# Carbon storage in soil and vegetation in paired roadside sites in the box woodlands of eastern Australia

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## Summary

The carbon content of soils and vegetation on roadside reserves was compared with carbon in adjacent paddocks along a 700 km transect through the box woodlands of eastern Australia. Biomass of the overstorey and understorey components of the vegetation was estimated at each site, and soil samples were collected for assessment of soil carbon. Total soil carbon in the surface 30 mm was not significantly different between paired sites, but significantly more carbon was stored in the aboveground components of the vegetation in the roadside reserves. In general, healthier and more diverse sites with more dense shrub and tree cover were associated with greater aboveground carbon and, to a lesser extent, soil carbon. These results suggest that, from a 'Kyoto' perspective, more attention should be given to retaining native vegetation and maintaining its condition in these landscapes of Australia.

*Keywords:* carbon; woodlands; woodland vegetation; woodland soils; roadside soils; Australia

## Introduction

Since European settlement, native vegetation in Australia has been extensively cleared and only a small proportion of the original cover of some vegetation types remains today (Benson 1999). Vegetation clearance has been especially intense in the sheep–wheat belt of eastern Australia, where agricultural activities currently dominate the landscape.

Loss of native vegetation has been linked to many forms of land degradation including erosion, salinisation, loss of soil organic matter and soil structure, and declines in biodiversity (Smith *et al*. 2000; Yates *et al.* 2000). In recent years, the issue of carbon storage in the landscape has also attracted considerable attention, mainly in response to the Kyoto Protocol of 1997 (AGO 1997, 2000; Rawson and Murphy 2000). However, much of the discussion to date has focused on Article 3.3 of the Protocol which allows for carbon stored in new 'sinks' (e.g. afforestation and reforestation activities) to be included in national carbon accounts. Article 3.4 also allows for the negotiation of 'additional sinks' (e.g. vegetation thickening) although debate still continues as to which of these will be eligible. Less attention has been given to the quantity of carbon that is stored in extant native vegetation and the potential loss of carbon that might occur when these are cleared. There is still a large degree of uncertainty about the levels of carbon storage in these native vegetation communities, which components of the community contribute most to carbon storage and how these levels compare with other land uses (Barson *et al*. 1998).

The most significant native vegetation community in the sheep–wheat belt of eastern Australia is the temperate box woodlands (Prober and Thiele 1995). In many areas of eastern Australia, these woodlands are now largely restricted to strips along roads and rail easements, many of which are used as travelling stock routes (TSRs; Nowland 1997). Road reserves in Australia exist alongside almost 900 000 km of roads (Forman and Alexander 1998). Despite having a limited area and in some places being severely degraded, these remnant communities still have value as refugia for woodland flora and fauna (Freudenberger and Ozalins 2000) and provide many other benefits in the rural landscape.

Here we report on a study of aboveground (vegetation) and belowground (soil) carbon in the box woodlands of eastern Australia. In this study we assessed the carbon in vegetation and soils at 111 paired roadside sites in comparison to the adjoining land-use (paddock) along a 700 km transect within the temperate box woodlands west of the Great Dividing Range in New South Wales. The aims of the study were to: 1) quantify the carbon stored in minimally managed roadside reserves by comparison with adjacent paddocks, and 2) quantify the relative contribution of vegetation and soil to total site carbon in the two systems.

## Methods

### The study area

The study was undertaken at sites along a 700 km transect running south–north through the temperate box (*Eucalyptus* spp.) woodlands of NSW. A transect commenced near Howlong near the NSW–Victoria border (35º59'S, 146º39'E) and ended near Coolah in northern NSW (31º51'S, 149º41'E). The route selected was along minor and secondary roads within the box woodlands

(Prober and Thiele 1995). Most roadside sites were roadside corridors managed by the Roads and Traffic Authority, or TSRs managed by the Rural Lands Protection Boards. Most were minimally managed with only intermittent light grazing, and most supported open woodland communities. The adjoining paired sites, referred to here as 'paddocks', were cropped, or grazed on improved or native pastures.

