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Vegetation thickening and carbon sinks in the grazed woodlands of north-east Australia

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Abstract

Historical, anecdotal and $\delta^{13}C$ data, along with permanent transect records, together provide convincing evidence of woody plant thickening (increases in number and size) in the grazed woodlands of north-eastern Australia. This thickening parallels similar structural changes in savannas grazed by domestic livestock in other countries. In both Australia and elsewhere in the tropics/sub-tropics the woodlands (savannas) were maintained as a fire mediated sub-climax prior to the introduction of domestic livestock. The prime agent changing the structure of these woodlands has been the conversion of land use from hunter-gathering or nomadism to the raising of sheep and cattle – a practice which has often been associated with increased grazing pressure, reduced fuel loads and the containment of fire. It is indisputably a change brought about by altered management practices.

Actual woody plant growth and death/decay rates recorded, coupled with detailed biomass determinations for selected communities, allow estimates to be made of carbon sequestration from this thickening in the above ground component of Queensland's grazed woodlands. This presently unaccounted for carbon sink is in excess of 100 Mt CO_2 equivalent/yr, and would reduce net emissions in Australia's current National Greenhouse Gas Inventory by > 20% if it was included in the NGGI.

Introduction

Most ecosystems throughout the world are subject to continuous change, whether initiated by natural or man induced causes. In the Australian context recent reviews (e.g. Pyne 1991, Ryan *et al.* 1996) present convincing historical and anecdotal evidence that much of Australia's **current** forests and woodland cover is far more closed to-day than it was under Aboriginal management. (This is not to deny that there has also been extensive land clearing since European settlement for agriculture, forestry and urban purposes). Parallel thickening of woodlands/savannas has also followed the arrival of Europeans in the Americas and Africa (see the extensive reviews of Archer (1995) and Idso (1995)).

Idso (1995) suggested that the worldwide invasion of grasslands by trees and shrubs, that began approximately two centuries ago, has closely followed the upward trend in the air's CO_2 content. However this argument has been refuted by Archer *et al.* (1995) who clearly demonstrate that the positive correlation between woody plant expansion and atmospheric CO_2 are not cause and effect. Further rebuttal is provided by innumerable fence line contrasts emphasising the role of management in determining vegetation structure and composition. In fact the common thread underlying most cases of woody plant thickening seems to be the introduction of domestic livestock and reduced fire frequency, in communities previously maintained as fire-mediated sub-climax vegetation.

This paper presents evidence of woody plant thickening in the grazed woodlands of north-eastern Australia based on historical and anecdotal evidence, along with studies of carbon isotope ratios in soil organic matter and quantitative ecological data. The role such thickening plays in carbon sequestration is also discussed.

Historical/anecdotal reports

Leichhardt's journal (1847) records that poplar box (*Eucalyptus populnea*) trees in the Maranoa district of south-west Queensland had a spacing of between 50 and 100m with little understorey. This contrasts with the dense woodlands in this area to-day, often with a prominent *Eremophila mitchellii* understorey. Likewise after only a short period of settlement a Royal Commission (1901) into the condition of lands in the Western Division of N.S.W. reported that "generally speaking it (the Cobar area) was originally open box-forest country with currajong and an occasional pine tree upon it. The overstocking of the country, coupled with the rabbits, prevented the growth of grass to anything like its former extent, and so caused a cessation of bush fires that had formerly occurred periodically. This afforded the noxious scrub a chance of making headway".

Domin (1911) concluded that in all parts of Queensland the open 'forests' are not a natural association, but a secondary one, changed through the influence of the aboriginal inhabitants, mostly by means of bushfires. Reynolds and Carter (1993) surveyed graziers in central western Queensland with Mitchell grass downs and/or gidgee (*Acacia cambagei*) country to get an objective record of what woody species concern them. They used a postal survey and received 315 replies covering an aggregate of 6 M ha. The major findings were that 11% of the area of affected properties had been 'lost' due to the invasion of woody weeds, while 55% of respondents said that their naturally timbered areas had thickened up.

