Establishing a Consistent Time-series of Greenhouse Gas Emission Estimates from Savanna Burning in Australia

Prepared for

the Australian Greenhouse Office

by

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Summary

Savanna fires have been have been identified by IPCC key source analysis as a high ranking key source in Australia's National Greenhouse Gas Inventory. The reason for its prominence are the significant contribution to total national emissions, and more importantly, the very large increase in fire activity between 1990 and 2002. This review was commissioned to address this issue, specifically:
(1) to establish a consistent data series of savanna fire scar area from 1989 to 1992 to confirm the 1990 baseline; and
(2) to review:

- the practice of averaging areas burnt over a 10 year period;
- the question of anthropogenic and naturally occurring ignition;
- the treatment of fires on lands not primarily used for agricultural purposes; and
- existing literature on fuel loads and burning efficiencies.

In order to meet the timelines required of this review, analysis was confined to Western Australia and NT, which together account for 80% of savanna fire activity in Australia.

The annual areas of firescars in Northern Territory and Western Australia for 1989 to 1992 were measured from AVHRR satellite imagery and confirmed that 1989 -1992 were years of low activity. Total areas burned in the inventory years 1990 ,1991 and 1992 from this new firescar analysis are respectively 22.4 Mha, 13.9 Mha and 16.8 Mha. These are similar to the estimates areas previously used in the 2002 National Greenhouse Gas Inventory (NGGI), and confirm that the substantial increase in fire activity between 1990 and 2002 is real, and not an artefact of changed methodology as previously suspected.

The cause of the trend is an increase in annual rainfall in the preceding seasons which promote vegetation growth and fuel accumulation. A large proportion of the year-to year differences in fire area is explained by rainfall and the decadal trend in fire activity was most probably the result of natural variability within a long term climate cycle. It is recommended that the 10 year averaging interval currently used in the NGGI is retained to remove the short-term variability in fire activity from the trend analysis.

Savanna fires occur across all land tenure, land use and vegetation categories in the Northern Territory and Western Australia. The trend in fire areas between 1990 and 2000 was confined to grassland and woodland, and was not evident in the small areas of open and closed forest. Fire activity and decadal trends in rangelands were similar to those in natural areas, and similarly in the land tenure classification, trends and fire areas in freehold/leasehold lands were comparable to those in aboriginal lands and crown reserves. Clearly, there was no single land class that accounted for a majority of fires in any region in NT or WA. It was concluded that fires on private pastoral lands and on aboriginal lands both met the current IPCC definitions of savanna burning. Also, there was no reliable basis to classify fires as anthropogenic or natural by ignition source. Therefore, it is recommended that the current NGGI practice be continued in which all fires in the NT and Northern and Central WA are classified for inventory purposes as savanna fires.

There have been several recent studies that provide substantially more measured data for fuel loads, nitrogen to carbon ratios, and burning efficiency than was available at last NGGI review. Recently published measurements of N:C content of savanna fuels indicate that the N:C ratio should be reduced from the value of 0.02, which is currently used in the NGGI, to 0.011 for woodland and 0.012 for grassland. New measurements indicate that fuel loads are approximately 3 t ha^{-1} in grasslands. In woodlands fuel is comprised predominantly from tree leaf litter and coarse woody debris with an average fuel load of 12 t ha^{-1}. These compare with the current NGGI estimates of fuel loads for WA and NT of 7.7 and 5.8 t ha^{-1} respectively. Burning efficiencies also differ between woodland (0.39) and grassland (0.76), primarily due to incomplete combustion of coarse woody fuel. The value the currently used in the NGGI (0.72) derives principally from measurements from fine fuel combustion. These availability of these new data now justify stratifying savanna regions into two broad vegetation classes: woodlands comprising vegetation with projected foliage cover greater than 20% and grasslands. It is recommended that the current NGGI methodology be extended slightly, stratifying the NT and WA into woodland and grassland regions, and applying the fuel load, N:C ratio and burning efficiency appropriate for each region.

