of carbon (50–150 tC/ha) were modelled to be throughout the Victoria River District and around the Gulf of Carpentaria. Low levels of carbon (<10 tC/ha) were estimated for the Tanami desert west of Tennant Creek and the Simpson Desert east of Alice Springs.

Above-ground carbon stocks in the NT reflect long-term average plant productivity (Kesteven *et al.* 2004), with carbon levels being influenced largely by vegetation type and climatic factors such as the rainfall gradient. For example the high levels of carbon found in Arnhem land and the Tiwi Islands reflect the dominance of eucalyptus open forest and Mean Annual Rainfall (MAR) of above 1000 mm where the seasonal drought is shorter. High levels of carbon are also found in most riparian areas, as such as along the Victoria and Daly rivers. The lowest levels of carbon occur in the arid interior where MAR is below 400 mm and vegetation is dominated by spinifex (*Triodia* spp.) grasslands. These dominate west of Tennant Creek and east of Alice Springs. An island of slightly higher carbon occurs around Alice Springs where the vegetation type is predominantly acacia shrubland and woodland.

Vegetation types within the NCAT contain a number of default parameters which influence estimates for a particular location (Fig. 5). Modelled carbon stocks were the highest in eucalypt open forests (158 ± 23 tC/ha) and rainforests and vine thickets (157 ± 32 tC/ha), though for rainforests this is largely due to the high NCAT default debris value of 89.78 tC/ha. Soil carbon estimates using the NCAT default settings reflected the general trends in the above-ground carbon, ranging from <5 to >110 tC/ha. The NCAT estimates for soil carbon were based on the pre-clearing soil carbon levels (Lynch 2002). Soil carbon levels are estimated to vary from 79 ± 20 tC/ha in tropical eucalypt woodlands/grasslands to 62 ± 19 tC/ha in woodlands to 40 ± 15 tC/ha in open woodlands.

Land clearing emissions were estimated for different vegetation types by estimating on-site carbon stocks before land use change, then producing an estimate of the net difference in carbon stocks by modelling a broadscale clearing and burning event in FullCAM. The net loss of carbon was then converted to tCO_2-e/ha by multiplying by 3.67. Carbon dioxide emission estimates ranged from 27 tCO_2-e/ha in shrublands to 439 tCO_2-e/ha in rainforests and vine thickets. The percentage of total onsite carbon

