The Contribution of "Vegetation Thickening" to Australia's Greenhouse Gas Inventory

A Report prepared by
Professor Ian Noble
of the
Australian National University
for the

Department of the Environment, Sport & Territories

Printed
28 May, 1997

[Note: See Postscript to this digitised copy of Prof Noble's Report on p.24]

Executive Summary

In many parts of Australia trees and woody shrubs are increasing in density in areas that were - previously open woodlands or grasslands. This process is called "vegetation thickening" in this report but is also known as "woody weed increase" and "woody regrowth". The phenomenon is not confined to Australia but also affects large areas of North and South America and southern Africa. A workshop in October 1996 brought together experts in relevant science and policy fields from throughout Australia and overseas to discuss the causes of "vegetation thickening", its extent within Australia, and its potential contribution to national greenhouse gas inventories.

Vegetation thickening typically results from changes in management practices that accompany the introduction of domesticated stock. There is usually an increase in grazing intensity and constancy, which leads, along with other management actions, to a decrease in grass cover and a decrease in the frequency and intensity of fires. These changes provide the opportunity for many tree and shrub species (both native and exotic) to establish and grow to dominate the site. The workshop regarded alternative explanations of the phenomenon - such as the effects of increased CO, concentration in the atmosphere or changes in weather patterns - as secondary or insignificant compared with the deliberate changes in land management practices.
It is estimated that over 60 million hectares of Australia are affected by vegetation thickening. Most of the areas identified are in Queensland but there are significant areas affected in the northern parts of the Northern Territory and Western Australia. Significant sections of more arid regions are also affected but they probably contribute little to greenhouse gas budgets.

In sites affected by "vegetation thickening" the biomass of woody plants increases and additional carbon is stored (sequestered) in these plants and in the soil. It is estimated that about 2 tonnes of CO_2 is sequestered per year by each hectare of land affected by vegetation thickening. This means that over 100 million tonnes of CO_2 are being stored per year in Australian landscapes affected by this phenomenon. This carbon sink is currently not included in the National Greenhouse Gas Inventory. A significant portion (25 Mt CO_2 /yr.) of the CO_2 emissions from land resources reported in the National Greenhouse Gas Inventory is a result of clearing carried out by graziers to combat the loss of stocking capacity caused by vegetation thickening.

It was concluded that there is a strong case to include the sequestration of CO_2 resulting from the management actions leading to "vegetation thickening" in the National Greenhouse Gas Inventory. The net effect, after allowing for the CO, losses through clearing affected areas (about 300,000 hectares per year), is an additional sink of over 100 million tonnes of CO_2. This would almost balance the emissions from other activities relating to land-use change and forestry practices and is roughly a fifth of Australia's net greenhouse gas emission (576 million tonnes of CO_2 in 1994).

The report documents the many uncertainties that remain in more accurately quantifying the fluxes of CO_2 associated with vegetation thickening. It points to the need for a coordinated. long-term program to monitor changes in areas affected by vegetation thickening and in the carbon stored at these sites.

If this sink is included in the National Greenhouse Gas Inventory there may be a potential conflict between land management goals and greenhouse gas reduction goals. An effective campaign to change management practices to reduce the occurrence of vegetation thickening and the associated loss in stocking capacity would lead to the loss of a significant sink for greenhouse gases.

The Contribution of "Vegetation Thickening" to Australia's Greenhouse Gas Inventory

1. Background

As a signatory to the United Nations Framework Convention on Climate Change (UN FCCC), Australia is required to produce and regularly update National Greenhouse Gas Inventories. The default methodology for these inventories is specified in a series of Work-Books prepared by the Intergovernmental Panel on Climate Change (IPCC).

At a meeting convened by Professor Farquhar in May 1996 on the contribution of changes in land-use to CO, emissions, it became clear that there is still considerable uncertainty about the role of "vegetation thickening" in carbon budgets (the "woody weed increase" and "woody regrowth" phenomena are components of this). There was uncertainty about the nature of this phenomenon, its causes, its net contribution to the carbon budget, and its areal extent. The importance of the phenomenon also varies greatly from state to state.

A meeting was held on October 27'h - 28'h 1996 to help reduce these uncertainties. This meeting brought together a wide range of people from across Australia with experience in issues relevant to "vegetation thickening". The workshop was also attended by Professor Steve Archer from the USA and Dr Robert Scholes from South Africa. Their participation contributed to a wider view of "vegetation thickening".

The work of Dr Bill Burrows was central to the workshop. He was instrumental in raising "vegetation thickening" as an issue in the National Greenhouse Gas Inventories. Dr Burrows made a presentation of his recent work at the outset of the workshop.

A full workshop timetable, outlines of the material presented by Professor Archer and Drs Burrows and Scholes and a summary of the discussions during the workshop are attached as appendices.

1.1 Objectives

Three objectives were identified:

- To establish what is meant by "vegetation thickening". What are its biological / ecological causes?
- To assess its extent in Australia and the extent to which thickened areas have been cleared . How much carbon is sequestered per unit area and what area is affected?
- To discuss whether the phenomenon meets the criteria to be called "anthropogenic" under the definition of the FCCC/IPCC.

1.2 What is meant by "vegetation thickening"?

The most common explanation for the phenomenon of "vegetation thickening" in Australia is that before the arrival of European settlers much of what is now the pastoral zone was a relatively open woodland or savanna maintained by relatively light grazing pressure from native herbivores and the fire regimes that prevailed under aboriginal land use.

With the arrival of pastoralism based on domestic stock, two processes changed.

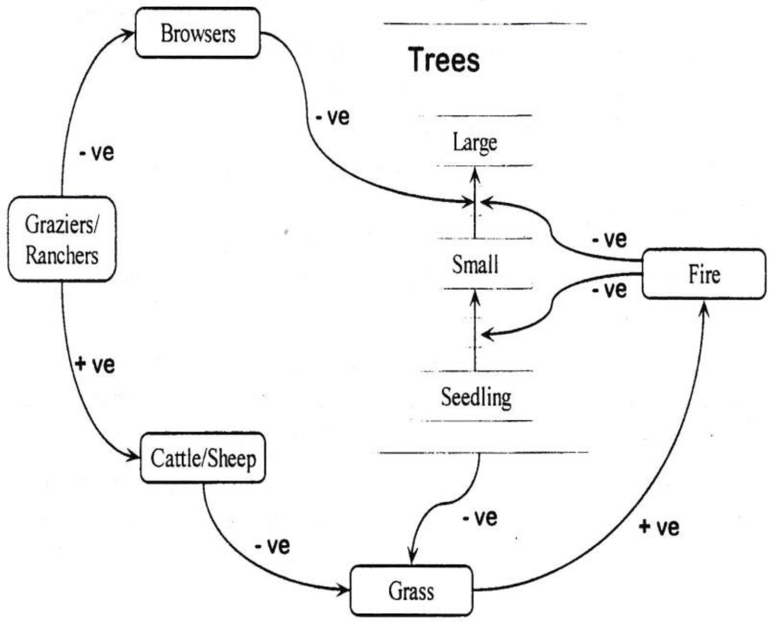
= Additional grazing led to the opening of the grassy understorey so providing more opportunities for successful establishment of seedlings of unpalatable trees and shrubs.

= Suppression of fires through the actions of graziers and via the reduction in grassy fuel loads allowed many of these seedlings to develop through to maturity leading to a thickening (an increase in density and biomass) of the woody component of the vegetation.

There are variants to this process in parts of Australia and locally the overall process is more complex due to small scale heterogeneities. There is also a feedback from the more dense woody growth leading to the further suppression of the grasses.

Material presented at the meeting and a literature review carried out by Professor Noble confirmed that the above description was consistent with phenomena observed elsewhere in the world.

The process can be summarised as follows:



From Bob Scholes. The +ve and -ve symbols show the direction of the influence.}

The meeting agreed on the following concise scientific definition of vegetation thickening"

> Changes in carbon per unit area arising from human induced changes in grazing or fire regimes.

And an expanded definition:

> The process of "vegetation thickening" usually involves an increase in the biomass of woody plants, (measured as an increase in basal area and height) and often a simultaneous increase in soil carbon and dead plant material. It typically results from an increase in grazing intensity and constancy, which lead, along with other management actions, to a decrease in the frequency and intensity of fires. The species of woody plants involved may be native or exotic.
>
> The reduction of browsers and the effects of elevated carbon dioxide may be contributory factors.