The impact of these revised data on estimates of non-CO_2 greenhouse gas emission from savanna fires in NT and WA was assessed. In the light of revised parameters it is probable that non-CO_2 greenhouse gas emissions annual emissions may be overestimated by the current NGGI methodology. The revised and more robust estimates of fire scar area, N:C ratio and fuel load and burning efficiency combined lead to reduced greenhouse gas emissions, compared to the current NGGI estimates, of 10%, 16% and 12% respectively. In combination these revisions indicate that the current NGGI methodology may be overestimating non-CO_2 greenhouse gas emissions by 38%.

Finally, both the current NGGI methodology and the proposed revised methodology were compared with independent international estimates of biomass burned in savanna fires. The early international estimates were substantially higher than the NGGI estimates, however more recent internal studies are similar to both the NGGI estimate and the newly revised estimate, certainly within the usual bounds of uncertainty. Therefore, the NGGI methodology appears to yield consistent and robust estimates of biomass consumed by savanna fires.

1 Introduction

The burning of savanna in Australia has been identified in recent years as a significant source of non-CO_2 greenhouse gas emissions and significant contributor to both trends in National emissions and uncertainty in National emissions. This is a significant issue, because these three characteristics classify the sub-sector as a key source, which under IPCC Good Practice, (IPCC, 2000. IPCC, 2003) requires the party to assess whether a higher tier methodology should be used to estimate the emissions. They also pose a major challenge for estimating projections of emissions for future years because the cause of the trend is currently undetermined and therefore the appropriate algorithm for estimating projections also cannot be determined.

Both the sector consultants and external bushfire experts consider the apparent trend in the time series to be problematic. This is because the timeseries of fire area presented in the inventory is actually the combination several time series. The current estimates are produced by analysis of satellite imagery, however estimates for the early part of the series were provided from a range of sources including remote sensing in limited regions and estimates from district fire authorities. The current estimates for the base line year are particularly uncertain.

In order to address these issues, the Australian Greenhouse Office (AGO) contracted CSIRO Atmospheric Research and the Satellite Remote Sensing Services Group of the Department of Land Information, WA Government (formerly known as DOLA) to provide robust estimates of the baseline period of 1989 to 1992 using the same methodology as the current estimates, and to review the significance of the apparent trend.

This report presents the finding of this review.

2 Scope

The scope of the project, specified in the contract was:

a) Subject to availability of data establish a consistent data series on area of savanna burnt between 1989 and 1992;

b) evaluate and discuss the current methodology and emission estimate constructs against IPCC guidelines. In particular:
    - the practice of averaging areas burnt over a 10 year period, where other activities are averaged over three years or not at all;
    - the question of anthropogenic and naturally occurring ignition and burning;
    - the practice of other Annex 1 countries reporting emissions from savanna burning;
    - the treatment of fires on lands not primarily used for agricultural purposes and fires on agricultural lands that serve no agricultural purpose, and

- a review of existing literature on fuel loads and burning efficiencies, as this may influence the estimation of greenhouse gas emissions from the area burned.

b) Assess and discuss the actual trend in emissions over time, including a discussion of the drivers/pressures on this trend.

Due to the short timeline, it was agreed that the review would be restricted to the savanna regions, as defined within the National Greenhouse Gas Inventory Methodology, of the Northern Territory and Western Australia. These two states contain more than 70% of the fire areas and non-CO_2 greenhouse gas emissions, and show the greatest inter-annual variability

3 Background

3.1 Emission algorithm

The emissions from sub-sector 4E of the National Greenhouse Gas Inventory (NGGI) are determined using the methodology presented in NGGI Workbook 5.1 (NGGIC, 1996) and subsequent methodology supplements

Briefly, the emission of the non CO_2 greenhouse gases comprising methane (CH_4) Carbon monoxide (CO), the non-methane hydrocarbons (NMVOC), nitrous oxide (N_2O) and the nitrogen oxides (NO and NO_2 which are collectively termed NO_x)