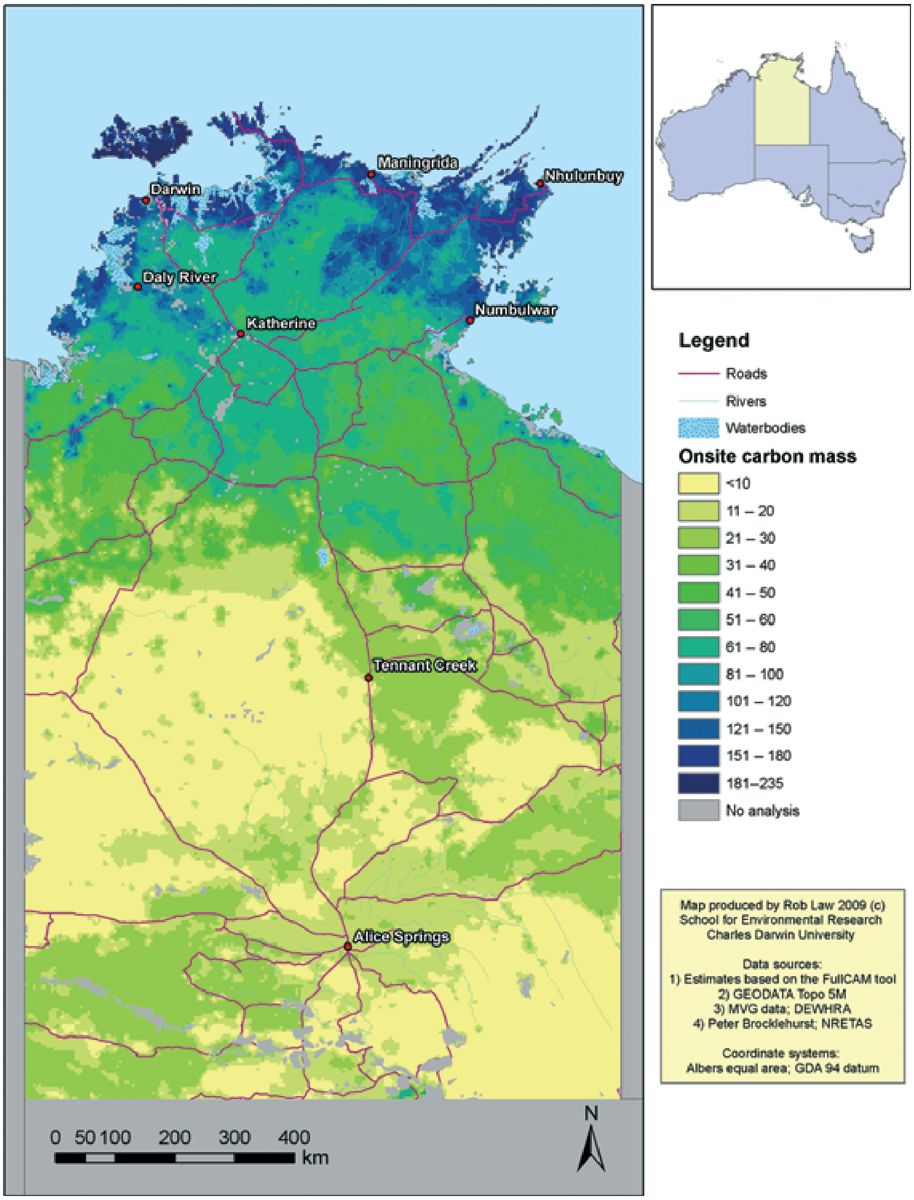

Figure 2. Potential carbon stocks in the Northern Territory using the National Carbon Accounting Toolbox to provide estimates of above and below ground carbon stores in woody and non woody vegetation. Estimates are sums of all carbon pools including stems, branches, leaves, coarse and fine woody debris, leaf litter and below ground root biomass and soil carbon down to 30 cm.

likely to be lost also varied depending on the ratios of above and below ground carbon, ranging from 34% in shrublands to 77% in rainforests and vine thickets.

Discussion

Caveats on using the NCAT in tropical Australia

The estimates for the tree carbon pool in NCAT are largely determined by the maximum above-ground biomass parameter and physiologically-based regression equations calculated from the FPI (Kesteven *et al.* 2004). The equations simulate the rate at which woody and other vegetation is expected to develop on the site and the latter sets a limit on the growth that a site can support under prevailing conditions. The estimates for the tree carbon pool in this report represent the initial above-ground biomass value and thus assume each vegetation type is mature. However savannas are frequently disturbed by fires, cyclones and floods, so it is unlikely that this assumption will hold across the landscape. However this inaccuracy is partly offset by the FPI which is based on field based measurements of savannas that will include those in a state of recovery. Therefore, the values available in the NCAT probably do reflect the true value on the ground in addition to biophysical constraints such as moisture and nutrient limitations rather than the potential above-ground biomass should there be no disturbance (DCC 2009b). Certainly the modelled data for the Wildman River Reserve are consistent with an estimate of the same area using remotely sensed data of 47 tC/ha aboveground (Collins *et al.* 2007). Nevertheless Liedloff *et al.* (2009) point out that most of the data for the savanna biome in NCAS come from Queensland and may not adequately reflect savannas in the NT where fire is more frequent and widespread. Their validation exercise comparing NT field data with NCAT predictions showed there was a tendency to overestimate biomass in many locations where tree populations were reduced through disturbances, and underestimate it in others. Similarly, when Law and Blanch (2009) compared carbon estimates from Chen *et al.* (2003) with the NCAT estimates for four open forest locations in high rainfall regions of the NT they found that, whilst the total carbon (all pools) was within 1 tCO_2-e/ha of the NCAT estimate, there were significant differences in the allocation of carbon within different pools, with the NCAT overestimating the amount of C stored in trees by a factor of two.