1.2.1 Supporting evidence

The supporting evidence may be summarised under the three headings below. Dr Bill Burrows provided such evidence to support his conclusion that "vegetation thickening" is occurring over large areas of woodland throughout Queensland.

1.2.1.1 Photographic and anecdotal information

Photographs and written records made during the nineteenth or early twentieth century provide many examples of increases in the woodiness of particular areas. There will always be a degree of uncertainty about data from these sources as it will be difficult to quantify and causation can be inferred only indirectly.

There is always the problem of controls. For example, it is possible that comparable sites did not undergo thickening and were never photographed or recorded. Nevertheless, there is a considerable body of such evidence from many widely dispersed regions and follow-up studies (eg $\delta^{13}C$) often provide confirmatory information.

1.2.1.2 Permanent Plot data

Records from permanent plots do have the advantage of showing directly whether there has been an increase in the density and biomass of woody species. Long term plot data are relatively rare but there are a number of studies that show such an increase.

Nevertheless, there remain other issues to be considered in relation to permanent plot data. First, is whether there are suitable controls. For example, if it is believed that "vegetation thickening" does result from the processes described above then control plots should be set up at sites that are not affected by domestic herbivores and deliberate fire suppression (eg national parks). If these plots were to also show thickening then the assumed causation would be challenged. However, even plots that apparently meet the criteria to be controls may, in fact, not do.so. For example' grazing by native herbivores may increase on sites free of competition from domestic herbivores, and fire suppression activities by graziers may reduce fire frequency and intensity throughout the region. It is a widely held view that fire regimes have been changed over the past century or so throughout most of Australia even in the least direct management intervention.

1.2.1.3 $\delta^{13}C$ signatures in the soil

Soil $\delta^{13}C$ signatures are a method that reflect the longer term history of a site and can indicate whether the site was dominated by C4 (mainly grassy) and C3 (mainly woody) vegetation in the recent past (see Box 1 in Appendix l). A number of studies throughout the world have supported anecdotal or permanent plot evidence for "vegetation thickening".

1.2.2 Counter evidence

The workshop sought out information that would provide counter-evidence of the suggested causation of "vegetation thickening". If such evidence was found it would call into doubt the arguments that "vegetation thickening" is predominantly anthropogenic in origin.

1.2.2.1 "Vegetation thickening" in little disturbed systems

The workshop could not identify any example in Australia where "vegetation thickening" was occurring in areas little affected by human activity. Examples were found where a decline in native herbivores is implicated in the increase of woody species. However, this observation does not challenge the suggested causation of "vegetation thickening" presented above. It simply suggests that not all cases of increased woody plant density should be interpreted as arising from "vegetation thickening" without additional support.

1.2.2.2 CO, fertilisation effect
The workshop supported the arguments made by Archer et al. in 1995.

In summary, Idso (1995) and others have suggested that "vegetation thickening" is driven by the processes often called CO_2 fertilisation (ie enhanced growth resulting from increased photosynthesis and water use efficiency in an atmosphere with higher CO_2 concentration). This should give a relative advantage to plants with the C3 pathway (most trees) over those with the C4 pathway (many grasses). However, in water-limited conditions we would expect C3 and C4 species to be equally responsive (Gifford et al 1992). Quantitative estimates of the CO_2 fertilisation effect show it to be much smaller than those changes associated with alteration of fire and grazing regimes.

The main evidence against the hypothesis (Archer et al 1995) is the large number of sites where one area has experienced "vegetation thickening" while nearby areas with similar edaphic and climatic characteristics have not. These observations do not demonstrate that CO_2 fertilisation does not have any role in "vegetation thickening". Nevertheless they point to the role of human activity in relation to grazing and fire as being the prime stimuli for "vegetation thickening"'.

1.2.2.3 Other hypotheses
The workshop considered several other hypotheses about the factors leading to increases in woody species. An example is the hypothesis that the increase in woody species is simply a lagged recovery of these species after the spread of grasses during the colder conditions of the "little ice age". None were regarded as likely explanations.

2. What is the extent and magnitude of "vegetation thickening"?

The participants of the workshop provided and assessed information about the extent and magnitude of "vegetation thickening" throughout Australia. The conclusions are summarised below and more detailed descriptions of the assessments are given in the summary of the workshop presentations.

2.1 Area affected

Queensland is the most important region in terms of total area affected and in relation to carbon budgets. There were insufficient data to assess the true extent of thickening in the top end of the Northern Territory and in the northern region of the Kimberley (W.A.). Nevertheless there is photographic and quantitative evidence that the phenomenon is widespread in these areas and that the "drivers" of "vegetation thickening" are likely to be as active as in Queensland.

Although thickening is occurring in some arid and semi-arid shrublands it was concluded that the amounts of carbon involved are not significant to Australia's overall greenhouse gas budget.

The area of the regions affected by "vegetation thickening" in Queensland is at least 60 M ha and probably greater (maybe another 10 M ha). However even within an affected region some parts of the landscape will remain unaffected, either because of land-use, unsuitable edaphic conditions or similar factors. It is important to assess the proportion of the unaffected area. Based on calculations described below, for each 1% of unaffected area, the sink is reduced by the equivalent of about 1 Mt CO_2 /yr.

It is not possible to estimate the total area in Australia affected by "vegetation thickening". It is likely that the 60 M ha estimated by Dr Burrows does represent the majority of the total area and the most important carbon sink. It can be used as a conservative estimate of the total area within

Australia affected by the phenomenon. A more accurate estimate will also require a systematic estimate of the additional land affected in the northern regions of the Northern Territory and Western Australia.

2.2 Carbon pools and fluxes

The data collected from permanent plots in Queensland and provided by Dr Burrows[1] was scrutinised by participants in the workshop.

The measurements were done during the 1980s and 1990s over a period when rainfall was lower than average. As discussed in Appendix 1, there are some concerns about demonstrating the true representativeness of the plots even within that region*. [See footnote below]

The TRAPS data set is based on 38 sites currently analysed. They range in initial basal area (at 30 cm above ground) from 0 to 19.9 m^2 /ha. When remeasured after intervals of 1.8 to 12.8 years the average increment was 0.24 m^2/ha/yr (range 0.0 to 1.16). These data were extended by using data from "undisturbed" permanent plots collected by the Queensland Forest Service. The initial basal area ranged from 0.10 to 7l .6 m^2/ha and they were remeasured over intervals ranging from 5.9 to 4l .4 years. They showed an average basal area increment of 0. l2 m^2 /ha/yr (range 0.09 to 0.55).

Dr Scholes stated that estimates for the Miombo savanna were similar with basal areas of about l2 m^2/ha and annual increments of about 3%/yr (ie 0.3 to 0.4 m^2 /ha/yr).

Dr Burrows also described other work in which he had estimated conversion factors from basal area (BA) to dry matter (DM) biomass. He concluded that a conversion of 4.7 t DM/m^2 of BA. including root dry matter to 1 m depth in the soil, was the best estimate for these woodlands, although there was no data for ironbarks, an important eucalypt group, incorporated in the conversion estimate. The ratio of carbon to dry matter was estimated to be 0.46 (Farquhar, pers. comm.) and that of CO_2 to carbon is that of the atomic weights (ie 44/12).

Most of the permanent plots are within the Fitzroy Basin and should be regarded as potentially representing only that region of about 30 M ha. A major item of discussion was whether these data could be taken to be representative even of that region - ie whether they are an unbiased sample of the region affected. There was no firm conclusion about this* [See footnote below].

2.3 Net effect on the greenhouse gas inventory

The calculations (described in detail (in Appendix 1) show that in Australia (and in Queensland in particular) "vegetation thickening" is a significant sink.

The best estimate of the net sequestration of CO, related to "vegetation thickening" is over 114 Mt CO_2/yr for Queensland alone (assuming 60 M ha are affected and the average rate of sequestration is just under 2 t CO2/ha/yr). This estimate probably accounts for the bulk of the effect in Australia but a continental wide estimate may be over 150 Mt CO_2/yr. Taking uncertainties about conversion factors and soil carbon estimates into account the true figure may range between 100 to 200 Mt CO_2/yr.