Jacobs (1955) noted that summer rainfall areas of the world are in general more likely to have forests which regenerate vigorously than winter rainfall areas. In the winter rainfall areas the developing seedling is subjected to hot dry weather in its establishment stages. In summer rainfall zones favourable water relationships in the warm growing period aid the development of trees.

In the plus 1500mm rainfall zone (of tropical Queensland) Stanton (1995) reported that massive habitat changes, largely related to decreasing fire incidence have taken place in the last 100 years, with demonstrable widespread and massive changes in the last 30 years. Grasslands have mostly disappeared under shrubs and trees and open sclerophyll communities have changed to closed forest.

Carbon Isotope Ratios

The ratios of $^{13}C/^{12}C$ (expressed as $\delta^{13}C$) provide diagnostic signatures which can be used to differentiate organic C derived from C_3 and C_4 plants (Tieszen and Archer 1990). Woody plants possess the C_3 photosynthetic pathway ($\delta^{13}C$ range = -27 to -32 ‰, whereas vegetation of tropical grass dominated zones is characterised by grasses with the C_4 pathway ($\delta^{13}C$ range = -13 to -17 ‰).

If woody plants have been long term constituents of the landscape the $\delta^{13}C$ signature of the soils beneath them should reflect this and fall within the -27 to -32 ‰ range. However if C_3 trees and shrubs had displaced C_4 grasses: -

(i) the soil $\delta^{13}C$ value would be less negative than -27 to -32 ‰

(ii) the degree of departure from the expected ratio would decrease as time of site habitation by woody plants increases, and

(iii) the soil $\delta^{13}C$ values would become less negative with depth along the chronosequence (Tieszen and Archer 1990)

(a)
Brigalow
(*Acacia harpophylla*)
scrub

(b)
Buffel grass
(*Cenchrus ciliaris*)
replacement of
cleared brigalow
scrub

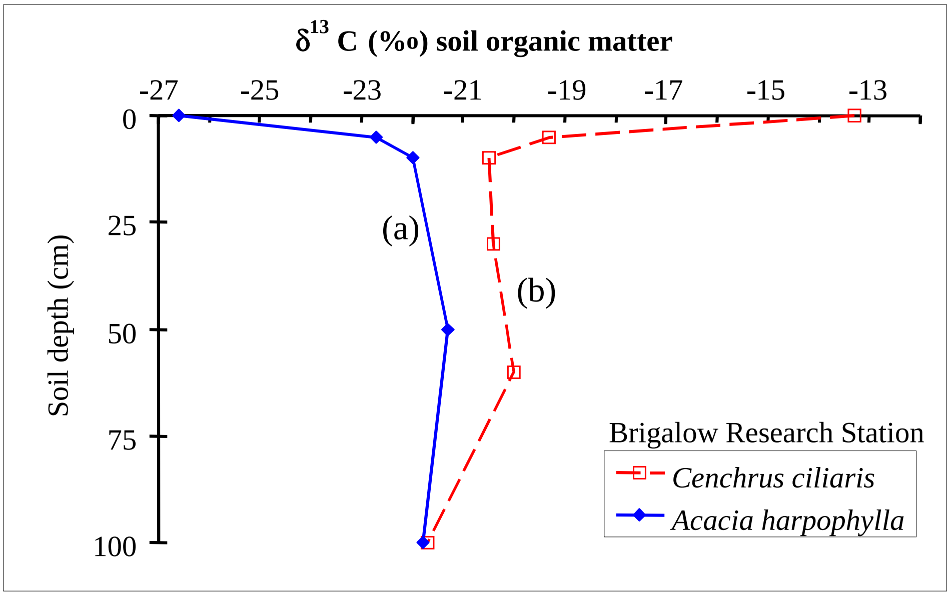

Figure 1. Comparison of $\delta^{13}C$ values in surface litter and soil organic matter of two adjacent soil profiles (a) under brigalow (*Acacia harpophylla*) scrub, and (b) under buffel grass (*Cenchrus ciliaris*) pasture sown on land cleared of this scrub 30 years ago. The $\delta^{13}C$ values at depth in (b) reflect that of the original dominant vegetation on the site.