The treatment of debris is one major potential source of this error. The NCAT separates debris into two classes; decomposable, in which debris totally decomposes within 2.5 years, and resistant, in which debris totally decomposes inside 10 years (Australian Greenhouse Office (AGO) 2005). For the NT the data associated with the MVG are combined with downloadable default data for the NCAT coarse woody debris and fine litter derived from studies on vegetation that were conducted mostly in the eastern states (Mackensen & Bauhaus 1999; DCC 2009b).

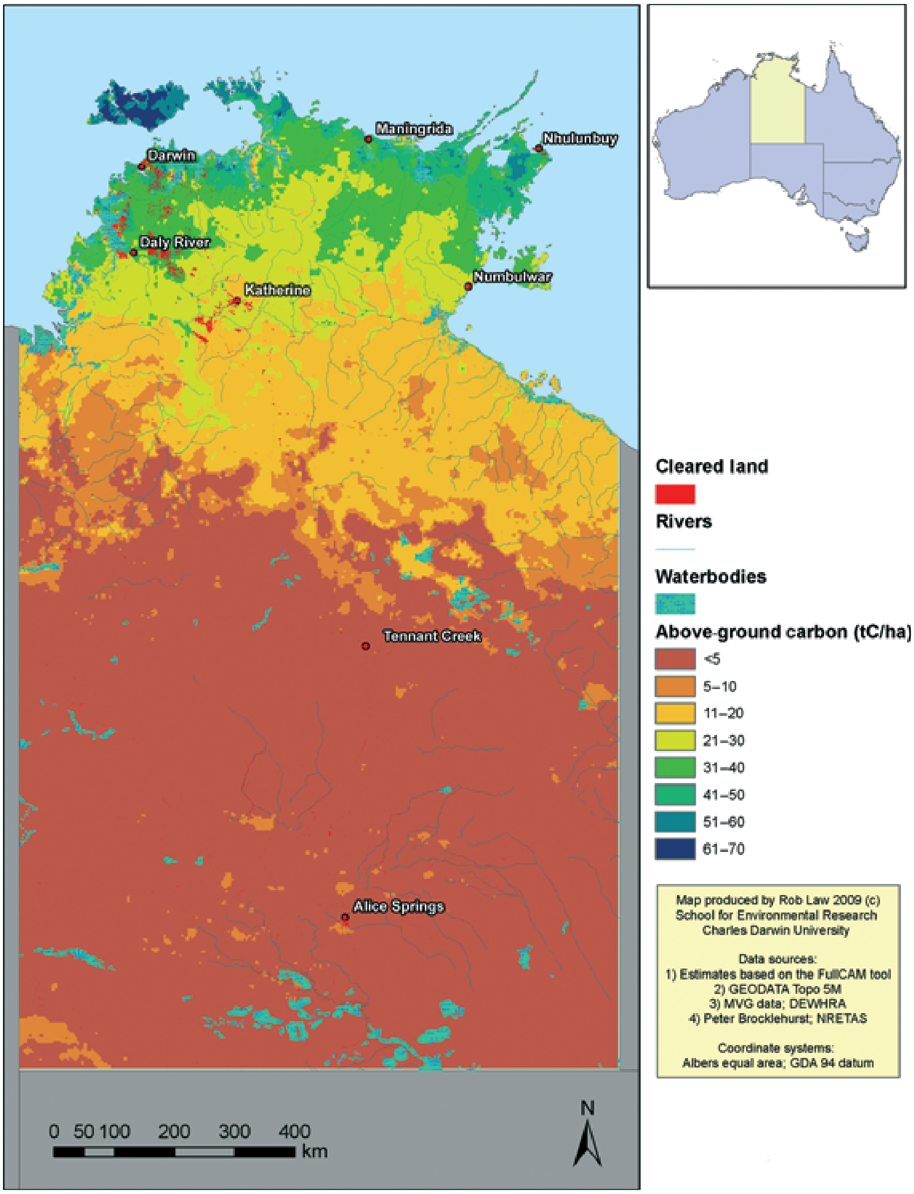

Figure 3. Potential above-ground carbon stocks in the Northern Territory of the tree and debris components, including stems, branches, leaves, coarse and fine debris and leaf litter.