**Vegetation, soils and climate**

The vegetation in the study area can be described broadly as a temperate woodland (Moore 1970) dominated by yellow box (*E. melliodora*) woodlands, yellow box–Blakelys red gum (*E. blakelyi*) associations, white box (*E. albens*), grey box (*E. microcarpa*) and river red gum (*E. camaldulensis*) woodlands on gently undulating slopes with cypress pine (*Callitris* spp.) associations on rocky hills.

Soils at sites along the transect ranged from massive red and yellow earths (Gn2, Northcote 1979), to red brown earths (Dr2, Db1) and red and yellow duplex soils (Dr2/4, Dy3.5) on the slopes and flats. Low-lying areas and depressions were dominated by deep alluvial loams (Um4) and cracking clays (Ug5.2), whilst hillslopes and rises were dominated by shallow loams (Um1). Surface textures ranged from loams to silty loams and clay loams.

The climate of the study area can be described as temperate, and although rainfall is not strongly seasonal, there is a weak gradient, from winter rainfall in the south to summer rainfall in the north (Costermans 1992). Mean diurnal temperatures range from a minimum of 12.7ºC in July to a maximum of 31.5ºC in February. The principal difference between the northern and southern sites is that the north generally experiences warmer winters (Costermans 1992).

**Field sampling**

Sites were selected at regular intervals of about 6 km along the route, with defined protocols relating to minimum separation between sampling sites and towns (Schabel and Eldridge 2001). Some sampling locations were excluded if, for example, the vegetation had been mowed or recently burned. Where sites were excluded for any reason, a replacement site was selected a further 1 km along the route. In total, 111 sites were sampled along the 700 km of transect. Soil samples could not be collected from 28 of the paired sites due to difficulties of access. Thus for studies of soil carbon, data from 83 paired sites were used, whereas for vegetation, data from all 111 paired sites were used.

At each site, a quadrat of 400 $m^2$ was positioned in the area between the edge of the road and the fence separating the road reserve or TSR from the adjacent property. Where possible, the aim was for all measurements to be made within a quadrat measuring 20 m long by 20 m wide, but in some situations where the roadside reserve was less than 20 m wide, the length of the quadrat was adjusted to produce a total area of 400 $m^2$. In either case, a paired quadrat of the same shape and dimensions was located in the adjacent paddock, and all care was taken to ensure that both quadrats were on similar slope and soil type. The placement of both quadrats directly adjacent to each other ensured that they were truly paired.

Within each quadrat, all woody plants (trees and shrubs) were counted and assigned to one of five classes; seedling (<1 m tall), dbh <10 cm (dbh = diameter at breast height), dbh 10–20 cm, dbh 20–40 cm or dbh >40cm. An assessment was also made of tree health (which was related to the proportion of the canopy affected by mistletoe or dieback), the number of hollows, canopy cover of trees and shrubs, groundstorey type and height (grasses and forbs; native, exotic or mixed), cover of logs and debris on the ground, and a subjective assessment of the degree to which the vegetation had been modified from a state considered to be pristine box woodlands (Schabel and Eldridge 2001). Cover of the groundstorey component and the degree to which the soil surface was eroded (by windsheeting, watersheeting or rilling) were measured inside ten quadrats of 0.5 $m^2$ placed along the two diagonals of each plot. The dominant plant species in each quadrat were recorded, and the ratio of annuals to perennials was assessed. Samples of the surface 30 mm of the soil were collected from the four corners and centres of both paired quadrats at each site, bulked, and thoroughly mixed for laboratory analyses.

**Landscape health assessment**

Vegetation and soil surface data collected at each site were used to assess ecosystem health (Noss 1990) based on the structure, composition and function of the landscape. Landscape *structure* is related to the cover of the biotic components of the site (in this case cover of trees, shrubs, logs and debris). Landscape *composition* focuses on the biota (Andreasen *et al.* 2001), which in this study comprised the diversity of trees, shrubs and groundstorey plant taxa. Landscape *function* refers to the effective operation of key biotic and abiotic processes such as competition, herbivory, infiltration and decomposition. Attributes used for deriving a measure of landscape function were the degree of site modification, degree of erosion, cryptogam cover, shrub and tree recruitment, a measure of plant demography, and tree health.