For savanna fire, prescribed forests and wildfires the emission of species i from State j (Eij, g) is defined by two algorithms. For the carbon species (CH_4, CO, VOCs), the emission is given by

$$E_{ij} = A_{jk} \times M_j \times \xi_{jk} \times C_j \times EF_{ik} \times 10^{-6} \text{ (g)} \qquad \text{Equation 3.1}$$

Where:

A_{jk} is the mean annual area burned (ha) for the inventory year *k* in state *j* averaged over 10 years, from *k-8* to *k +1*;

M_j is the mean fuel load for state *j* (t ha^{-1});

ξ_j is a combined burning efficiency, which accounts for the proportion of the scar that burns and the proportion of fuel exposed to fire that is volatilised

C_j is the carbon content of the fuel,

EF_{ij} is the emission ratio for species *i* for state *j* (pg $(g\ C)^{-1}$)

For the nitrogen species (NO_2, NO_x) the emission ratios (EF_{ik}) are defined relative to fuel nitrogen content and therefore equation 3.1 is modified by the addition of a sixth parameter, the nitrogen to carbon ratio (CN_j). That is, for i = NO_x and N_2O

$$E_{ij} = A_{jk} \times M_j \times \xi_j \times C_j \times CN_j \times EF_{ij} \times 10^{-6} \quad \text{(g)} \qquad \text{Equation 3.2}$$

Where:

CN_j is the nitrogen to carbon ratio of the fuel in state j and

EF_{ij} is the emission ratio for species *i* for state *j* (pg (g N^{-1})

A 10-year average for fire areas is used for two reasons:

a) The frequency and intensity of forest and savanna fires of all classes is determined to a large degree by climate and weather leading to extremely high year-to year variability. In order to reduce the influence of short-term weather variation, the standard integrating period of 10 years is used. The window is weighted to the previous 8 years, to allow an emissions estimate to be made within two years of the present, as required for the reporting of national emissions.
b) Australia, unlike all other annex 1 nations, covers a wide range of latitudes from the tropics to the temperate regions. The fire season in the tropics occurs during the winter dry season from April to October while the temperate fires season occurs in the summer (November to March). Therefore any definition of an inventory year will result in splitting either the tropical or the temperate fire season. By averaging across three or more years the effects of the phase difference between the tropics and the temperate regions is largely removed.

The averaging of activity data is unusual with most parties reporting annual emissions, however few nations have sector where the phase of an activity varies substantially across regions. A long averaging period removes the short-term climatic influence and reduces to probability that emissions estimated in a key inventory year will be determined predominantly by exceptional weather conditions.

3.2 Data sources

The inventory methodology was developed when satellite remote sensing was uncommon and fire records from many regions were limited. This was particularly the case for the Northern Territory and Western Australia. There were very few measurements of fuel loads in either tropical of temperate ecosystems, or fuel composition. However some measurements of trace gas emission factors had been made from Australian fires, and in fact the Australian measurements contributed substantially to the international data base at the time.

3.2.1 Fire area

The inventory working group reviewed the fire areas and fuel loads for the savanna and temperate grassland fires, forest wildfires, and prescribed fires in managed forests from 1982 to 1992 (Tolhurst, 1994). All these data were sourced from bushfire authorities and or district fire offices and are based on local records or expert judgement. The data for Queensland and Western Australia, principally the Kimberley region were expert estimates of long-term averages.

The exception was the fire data for the NT Central Australia; these data were estimated form analyses of high resolution AVHRR imagery, the first such use of satellite imagery for regional fire assessment in tropical Australia. The use of satellite imagery was extended to the Top End of the Northern territory in 1991/2. This single value was then used, in the absence of any other estimates, as indicative of fire activity in the previous years in order to allow estimates of the total national savanna fire areas from 1983 to 1992 to be made.

The Department of Land Administration, WA commenced routine monitoring of fires and firescars, initially in the Kimberley Region in 1993, across the entire state in 1994. Firescar mapping in NT passed to DOLA WA in 1996. National mapping was commissioned by Environment Australia for the 1998 State of the environment report, and has continued to the present.