These values are unlikely to consider wood type, species, tree age, local biological decomposers such as termites and climatic variation (Ximenes & Gardner 2006). Coarse woody debris is particularly difficult to measure as it is highly variable spatially, cannot easily be extracted from remotely sensed data and is probably most influenced by savanna fire events.

Soil carbon in the NT is also poorly understood. Soil carbon is also highly variable both spatially and temporally and many of the processes of soil carbon in the tropical savannas are still relatively unknown, such as the impacts of charcoal on soil carbon levels. Similarly, the state of knowledge of carbon soil sequestration in wetlands is an area that could be further developed. The estimates used here to set the initial soil carbon level in the NCAT are derived largely from soils sampled along a single north-south transect of the NT (Lynch 2002). Where data were missing for a particular soil type, they were extrapolated from areas with existing data in adjacent IBRA regions. While much historical data for soils, particularly in the Daly region, is soon to be digitised and incorporated into the NCAT (Brian Lynch, pers. comm., 2008), there is a need to obtain and analyse many new samples.

There may also be a need to revisit the 30 cm soil depth limit used by the NCAT. While this corresponds with the IPCC recommendations for measuring soil carbon, based on the assumption that this is the likely depth at which most interactions between soil and the atmosphere occur, Chen *et al.* (2003) found that 40% of the carbon occurred below 40 cm with losses as a result of land clearing occurring as deep as 1 m (Chen *et al.* 2005). In arid areas the effect of depth may be even more extreme. Roots of spinifex *Triodia* spp., which dominate large parts of the NT's arid zone, grow to depths of many 10 s of metres (Reid *et al.* 2007) and there is no knowledge of the interaction between fire, spinifex and soil carbon.

Given that native grasslands dominate all but a small portion of the NT, a further limitation of the current version of the NCAT is that the closest simulation of native grasses is to run the NCAT using an agricultural pasture grass. As a result the default parameters such as root to shoot ratios and turnover rates are unlikely to be representative of the native grasses that occur in the NT. Wetlands are also difficult to model within the NCAT using default data, as this is not a category Australia reports under for the UNFCCC and the Kyoto protocol (DCC 2009b). Given the extensive areas of wetland in the NT and their potential to store large amounts of carbon, this may be an area of future interest. Floodplains in the NT are affected by grazing, exotic plants and animals, fire management and inundation from rising sea levels, all of which are likely to have an impact on carbon. However, while wetlands/floodplains can contain very high levels of carbon, they may also have significant methane and nitrous oxide emissions through the different wet/dry stages and related soil microbial activity. Although Article 3.3 in the Kyoto Protocol currently omits wetlands as a category for reporting emissions, future policy frameworks may shift to a more comprehensive accounting approach in which they could be included.