This sequestration is partly countered by the release of CO, in clearing largely as a response to the thickening process. The upper limit of releases due to clearing is probably c. 50 Mt CO_2/yr

[1] Burrows W.H. (October 1996) *Queensland's grazed woodlands - an enormous anthropogenic carbon sink demanding recognition.* [*See: Burrows *et al.* (2002) *Global Change Biology* **8:** 769-784 for a subsequent analysis of the question of sampling representativeness – NB This last reference link has only been added to the document by WHB - after the Noble Report was submitted to DEST. Link for the GCB paper: https://www.keepandshare.com/doc22/111983/burrows-etal-2002-gcb-paper-pdf-598k?da=y].

and the best current estimate is about half of this (ie c. 25 Mt CO_2). This release of CO_2 is already incorporated into the Inventory.

The rate of sequestration will gradually decline as more and more areas of woodland approach the maximum biomass the site can support and eventually an equilibrium will be reached. The potential net sequestration at equilibrium was estimated to be at least 150 t CO_2 / ha which means that at least 9 Gt CO_2 could be sequestered in the Queensland woodlands alone. Based on current growth rates (and allowing for clearing rates) it will take 100 years or more to approach equilibrium.

In summary, using conservative estimates of the area affected by "vegetation thickening", taking the data presented by Dr Burrows as the best available estimate of the carbon flows and assuming that clearing rates remain at about the current rate of 0.3 Mha/yr then the net effect of "vegetation thickening" Australia wide is about 125 Mt CO_2 /yr (range 50 to 150 Mt CO_2 /yr)[2]. This sequestration could continue at approximately this rate for most of the next century.

This is a significant proportion of the estimated net emission from Land Use Change in the current inventory (about 120 Mt CO, equivalent) and is larger than the emissions from other sectors such as industry and transport. Although there may be substantial revision in the data, it remains likely that "vegetation thickening" is a significant sink for CO_2 in Australia.

3. Is "vegetation thickening" of anthropogenic origin?

The explanation of anthropogenic origin is given in the IPCC guidelines as follows.

> "The IPCC Guidelines are designed to estimate and report on national inventories of anthropogenic greenhouse gas emissions and removals. In general term "anthropogenic" refers to greenhouse gas emissions and removals that are the direct result of human activities or are the result of natural processes that have been affected by human activities. Users may include any human-induced emissions and removals in their inventory as long as they can be clearly documented and quantified."

There was considerable discussion of these issues and there was strong agreement that "vegetation thickening" does meet the definition of anthropogenic. It was agreed that the vast weight of evidence indicated that "vegetation thickening" arose from management actions relating to domestic herbivores and fire. Alternative causes (eg CO_2 fertilisation) were seen as most unlikely or secondary to the main causes. No clear counter examples (such as thickening in areas little affected by humans) were identified.

The precise wording of the definition of "anthropogenic" was discussed in detail. It was noted that the definition includes the term "the direct result of human activities". It was suggested that some might argue that fire is an indirect action. This was rejected. Introducing domestic herbivores and suppressing fires are direct actions by the land managers; just as direct as many other actions that lead to CO_2 emissions in industrial processes or forestry operations.

Another point that was debated was whether the contribution "can be clearly documented and quantified". It was agreed that documentation and quantification would be difficult. but that these could be achieved within a few years. This workshop is a first step. Dr Burrows was encouraged to complete the analysis of his data and to submit his conclusion for publication in peer reviewed scientific literature of international standing. If problems remained in establishing

[2] Made up of sequestration in thickening vegetation of I00 to 200 (best estimate 150) Mt CO2/yr less the releases due to clearing of thickened vegetation of 50 (upper) to 25 (best estimate) Mt CO_2 /yr. This estimate is described as "over 100 Mt CO_2 /yr" in some sections of the report.

the areal extent of "vegetation thickening" and/or the representativeness of the data sets, then publications based on a smaller, but significant region, such as the Fitzroy Basin would still serve the purpose of demonstrating the potential importance of "vegetation thickening" in greenhouse gas budgets.

4. Further work

4.1 Ten year time frame

SCARM has responsibility to develop a National Rangelands Monitoring program. It is necessary to ensure that within this program sufficient tree density and biomass data are collected to provide improved estimates of the extent and rate of "vegetation thickening". This will probably require state government support. It is important that physical and organisational infrastructure is maintained to ensure that long-term and consistent measurements are obtained.

4.2 Three year time frame

Dr Michele Barson's project to estimate land clearing based on satellite data will be completed. This will provide additional evidence of clearing and possibly some indications of sites where there has been significant woody increase and regrowth. Unfortunately there is currently no way of estimating biomass or standing dead wood from satellite data.

Dr John Carter has suggested that it may be possible to enhance the utility of satellite data by seeking relationships between foliage projected cover (FPC) and basal area. He had evidence that good relationships exist in some regions and since there is often a good relationship between NDVI (Normalised Differential Vegetation Index) and FPC this may provide an opportunity to estimate biomass from satellite data. There appears to be a good case for a project to field check these relationships at the most important sites.

It is important that methods allow for the need for estimates of the change in baseline measurements (area cleared, biomass etc). Sequential baseline studies using different technologies and estimation techniques will not necessarily provide estimates of change.

4.3 One year time frame

Dr Burrows should be supported in his goal to have his data and views about "vegetation thickening" published in the international literature. This will probably need a detailed description of the site selection and data analysis. It would be useful to include a literature review of other sites with biomass data.

It was agreed that it would be most useful to demonstrate beyond reasonable doubt that "vegetation thickening" is occurring in Queensland independently of what is happening in the rest of the top end. It would be useful to apply best available modelling techniques to assess the fluxes and pool sizes within the area represented by the available measurement sites. The rnodelling could also supply an assessment of the dynamics of the system and indicate whether other areas will begin or continue to show thickening.

4.4 lmmediate time frame

Participants at the meeting agreed that it is essential that we develop some clear conclusions about the role of land use and land cover change in the NGGI. If not there is a risk that its critical role in determining the net carbon budget and the opportunities it provides for managing Australia's mitigation responses may not be given the consideration warranted. There was strong agreement that Australia should seek to prepare a scientifically accurate carbon budget that fairly represents the contributions of all sectors.

"Vegetation thickening" leads to a loss of stocking capacity and many graziers and governments will seek to reduce the amount of thickening that occurs. If "vegetation thickening" were to be included in the NGGI and a successful campaign to reduce thickening were introduced, might this lead to problems in compliance with international goals?

It is essential that the economic costs of manipulating carbon sequestration via "vegetation thickening" be assessed and compared with alternative land use options and with alternative ways of sequestering carbon.

Dr Burrows raised the possibility that during clearing of areas affected by "vegetation thickening" strips of trees could be retained. He estimated that in some landscapes up to 50% of the trees could be retained in strips and still produce as much pasture as if l0% of the trees were left scattered across the area. This raises a number of options for "offset" agreements.

5. References

Archer S., Schimel D.S. & Holland E.A 1995 Mechanisms of shrubland expansion: Land use, climate or CO_2? **Climate Change** 29. I l -99.

Archer S. 1995 Tree-grass dynamics in a *Prosopis*-thornscrub savanna parkland: Reconstructing the past and predicting the future. **Ecoscience** 2, 83-99.

Burrows W.H. 1995 Greenhouse revisited - land-use change from a Queensland perspective. **Climate Change Newsletter** 7, 6-7.

Brown J.R. & Archer S. 1989 Woody plant invasions of grasslands: establishment of honey mesquite (*Prosopis glandulosa* var. *glandulosa*) on sites differing in herbaceous biomass and grazing history. **Oecologia (Berl.)** 80, 19-26.

Fisher M.J.. Rao I.M., Ayarza M.A., Lascano C.8., Sanz J.1., Thomas R.J. & Vera R.R. 1994 Carbon storage by introduced deep-rooted grasses in the South American savannas. **Nature** 371,236-238.

Gifford R.M., Cheney N.P., Noble J.C., Russell J.S., Wellington A.B. & Zammit C. 1992 Australian land use, primary production of vegetation and carbon pools in relation to atmospheric carbon dioxide concentration. **Bureau Rural Resources Proceedings** (14) 15l-I87.

Idso S.B.l995 CO_2 and the biosphere: The incredible legacy of the industrial Revolution. Special Publication, Dept Soil, Water and Climate, Univ. Minnesota.