(a)
Mitchell
(*Astrebla* spp.)
grassland

(b)
Prickly acacia
(*Acacia nilotica*)
invasion of Mitchell
grassland

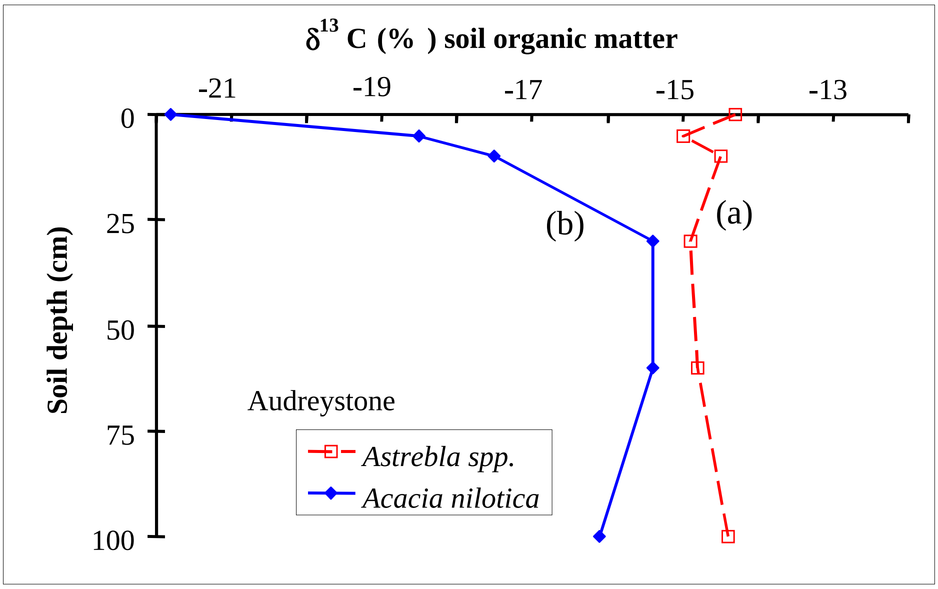

Figure 2. Comparison of δ^{13}C values in surface litter and soil organic matter in two adjacent soil profiles (a) under Mitchell (*Astrebla* spp.) grassland, and (b) Mitchell grassland invaded by the exotic prickly acacia (*Acacia nilotica*) since the mid 1970's. The δ^{13}C values at depth in (b) reflect that of the original dominant vegetation on the site.