The final area where the NCAT needs to be adapted for northern needs is its

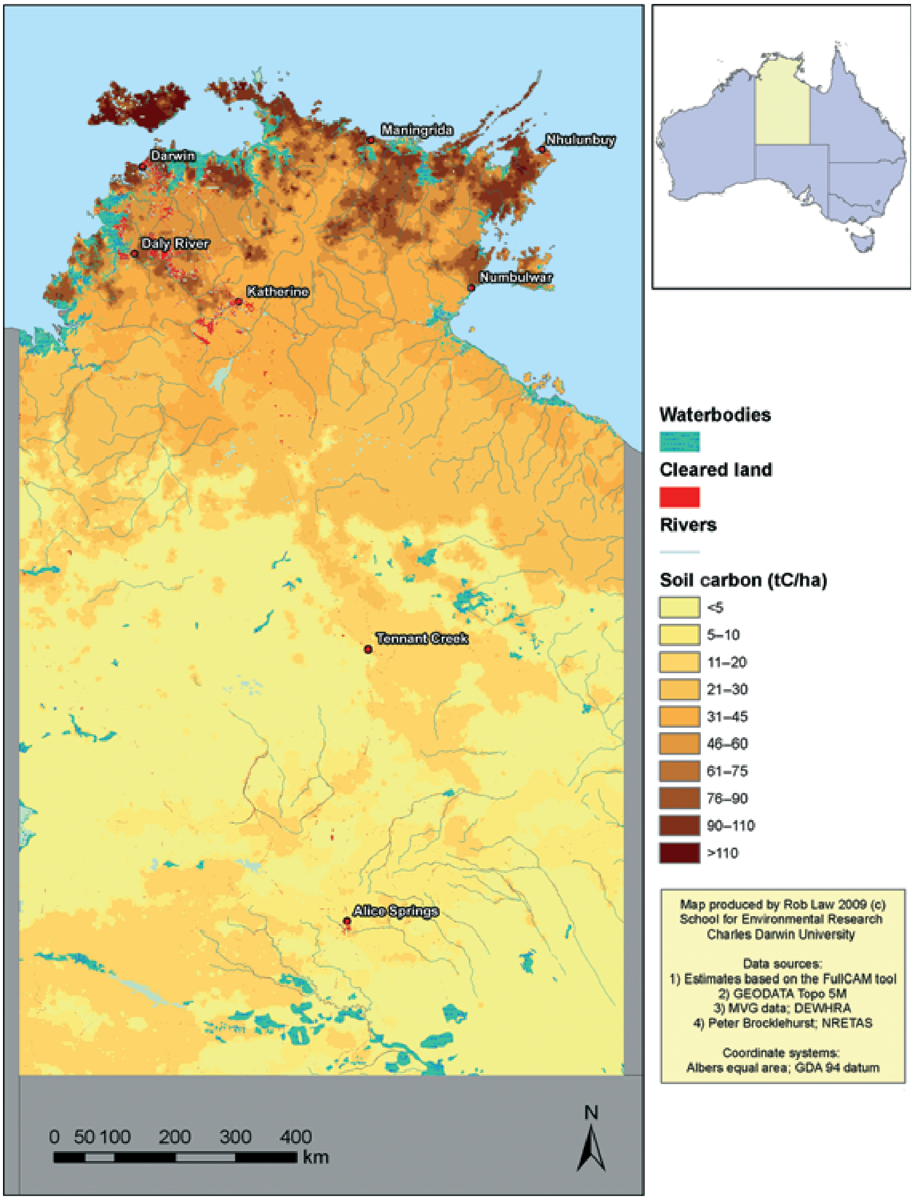

Figure 4. Estimates of total soil carbon down to 30 cm for the Northern Territory using the National Carbon Accounting Toolbox.

treatment of fire. Currently, fire is modelled in the NCAT as an event that can be defined by the user or downloaded. Liedloff *et al.* (2009) recommend that future research focus on the effects of fire on soil carbon dynamics, fuel consumption rates and emissions from burning, both CO_2 and non CO_2. NCAS does not report on CO_2 emissions from savanna burning, and instead only reports on methane and nitrous oxide emissions. This is based on the IPCC assumption that CO_2 emissions from savanna fires are essentially sequestered back through subsequent recovery after fire. It is unlikely that this assumption holds true across the savanna landscape, particularly with the spread of invasive grasses such as Gamba Grass (*Andropogon gayanus*) and changes in land management practices which alter the presence of woody vegetation in the landscape. There also needs to be coordination of the way fire is modelled using the NCAT and its measurement as part of agricultural emissions under the National Greenhouse Gas Inventory under which all emissions except those considered part of LULUCF are measured (Russell-Smith *et al.* 2009).