Manday M.H. & West N.E. 1983 Livestock grazing - fire regime interactions within montane forests of Zion National Park, Utah. **Ecology** 64, 661-667.

Neilson R.P. 1986 High resolution climatic analysis and southwest biogeography. **Science** 232, 27-34.

Parton W.J. , Stewart J.W.B. & Cole C.V. 1988 Dynamics of C. N, P and S in grassland soils: A model. **Biogeochem.** 5, 109- l31.

Scanlan J.C. & Archer S. 199 I Simulated dynamics of succession in North American sublropical Prosopis savanna. **J. Veg. Sci.** 2, 625-634.

Scholes R.J. & van der Merwe M.R. 1996 Sequestration of carbon in savannas and woodlands. **The Environmental Professional** I 8, 95-103.

Smeins F.E. & Menill L.B. 1988 Long-term change in semi-arid grassland. In Amos B.B. & Gehlbach F.R. (eds) *Edwards Plateau Vegetation,* pp 101-114. Baylor Univ Press, Waco Texas.

Tieszen L.L. & Archer S. 1990 Isotopic assessments of vegetation changes in grassland and woodland systems. In Osmond C.B. Pitelka L.F. & Hidy G.M. (eds) *Plant Biology of the Basin and Range,* pp 293-322. Springer-Verlag, New York.

Appendix 1 - Summary of the Main Presentations

Prepared by Professor Ian Noble

Professor Steve Archer

Professor Steve Archer summarised work he has published in several places[1]. He concentrated on the information available about the extent of shrub and tree invasion of previously grassy areas in parts of the USA and in Texas in particular. He divided the scientific evidence relevant to the "vegetation thickening" phenomenon into the following categories.

Anecdotal

A number of written accounts, photographs and anecdotal sources show that areas that were extensive grassy plains with scattered woody areas in the 1860s showed a rapid increase in woodiness. The increases appear to occur as a relatively rapid process over 30 to 40 years.

The best known area where "vegetation thickening" is believed to have occurred is southern Texas but it has also been described in widely different ecosystems such as coastal prairies & marshes.

Recent work using $\delta^{13}C$ (see Box) also supports the conclusion that there has been a shift in dominance with deep profile soils showing evidence of past dominance by C4 plants (eg tropical grasses) while shallow soils show more dominance by C3 species (eg shrubs and trees).

BOX 1 - The basic chemical characteristics of the photosynthetic pathways of grasses and woody plants often differ. Most trees and shrubs have the C3 photosynthetic pathway whereas many grasses have the C4 pathway.

The two pathways discriminate between the heavier and lighter isotopes of carbon (^{13}C and ^{12}C) differently. This means that the ratio of ^{13}C to ^{12}C (called $\delta^{13}C$) in tissues of plants with C3 and C4 pathways differ. The $\delta^{13}C$ for C3 plants ranges between -27 to -32 ^{o}/oo while that for C4 plants ranges between -13 to -17 ^{o}/oo [ppml].

Communities dominated by grasses or trees leave different signatures of $\delta^{13}C$ in the soil. This has been tested in communities known to have undergone changes in the dominance of C4 grasses and C3 shrubs and has been demonstrated to be a reliable technique.

See Tieszen & Archer (1990) for more details.

Climate change?

It has been argued (eg Neilsen 1986) that the grasslands developed during little ice age and that what we are observing is the lagged reinvasion of a more shrubby and woody ecosystem more in tune with the current environment. Grazing may have sped the process of reinvasion.

CO_2

Idso (1995) and others have suggested that woody encroachment is partly driven by plant responses to increasing atmospheric CO_2. Both the climate change and CO_2 fertilization hypotheses are discussed in Archer et al 1995. Professor Archer concluded that neither was likely to be the dominant cause.

Native herbivores

There are many example where native herbivores, especially browsers, appear to be implicated in maintaining the structure of ecosystems. For example, several African studies have shown that if browsers of small trees and shrubby plants are fenced out of previously relatively open areas massive shrub invasion occurs. Experimental studies have shown that prairie dogs are able to suppress mesquite establishment (*Prosopis glandulosa)*. In northern Texas prairie dogs were eradicated at about the time of the most rapid increase in mesquite density and thus may have been a factor.

[1] All references are in the main report.

Grazing pressure and invasions

Numerous studies have shown that seedling establishment is the critical period in shrub and tree establishment and that they usually need a disturbance of the grass layer to be released. Grazing by herbivores has been shown in many studies to provide this disturbance. For example, Madany & West (1983) showed that there was a massive increase in the establishment of ponderosa pine when grazing was introduced and a decline when it was removed. There were no similar changes in good control sites nearby.

Some species, like mesquite, do not need much of an opportunity to escape and a very short window of opportunity is sufficient. Once established they quickly establish a deep root system and grow faster on grazed sites even though there is more mortality. Grasses seem to be more competitive on ungrazed sites. Thus, it is difficult to control mesquite invasion via grazing. Mesquite needs 5 or more years to establishing a deep root system but during this period it is relatively small and often not seen as a problem by land managers. Once it starts to grow upwards it is very difficult to modify grazing to prevent further growth and establishment (Brown & Archer 1989).

This points to the critical importance of fire in many areas. Fires do not prevent shrubs from establishing but they keep the density down and stature small. Heavy grazing reduces grass fuels making fires less intense and less effective in suppressing shrub growth.

Cattle are also implicated in spreading mesquite seed as they graze the pods (especially during droughts) so scattering the seed widely. When the drought breaks mesquite has a great opportunity to establish among the heavily grazed grass sward.

Thresholds

Professor Archer suggests there is a very definite threshold in shrub invasion and once passed it requires major management intervention (herbicides etc) to reduce shrubs to previous densities. Changing grazing systems will be of little effect.

Smeins & Merrill (1988) showed that juniper increase and oak decline in their study area was not affected by grazing systems. But this appears to be a case where the threshold has been exceeded

Carbon budgets

Professor Archer summarised his work on shrub clusters (Scanlan & Archer 1991). These are patches of shrubs that originate from a bird dispersed founder and spread over periods of 50 years or more, waxing and waning with variations in rainfall.

Other greenhouse active gases

The release of NMHC (hydrocarbons) varies enormously between species. Some understorey species and mesquite are major terpene producers. Modelling work has shown that the amount released across the landscape has increased by or 1 or 2 orders of magnitude. However, it is likely that the effects in terms of greenhouse gas equivalents is very small although there may be larger ozone effects.

Discussion of Professor Archer's presentation

Some of the main points raised were:
Can the threshold conclusion be transferred across to different communities or continents? lt was concluded that this question could not be answered until a more systematic, cross-continental comparison had been done.

Nor could Professor Archer comment on the areal extent of the problem in the USA since most of the work had been carried out as a series of local studies.

It was agreed that soil type obviously affects the rate of thickening and the amount of carbon sequestered. Soil texture is a big factor especially the % clay. It was pointed out that many of the soil C estimates are based on the CENTURY model (Parton et al. 1988) and may be unduly sensitive to some parameters.

There was a discussion of the fire frequency necessary to suppress shrubs. The conclusion was that A 10 to 15 yr frequency was probably enough.

But the patchiness of fire is also important; for example, some north Australian fires burn only 50% of the area . Also fire intensity must be sufficient to kill shrub seedlings (about 3000 kj/m/s in South African studies).

The difficulties facing managers in using fire for shrub control were also discussed often spelling (ie resting) from stocking is required to build up grass fuels for an effective fire. But it is then possible that appropriate weather conditions for burning may not occur within a reasonable period.

Dr Bob Scholes

In tackling the issue of vegetation thickening and human activity, Dr Scholes asked whether causality of "vegetation thickening" can be demonstrated?

- Is "vegetation thickening" anthropogenic?
- Can it be quantified?
- Is it sufficient to matter?

He based much of his discussion on the Miombo - a 3M km^2 expanse of savanna and probably one of the largest relatively undisturbed ecosystems in the world (Scholes & van der Merwe 1996). It consists mostly of an acacia (fine leaf) savanna (*Brachystegia, Julbernardia, Combretum* spp) The Australian equivalent is the eucalypt woodland of the north – eg Kakadu.

Causes

Dr Scholes presented the summary diagram shown below.
ln summary, the introduction of domesticated grazing animals by graziers or ranchers leads to less grass and fewer fires. But fires are the limit on progression of small trees to becoming large trees. once large trees are present then fires have little effect.