For each site, the value of each attribute was allocated to one of a number of classes (usually four or five). These classes included the full range of values encountered for a particular attribute within the study, and ranged from very low (poor condition) to very high (good condition). Each class was then assigned a particular score depending on its perceived effect upon structure, composition or function. For example, pasture quality (the extent to which the site was dominated by native groundstorey plants), was divided into five classes based on the percentage cover of native species such that 1 = <10% native, 2 = 10–25% native, 3 = 25–50% native, 4 = 50–75% native, 5 = >75% native. Thus a particular site where 17% of the groundstorey plants were natives would receive a score of 2 for 'pasture quality'. This process was repeated for all the attributes for each of structure, composition and function and the scores for a site were summed and expressed as a percentage of the maximum possible score. In this way all sites were given a score for the three indices, with larger scores indicating a healthier vegetation community.

**Laboratory analyses**

Soils were air dried and passed through a 2 mm sieve to remove any large stones and debris. The organic carbon content was determined using the modified Walkley–Black method (Rayment

**Table 1.** Comparison of carbon storage (t $ha^{-1}$) in soils, groundstorey vegetation and overstorey vegetation between roadsides and paddocks

| Location | Soil carbon (t $ha^{-1}$) | | Groundstorey carbon (t $ha^{-1}$) | | Upper-storey carbon (t $ha^{-1}$) | | Total carbon in soil and vegetation (t $ha^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SEM | Mean | SEM | Mean | SEM | Mean | SEM |
| Roadside | $5.91^{a}$ | 0.32 | $1.69^{a}$ | 0.070 | $12.87^{a}$ | 3.92 | $18.22^{a}$ | 0.60 |
| Paddock | $5.76^{a}$ | 0.32 | $0.03^{b}$ | 0.005 | $0.55^{b}$ | 0.34 | $6.51^{b}$ | 4.05 |
| ***N*** | 83 | | 111 | | 111 | | 83 | |

Different letters within a column indicate a significant difference at $P < 0.05$; SEM = standard error of the mean.

**Table 2.** Differences in total carbon (t $ha^{-1}$) in the soil and vegetation in relation to vegetation community

| Vegetation community | Paddock | | | Roadside | | | Paddock and roadside combined | | |
|---|---|---|---|---|---|---|---|---|---|
| | *n* | Mean | SEM | *n* | Mean | SEM | *n* | Mean | SEM |
| Grassland | 62 | $5.13^{a}$ | 0.30 | 29 | $7.66^{a}$ | 0.57 | 91 | $5.91^{a}$ | 0.30 |
| Scattered trees | 10 | $8.58^{ac}$ | 1.67 | 2 | $9.34^{a}$ | 3.00 | 12 | $8.71^{a}$ | 1.43 |
| Regrowth pine | 2 | $8.67^{ac}$ | 3.70 | 1 | $16.99^{ab}$ | * | 3 | $11.44^{a}$ | 3.51 |
| Open woodland | 9 | $13.25^{bc}$ | 4.22 | 51 | $24.34^{b}$ | 6.41 | 60 | $22.71^{b}$ | 5.50 |

Different letters within a column indicate a significant difference at $P < 0.05$; SEM = standard error of the mean.

and Higginson 1992) with two replicate samples per quadrat. Percentage organic carbon was converted to total carbon (t $ha^{-1}$) using unpublished bulk density data (D.J. Eldridge unpublished data) and values collected at some of the survey sites with a soil corer of diameter 47 mm and depth 20 mm.