One of the strengths of the NCAT is its ability to model carbon under different management regimes. Clearing land of existing (usually native) vegetation to convert it to other uses is an important contributor to greenhouse gas emissions through the removal of existing tree biomass and subsequent burning of the debris. The land use that follows this land clearing event, such as crop, pasture or plantation, combined with management practices such as tillage and grazing intensity can significantly affect ongoing emissions. The rate at which carbon stocks change will depend upon the land use practices, the management regimes, the soil types and climatic factors (DCC 2009b).

Patterns of carbon in the Northern Territory and implications for management

Notwithstanding any consideration of conservation or cultural consequences (which is an assumed and necessary requirement), how does carbon accounting affect land-use decision-making in Indigenous and non-Indigenous lands of the NT?

As of March 2010 the NCAT is being employed to assess land clearing applications in the NT (Department of Natural Resources, Environment, The Arts and Sport (NRETAS) 2010). Government staff calculate the amount and value of carbon based on current or modelled carbon prices on the basis of information on where and how the clearing is to occur. This information is then used by the consent authority to assess 'the benefit or detriment of the development to the public interest', though what constitutes the public interest is not specified. Nevertheless the importance of the NCAT is explicit. And, despite the misgivings expressed above, the relative pattern of C stocks in woody vegetation at least is likely to be similar across the landscape to that modelled here.

There are two important implications of these patterns. The first is the quantum of carbon that could be released by land clearing. Unlike other jurisdictions in Australia, <1% of the native vegetation of NT has been cleared and large areas of native savannas remain intact (Woinarski *et al.* 2007). As a result, future agricultural

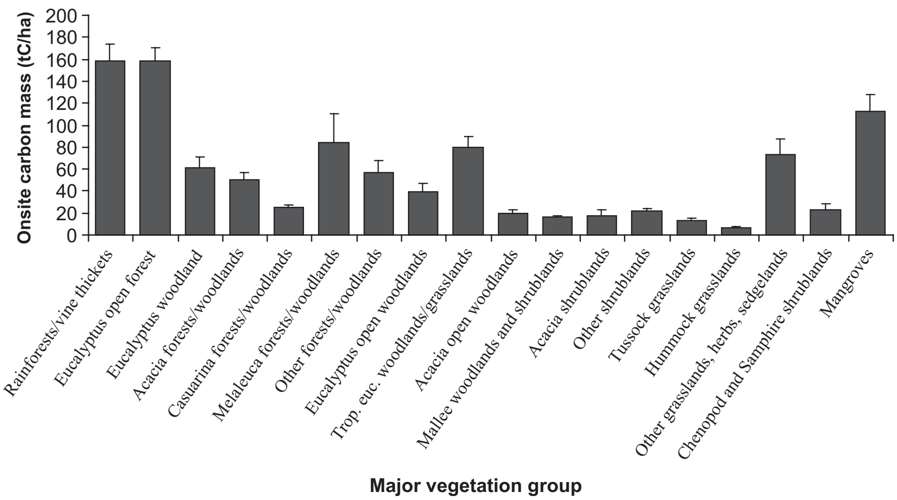

Figure 5. Average total onsite carbon for each major vegetation group.

development will most likely require the clearing of native savanna vegetation. Land clearing is already the biggest contributor of greenhouse gas emissions within the LULUCF sector for the NT and further expansion is expected of cropping of mango and mahogany plantations. A recent report on future options for northern Australia predicted intensive agricultural development could triple by 2030 if readily available arable soil is developed (Northern Australia Land and Water Taskforce 2009). Previous estimates, also using the NCAT, have suggested that clearing of native savanna for improved pastures alone could result in greenhouse gas emissions ranging from 50 to over 200 tCO_2-e/ha (Northern Territory Government 2008). The NCAT estimates in this report suggest a similar loss (Table 2). The vegetation categories for which clearing is likely to be permitted include open forest, tropical eucalyptus woodland/grassland, eucalyptus woodland and eucalyptus open woodland. The NCAT modelling suggests that these vegetation types could lose between 61% and 71% of their total carbon mass through a clearing and burning event. This research suggests that a future carbon price and policy framework that recognises avoided deforestation will be an important step towards recognising the value of retaining vegetation for its carbon and reducing greenhouse gas emissions.