Once high woody biomass has developed it suppresses the grass itself and thus the system is caught in a "fire trap". Also many graziers don't realise that they are losing grass production and do not reduce their stocking rate, thus reducing grass even further.

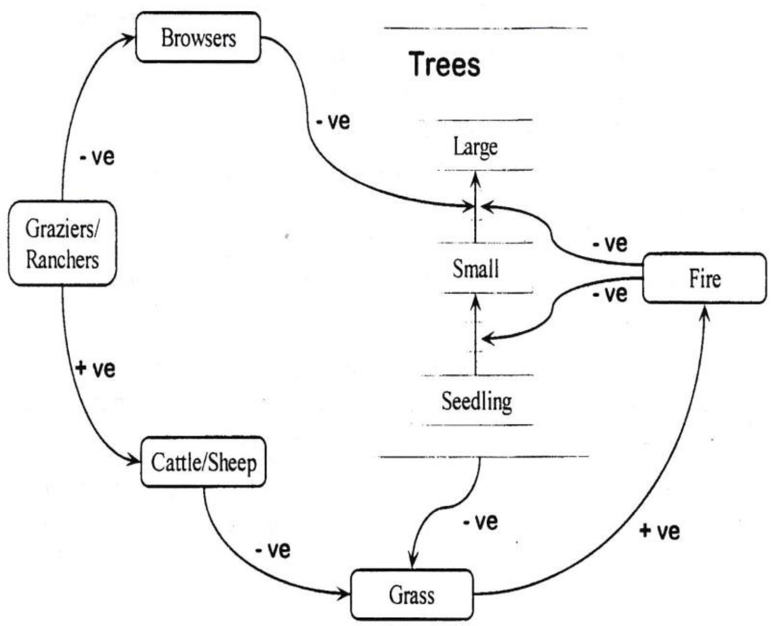


Fig. 1

Large trees eventually die but this can be accelerated by several factors. In some areas elephants are a major factor, but other animals are also very important. For example, porcupines during drought bite the bark near the base of trees and shrubs leading to an opportunity for a fire scar that eventually leads to the death of the individual in fire 30-40 years later (via asymmetrical growth, blowdown, hollowing of the trunk by termites).

Benefits of fire suppression to greenhouse gas budgets

- Woody biomass increases
- surface litter accumulates - re woody litter accumulates whereas grass litter decays rapidly
- soil C accumulates (often doubles in top 30 cm)
- Methane production from stock is reduced as stocking rates fall
- NOx production during fires is avoided (reducing 0_3 effects) (This shows up as a tropospheric 0_3 bubble over Africa during the fire season.)

Disadvantages of fire suppression for greenhouse gas budget

- Reduction of aerosols many of which arise from fires
- Reduction of elemental carbon sequestration as charcoal. Elemental C is one of the only ways to get C out of the cycle for a long period. Some soil scientists now suggest that much of the recalcitrant C in soils is probably of fire (pyrolitic) origin rather than from the humification . processes.

CO_2 fertilisation

A synthesis of the best available data shows perhaps a 30% increase in NPP in existing woody plants and 15% in grasses. The largest gains in water use efficiency are expected in savannas but there are few firm data to support this.

Where does the C pool increase?

- Wood
- Surface litter
- Soil (organic) C

Soil C levels are often twice as high under canopies than in surrounding grassland, but the overall level is low (2%) and is mostly in an unstable (particulate) form which decomposes relatively quickly especially if land management changes. Most savannas occur on warm soils and on clays that don't stabilise C very well.

Are the fluxes large enough to matter?

The estimated rates of carbon density increase arising from all factors in the Miombo are...
woody --- 0.3 t C/ha/yr for about 40-50 yr before an equilibrium is reached, and
soil --- 0.03 to 0.3 t C/ha/yr (depending on what happens to the surface litter).
This means that African savannas alone could account for 10% of anthropogenic CO_2 emissions if fire frequency was reduced to a lower level. That is, about 0.5 Gt of C could be sequestered per year for about 50 yr before it saturates. lf C sequestration was valued at about $5/t then it would make this more economically viable than most African agriculture. There may be other options in relation to bio-fuels.

Is there direct evidence of an increase in sequestration?

There are very few data available to confirm that the calculated levels of sequestration arising from elevated CO_2 and climate change are taking place. It is probably feasible to measure increases in tree biomass and surface litter over the next decade or so. It is less likely that soil C could be sampled and measured sufficiently to get a useful estimate of change. The measurements could be enhanced by modelling but the FCCC tends to be sceptical of modelling in these areas.

ls the phenomenon anthropogenic?

Similar response to commercial grazing are observed in Australia, S & E Africa and N America. ln Africa there are two different responses, one similar to those in Australia and America and another in tribal areas where trees are used as fuels and more goats are grazed and there tends to be less woody encroachment. This is consistent with the conclusion that the process of "vegetation thickening" is anthropogenic in the terms used by the IPCC.

Dr Scholes conclusion was that the contribution to carbon budgets from "vegetation thickening" must logically be included in national inventories and should have been so at the outset of the inventory process. The uncertainties in its estimation are no greater than in some other areas of the inventory.

He felt that its inclusion would probably be opposed for political reasons based on concerns about changes in methodology as the COP approaches agreements.

The whole question of burning, background levels of burning, and how much burning can be directly attributed to anthropogenic effects is likely to remain problematic.

Is "vegetation thickening" "additional" in terms of Joint Implementation?

lf a carbon sink is to be subject to negotiation under Joint Implementation clauses then it has to be an "additional" sink. lf the sink would have happened without additional effort then it does not count - ie it is not "additional". Thus, counting woody increase would be acceptable only if a specific program to encourage it was introduced. This arises not from the Convention but is enforced in funding arrangements of GEF etc.

Discussion of Dr Scholes' presentation

It was asked, 'lf a warmer and drier climate scenario arises will net sequestration be maintained?' It was concluded that it may not because savannas are very labile C stores. But it was also pointed out that fire-climate relationships in African savannas need to be considered. Savannas need wet periods to produce fuel to give more intense and frequent fires (which is opposite to boreal forests which need droughts). Thus, there would be several counter acting effects under any climate change scenario.

There was discussion about the design of long term experiments to test and monitor changes but it was concluded that it would be far more practical to reanalyse what has already been done,

There was discussion of deep translocation of carbon as described by Fisher et al (1994). There was considerable scepticism about the result and about its transferability to other areas. However, there is new evidence that many tropical trees have very deep roots (>20 m and even 45m) and this root material is decomposing. This can lead to significant amounts of carbon being moved to deep in soil profiles.

The net effect of 1% of biomass carbon being converted to charcoal in each fire was raised. The question was raised "why aren't we up to our eyeballs in charcoal?" It was suggested that fire-derived charcoal levels are probably higher than has often been assumed and that much of the charcoal was eventually blown and washed offshore.

Dr Bill Burrows

Dr Burrows spoke to the document that he had prepared for the workshop[2]. He summarised the anecdotal information about the timing, extent and cause of "vegetation thickening" in Australia (page 5 of his document) ; the Idso CO_2 hypothesis (page 11), and discussed some of the more recent studies (page 14) in an Australian context. He then went on to summarise new work on $\delta^{13}C$ (see Box) showing that in sites with known histories the $\delta^{13}C$ signature was consistent with expectations and that on many other sites the signature was consistent with "vegetation thickening".

[2] Burrows W.H. (October 1996) Queensland's grazed woodlands - an enormous anthropogenic carbon sink demanding recognition. Included as Appendix BB in this report.

He then moved on to discuss the data on biomass changes he had gathered for Queensland (page 16 – Appendix BB)

Transect data

Dr Burrows discussed the methodology used in obtaining his transect data.
The measurements were done during the 1980s and 1990s over a period when rainfall was lower than average.

The TRAPS data is based on 38 currently analysed sites ranging in initial basal area (at 30 cm above ground) from 0 to 19.9 m^2/ha when remeasured after intervals ranging from 1.8 to 12.8 years the average basal area (BA) increment was 0.24 m^2 /ha/yr (range 0.0 to 1.16). These data were extended by using data from "undisturbed" permanent plots collected by the Queensland Forest Service. Initial basal area ranged from 0.10 to 71 .6 m^2 /ha. They were remeasured over intervals ranging from 5.9 to 41. 4years and showed an average basal area increment of 0.12 m^2 /ha/yr (range 0.09 to 0.55).