### Total carbon calculations

Total aboveground biomass of trees was calculated using algorithms for *Eucalyptus* spp. woodland trees (Snowdon *et al.* 2000) and *Callitris* spp. (Harrington 1979) which relate stem diameter at breast height (dbh) to total tree biomass. Total carbon in the vegetation was calculated by multiplying biomass by a factor of 0.5 (see AGO 1998; Rawson and Murphy 2000). Root biomass was estimated on the basis of 0.25 of aboveground vegetation biomass after Snowdon *et al.* (2000). Given the extremely low density of shrubs at most sites, mid-storey biomass was not included in estimates of total carbon.

Groundstorey measurements were used to estimate standing dry matter using photostandards derived from several seasons of research in landscapes with similar plant communities (Williamson and Eldridge 1993; Eldridge unpublished data). These photostandards show cover and biomass values for a range of pasture types: for example, native tussock grasses, native herbs and forbs, and exotic forbs and grasses. Groundstorey biomass for each site was then converted to total carbon by applying a similar correction factor of 0.5.

### Statistical analyses

Differences in soil carbon between the roadside and adjacent paddock sites were tested using paired t-tests (MINITAB 1998). However, differences in groundstorey (grasses and herbaceous plants), upper-storey (trees) and total carbon were examined using the non-parametric Kruskal–Wallis test, as transformation of the data failed to standardise the variances. The Kruskal–Wallis procedure calculates a test statistic ($H$) which is analogous to a t-statistic in the Student t-test. Differences in relation to the four vegetation communities were examined using non-parametric Kruskal–Wallis tests, adjusting from ties (MINITAB 1998).

## Results

Mean values of carbon in soils, groundstorey and upper-storey vegetation for roadside and paddock sites (pooled across all vegetation communities) are shown in Table 1.

As most roadside sites (61%) supported woodland communities, and most paddock sites (75%) supported grassland communities (Table 2), we expected roadside sites to have greater levels of soil carbon compared with paddock sites. However, pooled across all vegetation communities and land uses, there was no significant difference in the quantity of carbon stored in the top 30 mm of the soil between roadside reserves and paddocks (Table 1). In an attempt to explore potential differences due to land use, management or present status of the vegetation, we partitioned sites in both paddocks and roadside reserves into two classes based on the cover of their groundstorey vegetation. It would have been preferable to have stratified sites based on management history, but the broad-scale nature of this survey meant that it was not possible to collect these data. We therefore had to rely on surrogates which we felt would be informative about how the sites were managed, either from a cropping or pastoral perspective. However, we still detected no significant differences in total soil carbon between well-vegetated (>30% groundstorey cover) and sparsely (<30% cover) vegetated sites at either paddock or road-side sites ($P > 0.05$).

Across all vegetation communities, paddock sites exhibited a wider range of total soil carbon values (range 1.9 to 18.9 t $ha^{-1}$) than roadside reserve sites (range 1.0 to 13.3 t $ha^{-1}$). Comparing vegetation communities, there was significantly more total carbon in the open woodland sites than the grassland sites in both the paddocks ($H = 16.5$, df = 3, $P < 0.005$) and the roadside reserves ($H = 13.0$, df = 3, $P < 0.005$). However, the roadside sites contained significantly more carbon in the upper-storey than the paddock sites ($H = 30.4$, $P < 0.001$). Similarly, there were significantly larger quantities of carbon in the groundstorey ($H = 170.51$, $P < 0.001$) component of the vegetation on roadside sites than on paddock sites (Table 1).

Enhanced landscape structure, function and composition were associated with significant increases in aboveground (overstorey and groundstorey) carbon in both roadside ($P < 0.03$) and paddock ($P < 0.004$) sites. In roadside reserves, healthier sites with more diverse structure, composition and function were also correlated with increases in total soil carbon ($P < 0.05$). Some of the variation in aboveground woody biomass will be related to differences in tree cover, which is one of the components of landscape structure.