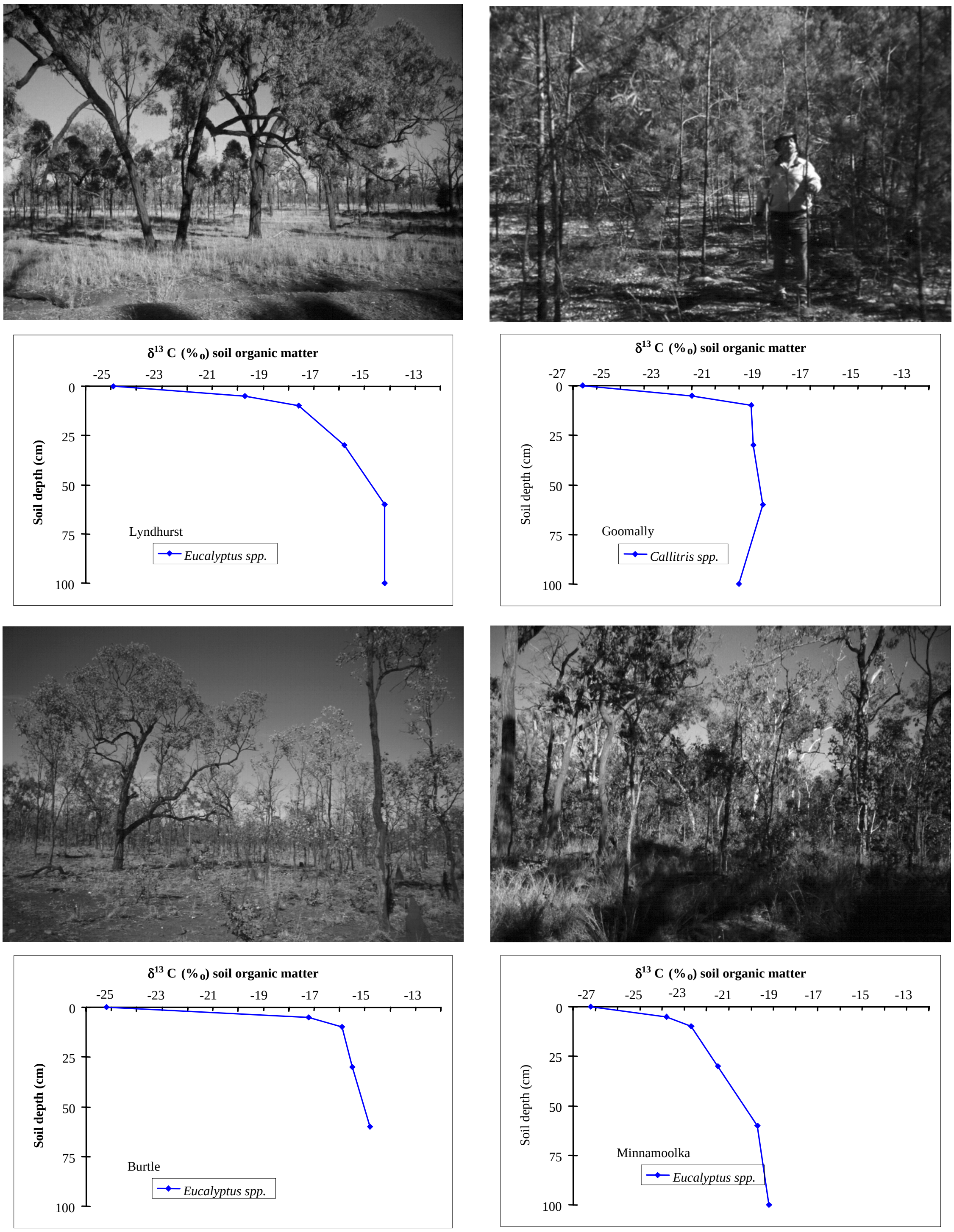

Figure 3a. Grazed woodland sites in Queensland showing δ^{13}C values in surface litter and soil profile organic matter highly suggestive of a more open grassy woodland structure in the past.