Dr Scholes stated that estimates for the Miombo savanna were very similar with basal areas of about 12 m^2 /ha and annual increments of about 3%/yr (ie 0.3 to 0.4 m^2 /ha/yr).

Dr Burrows also described other work in which he had estimated conversion factors from basal area to dry matter (DM) biomass. He concluded that a conversion of 4.7 t DM/m^2 of BA, including root dry matter to 1 m depth in the soil, was the best estimate for these woodlands, although there was no data for ironbarks, an important eucalypt group, incorporated in the conversion estimate.

Dr Burrows noted that on clearing areas affected by "vegetation thickening", many managers leave scattered trees. This is usually done for appearance and conservation purposes tut it was agreed that this practice encourages regrowth and that it would be better to leave trees in block or strips. It is possible that by leaving strips graziers can achieve the same improvement in pasture growth with higher sequestered C.

Conclusions

Dr Burrows concluded by saying that if it was concluded that if any part of the methodology recommended by IPCC is wrong or inappropriate to Australia, we should defend the better methodology and not sell out the science.

Dr Scholes commented that he could see no reason why properly documented growth in carbon storage in grazed woodlands could not be included in inventory calculations under the current IPCC methodology.

Discussion of Dr Burrows' presentation and document

The discussion of issues relating to the transects, biomass estimations and extent of the "vegetation thickening" phenomenon continued throughout the second day of the meeting and are not summarised in detail here. Most of the discussion is incorporated in the sections of the main report.

Mr Ian Carruthers

Mr Ian Carruthers made some comments on how to move Australia's efforts in greenhouse gas inventory forward on an international basis?
Australia has some characteristics that do not fit well with recipes designed for developed countries of the northern hemisphere. These affect industrial and trading activities and particularly greenhouse gas emissions from agricultural land and land use systems.

ln the 1994 Inventory, Australia was just about the only OECD country that gave any significant treatment to land use issues. The 1988 -1990 Inventory brought together the best available information, but since then many more issues have arisen. DEST see greenhouse gas emissions from agricultural and land use systems as a top priority in the NGGI because of size-of emissions and methodological challenges. The next update of the Inventory was due in the first quarter of 1997 and he felt that there must be some revision to the land uses change and forestry sections.

Mr Carruthers said that DEST wants a valid and complete inventory. There should be no embarrassment in changing the estimates in the land use sections if they could be justified. The Government wanted the best estimates possible. - since then 1988-1994 but no update of land use section.

Australia would not be confining these activities to the national scene but would be active in technological advisory areas. He felt it was particularly important to achieve more concerted international effort in this area. It appears to be an important issue for some other developed countries, such as the USA, and it would be helpful to have GEF support more work in developing countries. Many of these issues have already been raised in the Valdivia group (a group of cooperating southern hemisphere countries).

Summary of Discussions

A definition of "Vegetation Thickening"

The meeting agreed on the following concise scientific definition of "vegetation thickening":

> Changes in carbon per unit area arising from human induced changes in grazing or fire regimes.

And an expanded definition:

The process of "vegetation thickening" usually involves an increase in the biomass of woody plants, (measured as an increase in basal area and height) and often a simultaneous increase in soil (organic) carbon and dead plant material. It typically results from an increase in grazing intensity and constancy, which lead, along with other management actions, to a decrease in the frequency and intensity of fires. The species of woody plants involved may be native or exotic.
The reduction of browsers and the effects of elevated carbon dioxide may be contributory factors.

The extent of "vegetation thickening"

What to include

It was agreed that it would always be difficult to assess the precise area affected by "vegetation thickening". Even if reliable and comprehensive mapping systems were developed, there will always remain problems of identifying precisely which areas to count. There will also be variation in the degree to which areas are affected and its patchiness. Regrowth from clearing thickened areas is a related issue that has to be taken into account.

The meeting considered each of the areas across Australia that might be subject to anthropogenically induced "vegetation thickening" and tried to assess their extent and degree.

Queensland

Dr Burrows has presented arguments elsewhere (Burrows 1995) that at least 60 M ha of woodlands in Queensland are potentially affected by "vegetation thickening". Woodland was defined from satellite imagery with National Parks, reserves and any other sites that might reasonably be challenged as not being grazed-woodland were removed; ie it is a conservative estimate of the area that might be affected by "vegetation thickening".

This estimate excludes another 6 Mha of Mitchell grasslands invaded by *Acacia farnesiana, A. nilotica* and *Prosois* spp, and another 0.7 Mha densely affected by invasion by rubber vine (*Cryptostegla grandiflora*).

Dr John Carter, presented information on *Acacia nilotica* which appears to be increasing in some parts of Queensland. Some increase may be a rebound from decline during a drought. Estimates suggest that 6M ha may be subject to some degree of thickening of *A. nilotica* but the dense areas are relatively small and biomass involved is small (eg 15 t DM/ha and thus similar order to grass). He presented estimates that from 1976-86 annual increment over the affected area was 113.000 t DM/yr and this fell to 11, 500 t/yr from 1986-96. These are only small amounts and their impact is even less when the loss of grass biomass due to tree competition in thickened conditions is taken into account.

Dr Brown described additional work on *A. nilotica* in the Richmond Shire of north Queensland. He had no data on the extent but had developed some predictive models with Dr J. Scanlan cf. increases in tree density and tested these against satellite images. This work has been submitted for publication.

Dr Harrington, in a written submission, stated that there are areas where rainforest is invading sclerophyll forests, but the area affected is small (80,000 ha) and the net change in basal area small (c. 10 m2/ha).

New South Wales

Dr Ron Hacker concluded that "vegetation thickening" was definitely occurring in the Western Division of NSW (32.5M ha). However, the trends were not always towards increasing woodiness as in the Queensland data; some sites showed increases and some decreases. Most of western NSW has been mapped for cover change from satellite images but only for two dates; 1979-87 and 1991-95. Seasonal trends may be reflected in the data and it is not possible to convert the imagery into biomass data. The conclusion was that no clear trend was discernible and that this probably reflects different management practices and different points in a build up and breakdown cycle. It would be possible to do some calibration harvests to covert the cover imagery information to biomass if DEST wanted the data. But, there remain some doubts about how effective the cover estimate scheme is.

Dr Harrington, in a written submission, provided data on regrowth after ring-barking of woody savannas showing that in ungrazed sites annual above ground production was 1 .4 t/ha/yr while on grazed sites it was 0.4 t/ha/yr.

Western Australia

Dr Novelly discussed the limited data from the Kimberley. ln the western region about 300,000 ha (out of 10.4 M ha in that District) appears to be increasing but mainly in specific areas such as levy banks on particular soils. The estimate is based on a manager survey and only 16 replied. *Acacia farnesiana* was seen as the greatest problem but most would have assessed the problem via difficulties in access caused by dense growth and not in terms of fodder loss or dry matter stored. Also *A. farnesiana* is good stock feed and graziers are happy to tolerate a fair bit of it before describing it as a problem. This highlights some of the difficulties in using this form of assessment, There is little data from more northerly regions although there were some reports of patches of thickening.

There are now about 350 monitoring sites across the Kimberley but most have been in place over only the past 5 yr. They show that woody weed ingress is happening, in particular acacia, bauhinia rosewood, parkinsonia; but mainly in areas fenced from stock and where fire has been excluded. There are no sound estimates of the biomasses but they may be about 20-30 t DM /ha plus another 1 to 1.5 t DM/ha of herbaceous material.

Dr Novelly concluded that it is possible that there have been significant increases over the last few decades – all we know is that it is not perceived by managers as a problem

Dr Hacker added his experience of the Gascoyne region of WA. He concluded there is a woody weed problem and that non palatable shrubs are increasing in shrublands. But the biomass in these arid shrublands is very low and so there can probably be little effect on carbon budgets.

Northern Territory

There was little data on the extent of thickening in the Northern Territory. The evidence of increase in basal area and density of woody plants in the Mummalary trial (Kakadu N.P but until recently subjected to buffalo grazing) was discussed as a source of information as were some long term plots in the

Victoria River Downs area. It was agreed that although the invasion of *Mimosa pigra* was having significant local effects it was probably insignificant in carbon budgets. There was also some evidence of thickening of whitewood in the lower gulf area. In the more arid regions of the NT there was little evidence of "vegetation thickening" probably because fire is not being excluded.