## Discussion

Results from this study broadly indicate that roadside reserves contain significantly more carbon in the landscape than do adjacent paddocks. Differences in the vegetation, and not in the soils, accounted for most of this difference. The soil samples in this study were collected to a depth of only 30 mm because it has been demonstrated in a range of environments (including Central Western NSW), that soil carbon is concentrated in the near-surface soil layers and diminishes rapidly with depth (Keith *et al.* 1997; Northup and Brown 1999; Turner and Lambert 2000). Were differences to exist in the soil carbon content between land uses, it would therefore be expected that these would be observed most strongly in the near-surface layers (e.g. MacLeod 1999). In our study, however, no such differences were found.

Nevertheless, many studies have found that vegetation cover has a marked influence on soil carbon content (Grierson *et al*. 1993; Weston and Attiwill 1996), and that vegetation disturbance and clearance result in a decline in soil carbon content (Rawson and Murphy 2000). Most of these studies, however, compared cleared land with woodland and forest that was initially relatively undisturbed and in good condition. In our study most paddock sites had been cleared of their woodland cover, and it might therefore have been expected (e.g. AGO 2000; Murphy *et al.* in press), that the soils of roadside sites would contain larger quantities of carbon. The limited difference in soil carbon between land uses in our study may be a reflection of enhanced levels of carbon in the paddocks through fertilisation, improved tillage practices or grazing management strategies which aim to maintain high levels of plant cover on the soil. Alternatively, roadside sites may have been degraded due to grazing or other management pressures. It is well known that not all the roadside reserves are in good condition (Nowland 1997), and there was ample evidence during field surveys that some reserves were highly degraded. This historical overgrazing could conceivably have resulted in declines in organic carbon to levels equivalent to the paddock soils.

In the overstorey vegetation, additional carbon in the roadside reserves undoubtedly resulted from the larger number of trees and our estimates for carbon stored in these systems was within, but at the lower limit of, the estimated 5.5 to 55 t C ha$^{-1}$ predicted for woodland trees in Snowdon *et al*. (2000). Where the vegetation was healthier and structurally more diverse, however, soil carbon content was also larger. These results indicate that in the sheep–wheat belt of NSW, differences in the storage of carbon in the landscapes studied were attributable chiefly to differences in vegetation cover. From the perspective of the Kyoto Protocol and the development of methods to retain carbon storage in the landscape, it is therefore likely that changes in the vegetation cover will have the most significant effect while changes in soil carbon content will play a more minor role.

Land managers have a limited suite of practices available by which to increase the carbon store, and discussion of carbon storage in farmed landscapes has tended to focus on soil carbon. Techniques such as conservation tillage have been proposed in relation to maximising carbon storage in agricultural soils (under Article 3.4 of the Kyoto Protocol), but the magnitude of changes in carbon stored as a result of these is typically relatively low (Lal 1997; Wilson 2002). In grazing systems, enhancement of soil carbon is an especially complex process, and is typically difficult to achieve. Best practice strategies such as low-risk (conservative) stocking and the judicious use of fire (Ludwig *et al.* 1997) might increase the soil carbon store but will probably have little impact on the total quantity of carbon at a site.

Notwithstanding the above, retaining existing vegetation in these environments, particularly communities containing structurally diverse understorey and overstorey species, would seem to offer an effective strategy for retaining carbon in the landscape which would otherwise be lost through clearing. Retaining carbon in this way would therefore contribute to a reduction in the losses derived from clearing and is therefore accountable under Article 3.7 of the Kyoto Protocol. Management of vegetation is a simpler and less demanding alternative than managing soil carbon, and retaining vegetation, especially those communities with a more complex mixture of native shrubs and grasses, would provide substantial carbon benefits.

## Conclusions

The results indicate that differences in total carbon storage between roadside reserves and adjacent paddocks in the box woodlands of NSW are due principally to differences in carbon storage in vegetation rather than in soil. Whilst we acknowledge that strategies are available for enhancing soil carbon under cropping and grazing enterprises, retention and management of existing vegetation, and increases in vegetation cover, are likely to be more effective strategies for retaining carbon in the landscape and potentially increasing carbon sequestration. Increasing both the cover and condition of vegetation is an important objective for managing roadside reserves. This is likely to maximise the storage of carbon and the value of the landscape for other ecosystem goods and services.

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