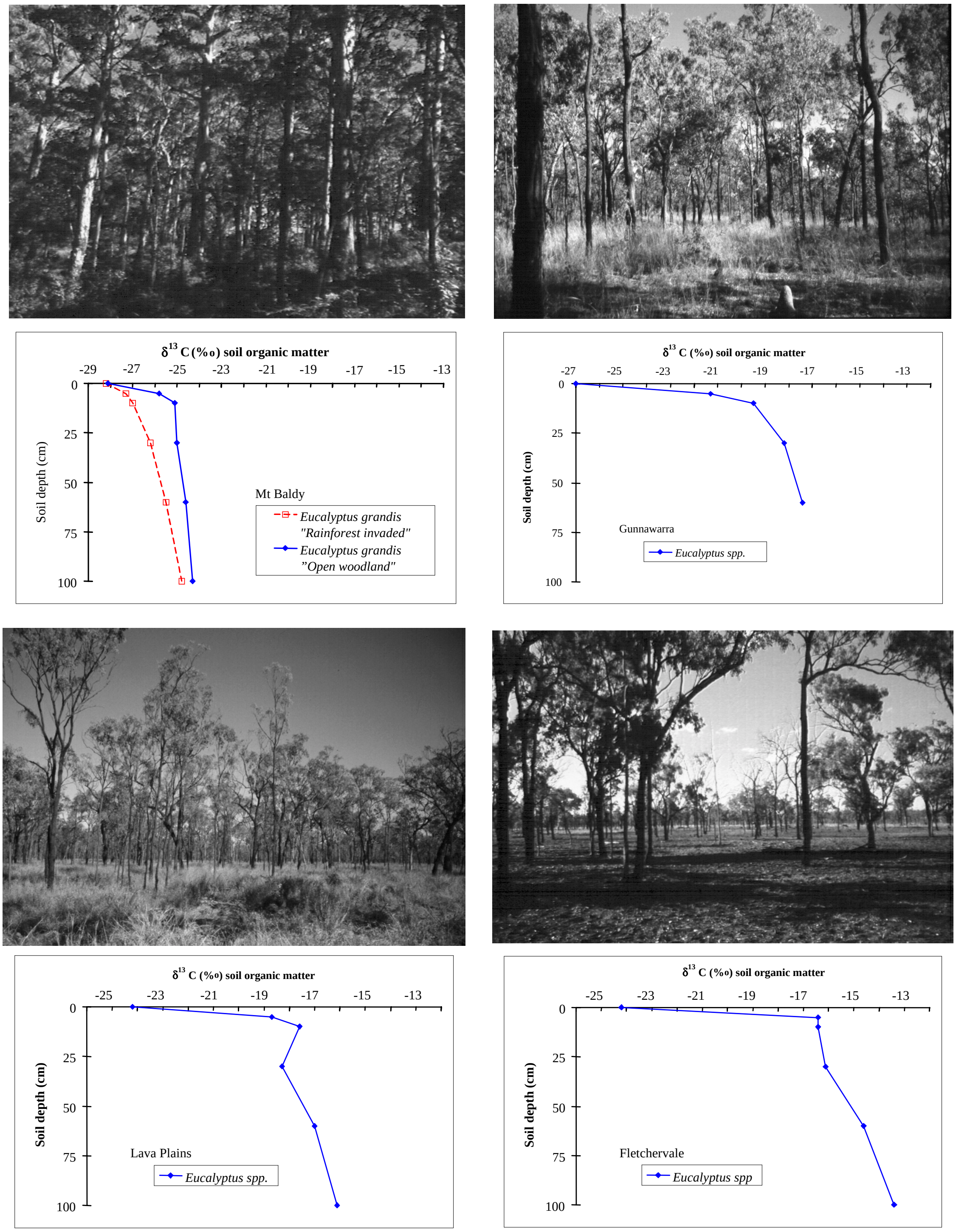

Figure 3b. Grazed woodland sites in Queensland showing (apart from Mt Baldy) $\delta^{13}C$ values in surface litter and soil profile organic matter highly suggestive of a more open grassy woodland structure in the past. The Mt Baldy site is a *Eucalyptus grandis* community known to have been recently invaded by rainforest species. In this case the $\delta^{13}C$ soil organic matter profile indicates a consistent history of C_3 dominant vegetation.

Schwartz *et al.* (1996) noted that the organic matter $\delta^{13}C$ in a soil in equilibrium with vegetation of a precise photosynthetic pathway is very similar to that in the dominant vegetation. There have now been many studies of sites with well documented vegetation records that show the $\delta^{13}C$ of soil organic matter accurately reflects plant community history. This suggests it is reasonable to apply this technique where past vegetation history is unknown.

Two well known vegetation transformations in Queensland – the conversion of brigalow (*Acacia harpophylla*) scrubs to buffel grass (*Cenchrus ciliaris*) pasture (Johnson 1964) and the invasion of treeless Mitchell grasslands (*Astrebla* spp.) by the exotic prickly acacia (*A. nilotica*) (Burrows *et al.* 1990) provide examples to illustrate this technique. The $\delta^{13}C$ signature of the soil organic matter beneath the buffel grass (C_4 species) should reflect that of the previous brigalow scrub (C_3 species). Likewise the $\delta^{13}C$ signature in soil organic matter beneath prickly acacia (C_3) should reflect that of uninvaded Mitchell grassland (C_4). (Figs 1 and 2).

A preliminary survey has been carried out in the grazed woodlands of Queensland utilising the $\delta^{13}C$ technique. The examples given for sites of unknown history strongly support the view that these woodlands have thickened up in recent times, as they display signatures characteristic of very open woodland at depth (Fig 3 a, b). The only situation where equivocal results (little change in $\delta^{13}C$ values down the soil profile) were obtained was where rainforest had apparently invaded *Eucalyptus grandis* open forest of similar $\delta^{13}C$ signature (Fig 3b).