Summary

Queensland is the most important region in relation to carbon budgets. However there was too little data to assess the true extent of thickening in the top end of the NT and in the northern region of the Kimberley.

There is probably potential for thickening to occur in many areas with changes in grazing and fire management; especially in the top end of NT and WA. Grazing can lead to reduced fire intensity which is the main trigger for thickening. However, the trigger can be things other than grazing - eg fire suppression, roads etc.

Although thickening may be occurring in the arid and semi-arid shrublands it was concluded that the amounts of carbon involved are not significant to Australia's overall greenhouse gas budget.

The area of regions affected by "vegetation thickening" in Queensland is at least 60 M ha and probably more (maybe another 10 M ha). However, even within an affected region some areas will remain unaffected, either because of land-use, unsuitable edaphic conditions or similar factors. It is important to assess the proportion of the unaffected area[3]. Another way of rephrasing this problem is to ask whether the sample sites presented in the next section are an unbiased representation of the region affected by "vegetation thickening" in Queensland.

It is not possible to estimate the total area in Australia affected by "vegetation thickening" However, it is likely that the 60 Mha described by Dr Burrows does capture the majority of the total area and the most important carbon sink.

The size of the carbon sink

Two general issues were raised. One was the necessity to take necromass (mass of dead material) into account. Dead trees often took decades to fall and decay and these should be carefully accounted for in any carbon budget. Necromass must also be considered in cases such as the invasion of existing vegetation by rubber vine (*Cryptostegia grandiflora*). Rubber vine invades and smothers existing vegetation, probably simply replacing live biomass of one species by that of another. However, much of the biomass of the previous vegetation remains as dead matter.
The other was the changes in soil carbon that occur under various grazing regimes. There was strong agreement that this is a poorly understood area and the amounts of carbon involved are very significant in calculating greenhouse gas budgets.

Sequestration through “vegetation thickening"

Dr Burrows presented an estimate of the size of the carbon sink arising from the thickening process. This estimate is:
Area affected * Average BA increment * Conversion BA to DM * Conversions DM to CO_2
60 M ha * 0.24 m^2/ha/yr * 4.7 t DM/m^2 * 0.46 * 44/12
= 114 Mt CO_2 /yr.
The uncertainties associated with the components of this equation were discussed in detail. The estimate of 60 M ha of affected land in Queensland is discussed above.
The conversion factors converting dry matter (DM) to CO_2 are not likely to have major errors. The 44/12 is a physical constant based on the atomic weights of the elements of CO_2 . The 0.46 conversion for DM to carbon does vary with species and community type (Farquhar pers. comm.). However, it is most unlikely that it is in error by more than ± 10%

[3] For each 1% of unaffected area, the estimate of the net sink due to "vegetation thickening" is reduced by the equivalent of about 1 Mt CO_2 /yr.

The conversion from BA to DM could lead to greater errors, although the data collected for a range of species at a range of sites was very consistent (4.7 ± 0.2 s.d. t/m^2). Estimates for other woodland communities range from 4.8 to 10.3 t/m^2 . Thus there is room for an error associated with this estimate but it is probably within ± 25%.

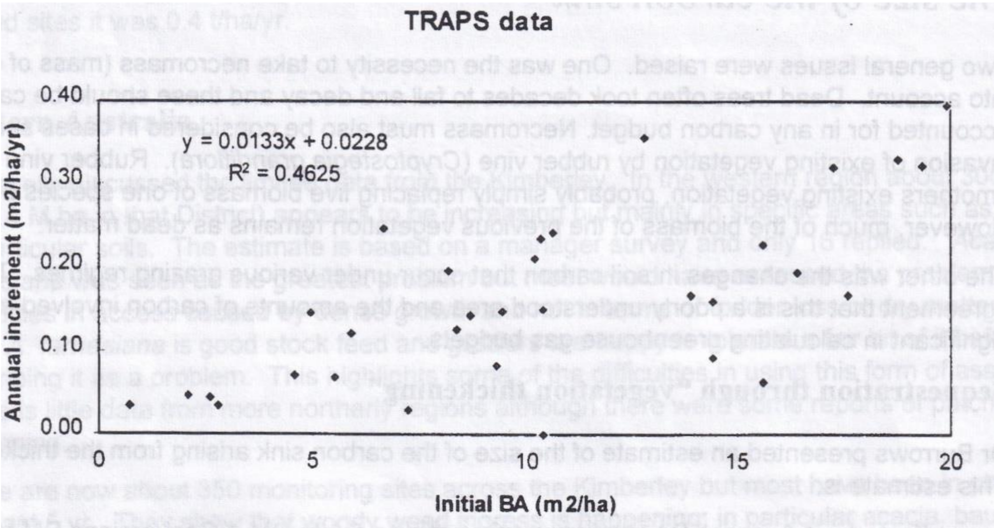
This leaves the estimate of the average annual basal area increment. Two issues were discussed in detail. Both relate to whether the data sets presented by Dr Burrows represent an unbiased estimate for the area affected by "vegetation thickening" in Queensland. If a sampling system could have been designed from the outset (obviously not possible in this case) then some form of randomised sampling system, probably with stratification by community type and time since disturbance, would have been set up. There is simply not enough information to assess whether the data set does show any bias but it must be noted that much of the data derives from the Fitzroy Basin.

lf it could be demonstrated that the annual increment was more or less similar regardless of community type and time since disturbance, then it is unlikely that any sampling bias would have a great effect on the estimated average increment. Initial BA reflects both age since disturbance and site quality. An analysis of Dr Burrows' data sets carried out after the workshop [by Professor Noble] shows that annual increment appears to be related to initial BA.

Figure 2 excludes five sites (Summerdell Pulled 1 & 2, Wigton Control Reps 1, 2 & 3) because they are obvious outliers. They have the lowest initial BA sites (0 to 3.1 m^2 /ha) and among the shortest measuring periods (2.2. to 4 years). The Wigton sites are also the only *Acacia* dominated sites. They had BA increments of 0.33 to 1.0 m^2/ha/yr. Dr Burrows suggested that a different (larger) estimate of BA increment should apply for the first decade after clearing.

The data show that annual increment is positively related to initial BA, implying that larger stands are growing faster in terms of absolute increment of basal area than smaller stands (except for the youngest stands which were excluded as described in the previous paragraph). This implies that good estimates of the current distribution of basal areas is important in calculating mean annual increment.

Figure 2



Sequestration at equilibrium

Another important parameter to estimate is the eventual equilibrium basal area of the woodlands. In most stands growth gradually slows and the stand reaches a steady state basal area and biomass. Dr Burrows estimated that this value for the stands he sampled is 20 to 23 m^2 /ha (BB page 16). Some of the Queensland Forest Service stands greatly exceed this value with maximum basal areas of almost 100 m2/ha but these represent forest communities on much wetter sites. Another estimate of the equilibrium basal area can be gained by assuming that growth follows a simple exponential growth equation...

$$BA_{t+1} = BA_t {}^{*} \exp(r*time)$$

The value of r, the exponential growth rate, can be estimated as

$$r = \ln (BA_{t+1}*/BA_t)/ \text{time}$$

Figure 3

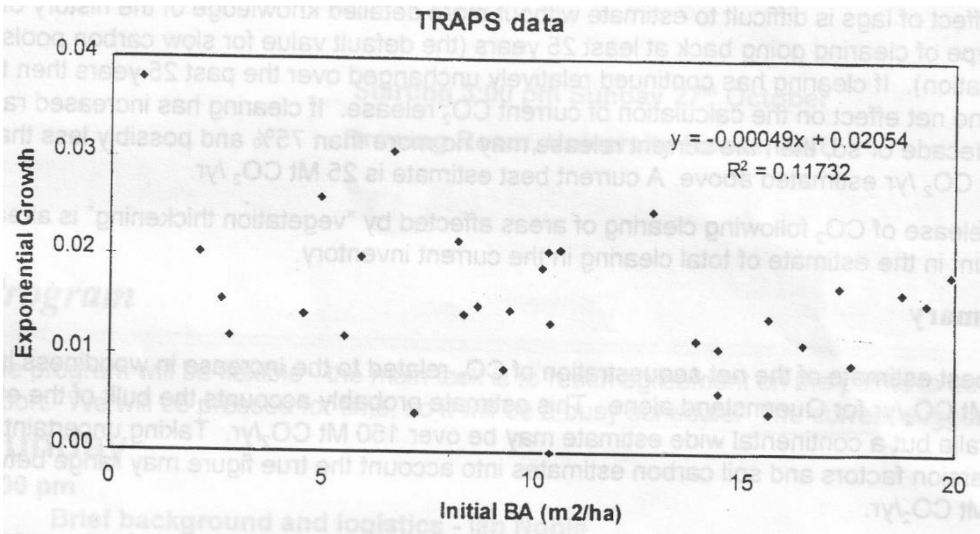


Figure 3 shows r plotted against Initial BA. Although the relationship is weak (Prob = 0.05) it suggests that growth rates fall as the woodland basal area increases and an extrapolation of the trend shown in Figure 3 predicts that the equilibrium basal area is 42 m^2 /ha.