Satellite imagery is currently used to estimate savanna fires in Queensland, Western Australia, Queensland and South Australia. NOAA AVHRR imagery cannot detect firescars less than 100ha area, which is too low resolution for most grass fires in Tasmania, NSW and Victoria, Fire estimates from these states continue to be sourced from local fire authorities. More recently, these fires have been mapped with portable global positioning systems (GPS) which presumably has greatly improved the accuracy of these local estimates.

Table 3.1 Fires in savanna and temperate grassland in Australia 1983-2003 used in the 2002 NGGI.

	State							**NT**		
Year	**NSW**	**Tas**	**SA**	**Vic**	**ACT**	**Qld**	**WA**	**Top End**	**centre**	**Total**
1983	121,000	21,796	175,229	99,166	0	6,300,000	11,300,000	8,548,400	4,880,000	13,428,400
1984	12,500	19,589	13,129	10,979	0	6,300,000	11,300,000	8,548,400	3,160,000	11,708,400
1985	2,478,000	11,305	177,130	205,054	0	6,300,000	11,300,000	8,548,400	5,720,000	14,268,400
1986	93,148	61,582	178,029	11,170	0	6,300,000	11,300,000	8,548,400	100,000	8,648,400
1987	207,878	32,068	350,179	37,830	0	6,300,000	11,300,000	8,548,400	0	8,548,400
1988	51,048	11,193	1,769,006	72,550	0	6,300,000	11,300,000	8,548,400	20,000	8,568,400
1989	40,657	14,803	71,462	44,330	0	6,300,000	11,300,000	8,548,400	0	8,548,400
1990	195,073	15,785	62,264	14,210	0	6,300,000	11,300,000	8,548,400	170,000	8,718,400
1991	517,168	5,301	789,808	NE	0	6,300,000	11,300,000	8,548,400	250,000	8,798,400
1992	50,600	3,761	217,188	5,880	0	6,300,000	11,300,000	8,548,400	150,000	8,698,400
1993	21,772	4,343	7,557	11,500	0	6,300,000	7,790,000	8,550,000	200,000	8,750,000
1994	382,398	7,574	207,875	17,900	0	6,300,000	14,990,000	15,300,000	3,400,000	18,700,000
1995	89,112	28,134	88,338	17,502	0	6,300,000	14,790,000	13,250,000	9,650,000	22,900,000
1996	90,480	18,662	3,707	7,564	0	7,500,000	19,382,000	15,000,000	10,000,000	25,000,000
1997	131,068	2,585	191,670	15,131	0	3,802,000	13,658,703	17,273,000	500,000	17,773,000
1998	NE	5,017	26,000	7,965	0	4,619,892	22,248,007			20,123,786
1999	16,380	1,428	24,600	18,979	0	4,392,000	10,517,400			15,486,900
2000	5,528	14,177	441,168	11,776	0	8,683,800	21,392,300			20,980,500
2001	NE	9,198	18,680	32,925	0	7,276,300	41,933,500			35,078,700
2002	NE	7,623	13,036	21,912	0	13,898,700	17,052,500			38,129,200
2003	NE	NE	48,671	NE	0	6,904,000	14,430,700			26,567,000

In summary, the current NGGI firerscar timeseries is a combination of several timeseries- from local records, from satellite imagery, and on occasion, a combination of the two. While unavoidable in the absence of consistent timeseries, the use of combined timeseries generally leads to higher uncertainty.

The current timeseries for savanna fires in NT and WA and the 10-year running mean, (activity A_{ij}, Eq 3.1) is shown in Figure 3.1. The fire area estimates in the early to mid 1990s are strongly biased to the limited fire area estimates of the 1980s.