Tree-shrub dynamics and carbon store

The Queensland Department of Primary Industries has developed a transect recording and processing system (TRAPS) and software package for field data capture, storage and synthesis of tree growth parameters (Back *et al.* 1997). The usual TRAPS layout comprises five permanently positioned parallel belt transects 100m long arranged along a north-south axis, 25m apart and with recordings made of all woody plants within a 2m band located either side of the transect line.

The position of plants along and either side of the transect line is recorded with a measuring tape and graduated stick. The stem circumference of all trees and shrubs present in the belt is measured 30cm above ground level. This height ensures seedlings as well as mature plants are monitored. Plant height and canopy measurements are also obtained and a fixed photographic record maintained at each recording by focussing back from the top of the northern most steel picket in each line.

Burrows *et al.* (1998) present summarised data for a subset (47) of these TRAPS sites which have been located throughout Queensland's grazed woodlands (Fig. 4). Comparative permanent plot data collected by the Queensland Forest Service are also presented (Table 1). These data collectively confirm that living trees and shrubs have recorded significant annual growth in basal area in those grazed woodlands not subject to clearing, even over a period of below average rainfall.

Table 1 also records natural and/or man induced tree deaths which approximately match live tree growth (in basal area equivalents) within monitored stands over the observation period. However, when the slow decay rates of standing dead trees (mean 39.7% loss of above ground biomass over 10 years for *E. populnea*) are taken into account (Burrows, unpublished data) the average "increment" in total (live + dead) basal area remains around $0.15m^2$/ha/yr [$0.24m^2$ basal area/ha/yr growth of live trees + 0.14/9m^2/ha/yr ingrowth – (0.397 * 2.3/9m^2/ha/yr maximum decay of trees which die over sampling period) (see Table 1)]. Also scattered live trees remaining after drought or man induced deaths (aboricide injected) within the stand tend to grow much faster than those in plots not subject to such thinning.

The above calculation enables an estimate to be made of carbon sequestration in the above ground biomass of Queensland's grazed woodlands. But before such sinks are determined one needs to be reasonably confident that the growth rates recorded are truly representative of woody plant basal area increment in the region. Since the focus is on growth of woody plants it is not necessary to sample non wooded areas, as would inevitably be included under completely random sampling.

Burrows *et al.* (1998) carried out a sensitivity analysis of mean growth rates by stratifying the TRAPS data into 'regrowth', 'growth' and 'mature' sites and varying the area of each (3-10, 30-47, 10-20 M ha respectively), based on estimates of past clearing activity, community size class diagrams and local knowledge. This analysis indicates that combining all TRAPS data sets and obtaining an overall 'live' tree basal area growth rate ($0.24m^2$/ha/yr - Table 1) multiplied by the total area of grazed woodland in Queensland (60 M ha - Burrows 1995) produces an estimate of total growth within the bounds of the sensitivity analysis (mean statewide grazed woodland live basal area increment of 14.35 M m^2/yr cf. sensitivity analysis range of 12.99 – 15.07 M m^2/yr).

Conversion of tree mean basal area growth increment to biomass and carbon sequestration ideally requires allometric relationships to be developed for each species. This is obviously an impossible task, so the best compromise is to determine such relationships for representative dominant trees. By applying the appropriate regression to community stand tables (e.g. obtained from TRAPS transect records) it is possible to estimate the above ground biomass present per hectare and biomass per m^2 of tree basal area. The latter figure is used to convert basal area increment per year to a carbon fixation measure.
The mean above ground biomass of *Eucalyptus* spp. (the dominant grazed woodland genus) per m^2 of tree basal area in north-eastern Australia is 6260 kg/m^2, based on 9 *E. crebra*, 6 *E. melanophloia* and 8 *E. populnea* sites (Burrows *et al.* 1998). When data for one *A. aneura* and one *A. harpophylla* site are also included this mean figure is slightly lower (6150 kg/m^2 basal area).

The National Greenhouse Gas Inventory assumes 50% carbon content in woody plant matter. So the estimated CO_2 sink above ground in Queensland's grazed woodlands = 60Mha * $0.15m^2$/ha/yr basal area increment * 6.15t dry matter/m^2 basal area * 0.5 (C content) * 44/12 (CO_2 conversion) ≈ 101.5 Mt CO_2 fixed per year.