Thus, there is a considerable degree of uncertainty about the equilibrium basal area and thus about the maximum amount of carbon that can be sequestered per unit area in these ecosystems. Estimates range from 20 to 100 m^2/ha of basal area or about 100 to 400 t DM/ha or 150 to 750 t CO, equivalent sequestered per ha at equilibrium. Dr Burrows (pers. Comm.) feels from his experience that the value is most likely to be near the lower end of this range. Irrespective of the model of growth used, it will take about 80 to 150 years for stands to reach even the lowest estimate of the steady state condition[4]. This implies that the sink could prove to be effective well beyond the end of the next century (ie 2100).

Impact of clearing

Much of the clearing observed to be occurring in Queensland is associated with clearing land affected by "vegetation thickening". Graziers clear affected lands to reduce the tree and shrub density and to improve grass production and hence stocking capacity.

Different clearing treatments are used. These include pulling (ie simply flattening the trees and shrubs and leaving them to decay); pulling and burning (ie burning to accelerate the loss of the woody material), and stem injection (ie poisoning the trees and larger shrubs but leaving them standing in the paddock). Each treatment releases different amounts of CO_2 to the atmosphere over different time courses.

The maximum release of CO, due to clearing can be estimated by assuming that the clearing process is completely effective and that all above ground carbon and that in roots to a depth of 1 m is released in the year of clearing lt is also assumed that sites with high basal areas are selected (here taken to be 24 m^2/ha). Current estimates suggest that about 0.3 M ha/yr of woodland is being cleared in Queensland. Thus, the amount released per year is

CO_2 equivalent (Mt/yr) Area (0.3 M ha/yr) * 24 (m^2/ha) * 4 7 (t DM/m^2) * (0.46 C *44/12)

= 57 Mt CO_2

[4] Equilibrium is reached most rapidly if basal area increment continues to increase at calculated average rate of 0.24 m^2/ha/yr up to an equilibrium of 20 m^2/ha. Growth, and sequestration would almost certainly slow as the equilibrium was approached.

It must be emphasised that this is a maximum estimate of emission of CO_2. Dr Burrows has estimated that up to 60% of the current clearing is of areas previously cleared and that the average basal area is likely to be less than 15 m^2 /ha. There will also be long lags in the release of CO_2 especially where standing dead timber is left on the site. Dr Burrows also argues that there is a period of rapid regrowth in the first decade following clearing (as supported by his data set) and this will compensate for some of the CO_2 emissions although the effect is small (c. 1 Mt CO_2 /yr).

The effect of lags is difficult to estimate without more detailed knowledge of the history of the extent and type of clearing going back at least 25 years (the default value for slow carbon pools in the IPCC calculation). lf clearing has continued relatively unchanged over the past 25 years then the lags will have no net effect on the calculation of current CO_2 release. lf clearing has increased rapidly over the past decade or so, then the current release may be no more than 75% and possibly less than 50% of the 57 Mt CO_2 /yr estimated above. A current best estimate is 25 Mt CO_2 /yr.

The release of CO_2 following clearing of areas affected by "vegetation thickening" is already taken into account in the estimate of total clearing in the current inventory

Summary

The best estimate of the net sequestration of CO_2 related to the increase in woodiness is over 114 Mt CO_2 /yr for Queensland alone. This estimate probably accounts the bulk of the effect in Australia but a continental wide estimate may be over 150 Mt CO_2 /yr. Taking uncertainties about conversion factors and soil carbon estimates into account the true figure may range between 100 to 200 Mt CO_2 /yr.

This sequestration is partly countered by the release of CO, in clearing largely as a response to the thickening process. The upper limit of this value is probably c. 50 Mt CO_2 /yr and the best estimate about 25 Mt CO_2 /yr. This release of CO_2 is already taken into account in the NGGI.

lf clearing rates remain at about 0.3 M ha/yr then best estimate of the net effect of "vegetation thickening" Australia wide is over 100 Mt CO_2 /yr (range 50 to 150 Mt CO_2 /yr) and that sequestering could continue at this rate for most of next century.

The potential net sequestration at equilibrium is at least 150 t CO_2 / ha which means that 9 Gt CO_2 could be sequestered in the main Queensland area alone.

Appendix 2 - Workshop agenda

Workshop on "Vegetation Thickening"

October 27th - 28th 1996

Starting 3:00 pm Sunday 27th October
Drawing Room, University House, ANU

Program

The program will be flexible - the main task is to reach agreement on the points to be made in the Report. We will be pressed for time so it will be a busy schedule. The current suggestion is

Sunday

3:00 pm
Brief background and logistics - Ian Noble
3:30 pm
Steve Archer - A global view
4:30 pm
Break
4:45 pm
Bob Scholes - A global view
5:45 pm
Discussion
6:30 pm
Dinner
7:30 pm onwards
Bill Burrows will present his recent work

Monday

9:00 am
Background from DEST (Ian Carruthers)
9:30 am to 12:00 noon
Opportunity for additional presentations of information etc (with coffee break etc)
12:00
Lunch
1:00
Discussion of the content of the report of the workshop. This session will be left flexible. This will run through to dinner - be it ear$ or late.

Invitees

- Dr Bob Scholes — South Africa
- Dr Steve Archer — USA
- Dr Graham Harrington — Atherton Qld (unable to attend - written contribution)
- Dr John Carter — Brisbane, Qld
- Dr Bill Burrows — Rockhampton Qld

- Dr Paul Novelly Kununara WA
- Dr Ron Hacker Dubbo NSW
- Mr Ian Carruthers Canberra
- Mr Peter Cheng Canberra
- Mr Sal Emmanuel Canberra
- Dr Tony Weir Canberra
- Dr Michele Barson Canberra
- Prof Graham Farquhar Canberra
- Dr Mike Roderick Canberra
- Prof lan Noble Canberra

[**Appendix BB** referred to in this Report – the compilation by Dr Bill Burrows outlining the evidence for thickening in Queensland woodlands - was a lengthy document combining fence-line contrast photos, data from permanent vegetation monitoring (TRAPS) sites, literature review etc. Hard copies were distributed to all attendees at the Workshop, but are not included here for logistical reasons. As Prof Noble refers to Appendix BB as part of his Report (page 5, or page 15 in this version - which does not restart new page numbering for the Appendices) it is assumed that this Appendix was included in the documentation provided to DEST – 28 May 1997].

POSTSCRIPT

[Please Note: This digital version of Prof Noble's Report was compiled from an OCR copy of the original 1997 typed paper version distributed to Workshop Attendees at that time. The opportunity to do this was taken given the on-going need for accurate and precise GHG Accounting in Australia, along with the rapidly developing worldwide political demand for nations to adopt "net zero (GHG) emissions by 2050". Further, our published knowledge base has increased substantially since 1996 and this suggests an urgent re-evaluation is necessary of what 'carbon sinks' may be included in Australia's NGGI today. In my view revisiting discussion of what inclusions and exclusions would form part of the developing LU, LUC&F component of Australia's NGGI in 1996 provides a good start and 'baseline'.

The production of this digitised copy of the 1997 Report provided a means to make a few minor text corrections to the initial manuscript. Other than that this version mirrors the original. However one highly relevant publication addressing field sampling "representativeness" in Queensland's TRAPS (vegetation transect recording network) - which was not available when Prof Noble's Report was compiled – has been cited in a footnote on p.7 because it addresses many questions raised of the Queensland studies by Workshop participants.

Bill Burrows – 10 April 2021]