The second practical implication from this research is that much of the most carbon rich forest in the NT is on Indigenous-owned land. Equity issues could therefore arise should Indigenous people be refused permits to clear native forest for agricultural development in the future when non-Indigenous people have profited from clearing their land in the past. There have already been cases where Indigenous people with permits to clear have chosen to do so even though funds could have been available to keep the trees standing for their carbon value (van Oosterzee & Garnett 2008). Nevertheless, if the carbon retained and managed on Indigenous lands can be adequately recognised through the Carbon Farming Initiative (DCCEE 2010) or other policy settings, then this may be more desirable for Indigenous landholders who seek to strengthen and revitalise traditional land management practices (Whitehead *et al.* 2008). In most cases such credits will still not be permissible under the Kyoto provisions for reduced deforestation as there will not be additionality, i.e. more carbon stored than would have occurred otherwise, by keeping the forests in place. However, it could be argued that where regional planning allows clearing (provided a level of protection of biodiversity, water and soils is accommodated, as is happening in the NT) voluntary restraint from the permitted clearing could be argued as reduced deforestation and thus could attract international carbon credits. For any such initiatives, quantification of the carbon saved will require use and improvement of the NCAT.

Conclusion

Understanding how the NCAT measures and accounts for land-based emissions and sequestration in the NT is important for identifying where opportunities lie for different stakeholders, and where there are gaps in knowledge or inappropriate default data being used for the local context. The NCAT is already being used to assess

Table 2. Estimated impacts of a land clearing and a broadcast burn event on total carbon (with SD) across different wooded vegetation types

Major vegetation group	*n*	C mass lost (%)	Emissions (tCO_2e/ha) per vegetation type
Rainforests and vine thickets	35	77 ± 5	439 ± 65
Eucalypt open forests	835	71 ± 4	415 ± 59
Eucalypt woodlands	2388	61 ± 8	136 ± 42
Acacia forests and woodlands	385	56 ± 8	102 ± 19
Casuarina forests and woodlands	995	66 ± 1	62 ± 6
Melaleuca forests and woodlands	365	61 ± 7	183 ± 110
Other forests and woodlands	288	55 ± 8	116 ± 46
Eucalypt open woodlands	3316	61 ± 7	88 ± 34
Tropical eucalypt woodlands/grasslands	1198	67 ± 6	195 ± 44
Acacia open woodlands	736	45 ± 10	32 ± 9
Mallee woodlands and shrublands	18	52 ± 4	31 ± 6
Acacia shrublands	1413	51 ± 6	34 ± 26
Other shrublands	69	34 ± 8	27 ± 8
Chenopod shrublands, Samphire, shrublands and forblands	181	50 ± 7	42 ± 25
Mangroves	40	53 ± 10	225 ± 87

land-clearing permits in the NT, is likely to be linked to a future Emissions Trading Scheme and will be the main tool used for official carbon markets. As such, it is imperative that the model continues to have its assumptions tested for different environments, particularly in areas such as the savannas where very little calibration work has been done.

The following areas should continue to be researched and developed:

- More comprehensive soil carbon datasets over a wider proportion of the landscape and subsequent inclusion in the NCAT.
- The above-ground biomass models used in the NCAT and their validation for different vegetation types, particularly wetlands and native grasslands.
- Effects of land clearing and post-clearing treatment of debris and other disturbance events on the carbon cycle.
- The interactions between greenhouse gas cycling and human use and management of tropical wetlands.
- Incorporation of fire consumption rates for debris and better understanding of transfers of carbon in vegetation to the soil pool.

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