Discussion

There has been significant thickening (increases in woody plant basal area) in the grazed woodlands of north-eastern Australia since European settlement, as evidenced by convincing historical, anecdotal and $\delta^{13}C$ data, along with measured fluxes in tree/shrub populations on permanent plots. Concomitant deaths also recorded on many plots in recent drought years do not negate the overall increase in carbon sequestration in woody plant biomass, when both live and dead plant stores are taken into account.

This woody plant thickening parallels that occurring elsewhere in the world's savannas which are also grazed by domestic livestock. The prime cause of the increasing number and size of woody plants is additional grazing pressure (following the introduction of sheep and cattle), leading in turn to reduced fire incidence in what was, before European settlement, a fire mediated sub-climax. This is indisputably a man induced change in the vegetation structure of these grazed woodlands.

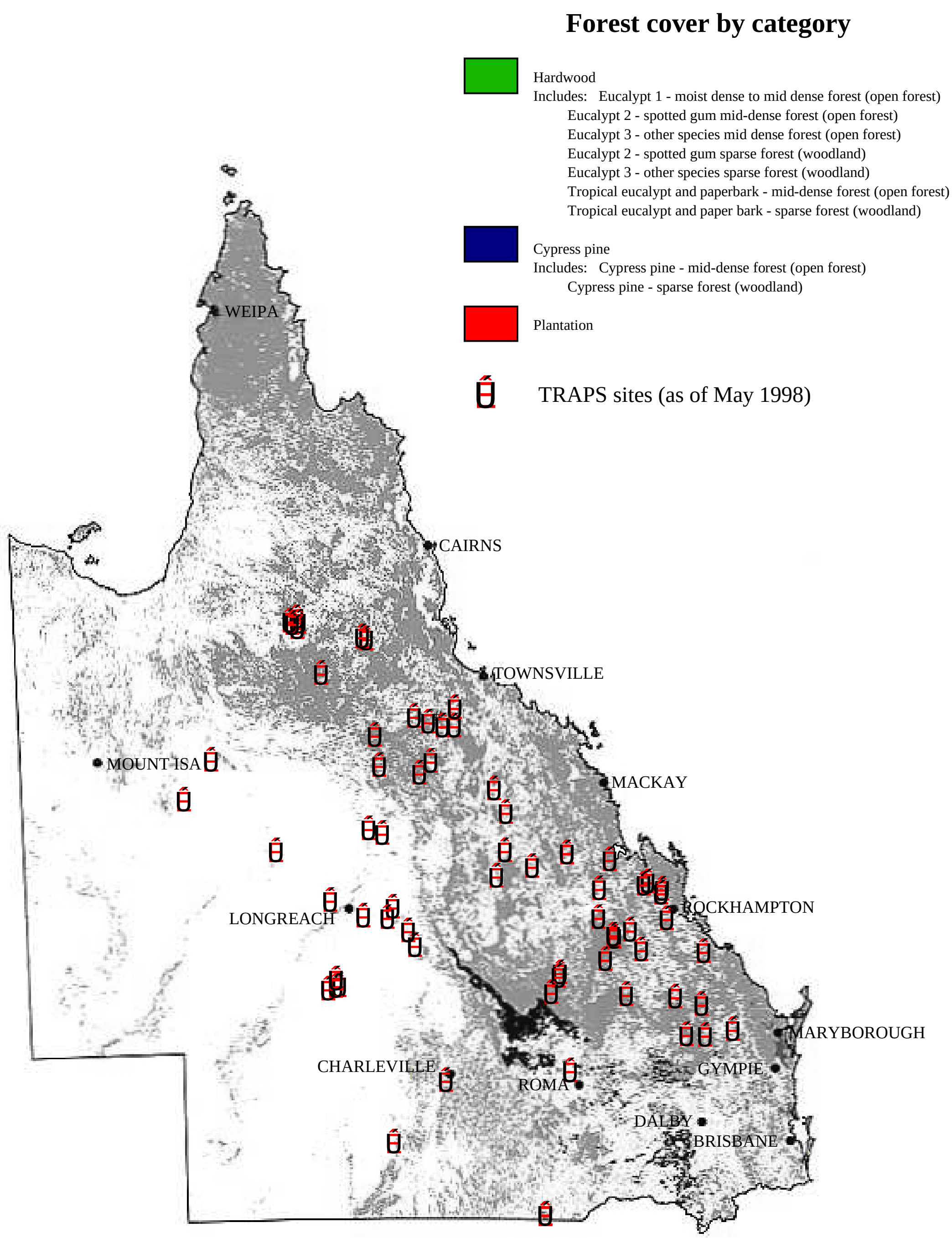

Figure 4. Current distribution of permanently positioned woodland monitoring (TRAPS) sites in Queensland. Indicative forest cover is also shown (Source: DPI Forestry Information Series Q198015).

$\delta^{13}C$ data confirm that the reported changes in vegetation structure have occurred across most grazed woodlands sampled. Within accepted constraints of the analysis (lack of age determination for the woody components) size class distribution diagrams (not presented here) support arguments that the vegetation on most TRAPS transects is not stable and is increasing in density and size. A new equilibrium status in the grazed woodlands, based on current growth rates, should take some 50 years to establish – assuming an average woody plant 'carrying capacity' of 20 to 23 m^2/ha basal area [(23m^2/ha – current mean live basal area 9.6m^2/ha) /0.24m^2/ha/yr live basal area growth increment (see Table 1)].

Application of mean basal area growth rates from 47 widely divergent grazed woodland communities in Queensland and their estimated mean live + dead biomass 'increment' per m^2 basal area, suggest above ground carbon sequestration is of the order of 100 Mt CO_2 equivalent/year. This huge biological greenhouse gas sink is currently not included in Australia's National Greenhouse Gas Inventory (NGGI). Moreover the size of this sink, which inarguably derives from man induced causes, would be enhanced further if below ground growth ($^1/_3$ of that above ground?) was also taken into account. Woodland growth in New South Wales and the Northern Territory provides an additional potential carbon store not presently included in these calculations.

Paradoxically, one of the main reasons growth of woody plants in savannas and rangeland has not been documented is that these 'forests' are rarely subjected to forest mensuration practices, unless commercially valuable timber is involved. The TRAPS program has overcome this problem in north-eastern Australia and coincidentally revealed an anthropogenic greenhouse gas sink that is > 20% of the nation's published NGGI (National Greenhouse Gas Inventory Committee 1996). No scientifically credible NGGI can exist for this country while this huge sink is not factored into inventory calculations.

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Table 1. Mean basal area growth statistics for a broad range of woody plant communities in north-east Australia (a) plots located in the grazed woodlands (b) 'undisturbed' native forest plots maintained by the Queensland Forest Service (QFS data courtesy M. Cant). (Source: Burrows *et al.* 1998)

	Mean plot area (ha)	No. of plots	Mean years recorded	Initial basal area (m^2/ha)	Final basal area (m^2/ha)	Basal area change (m^2/ha/yr)	Standing dead* (m^2/ha)	Ingrowth** (m^2/ha)
(a) Grazed woodlands								
Eucalyptus spp	0.25	47	9.0 ± 0.4	7.40 ± 0.88	8.94 ± 0.94	0.21 ± 0.03	2.10 ± 0.33	0.10 ± 0.03
All woody plants	0.25	47	9.0 ± 0.4	7.84 ± 0.89	9.62 ± 0.95	0.24 ± 0.03	2.30 ± 0.37	0.14 ± 0.03
(b) QFS plots								
All woody plants (>20cm DBH)	0.32	21	20.4 ± 2.9	34.89 ±1.31	41.77 ± 5.85	0.32 ± 0.12 (0.12 ± 0.04)	4.12 ± 0.87	0.64 ± 0.29

* Plants which died (or were killed in the course of woodland development) over the observation period but remain **standing** on site. Their initial basal area and growth are **not** included in change calculations in (a) but are included in such calculations in (b). Bracketed values for (b) are basal area change when trees that died are excluded.

** Plants which establish between initial and final recordings. These plants are not included in change calculations