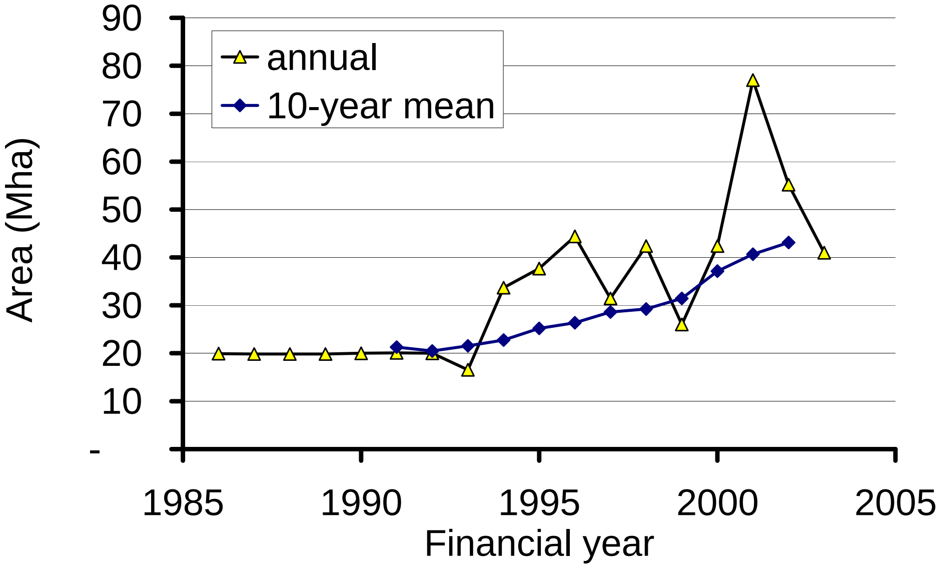


Figure 3.1 Current estimates of annual fire scar areas in NT and WA, and the 10-year running. These data were used to estimate greenhouse gas emissions from subsector 4E, burning of savanna, in the 2002 NGGI.

3.2.2 Fuel load

The estimates of fine fuel loads were initially derived from the review of Tolhurst (1994), and subsequently revised in workbook 5.1 (NGGIC, 1996) and the methodology supplements of the 1995 and 1999 National Inventories (Table 3.2). The main revisions were to the fuel estimates for NT, Queensland and Western Australia on advice from state reviewers of the NGGI, and the emergence of new data. The revision in 1999 to the NT and WA fuel loads was based on measured rates of litter fall, temperature dependent decay rate and fire frequency rather direct measurement.

Table 3.2. History of changes to savanna fuel loads. Changes to fuel load are highlighted.

State	Workbook 5.0 (NGGIC, 1994)	Workbook 5.1 (NGGIC, 1996)	1995 NGGI supplement (NGGIC, 1997)	1999 NGGI supplement (AGO, 2001)
NSW	11.1	11.1	6.9	6.9
TAS	10	10	10	9
WA	10	10	8.3	7.7
SA	3	3	3	3
VIC	11	11	11.7	11.7
QLD	10.3	**3**	3	3
NT	5	5	4.1	5.8
ACT	11.1	11	11.1	11.1

3.2.3 N:C ratio

There were several values for the N:C ratio, all estimated from ecological studies current in the NT in the early 1990s. A value of 0.011 was cited by Hurst et al. (1994a) from results in Cook and Andrew 1991; a value of 0.010 was cited in Workbook 5.0 (NGGIC, 1994) from data reported for Kapalga, NT by Hurst et al. (1994b); and a value of 0.02 was reported by Hurst et al. (1996) also citing Hurst et al. (1994b), perhaps erroneously. The value of 0.02 was recommended in the workbook revision 5.1 and has remained unchanged to the present. Rounding the value up to 0.02 was within the estimated error of the parameter at the time of the revision and consistent with the current IPCC default value for Sorghum, which is the dominant grass species in the savanna woodlands. However, further data collection has confirmed that the original value of 0.011 was the more accurate estimate.

3.2.4 Burning efficiency

There were virtually no data available for Australian savanna fire burning efficiencies. The value for burning efficiency used in the inventory (0.72) is derived from expert estimates based on field observation (Tolhurst, 1994) that approximately 80% of a fire scar is burned, and the 90% of the fuel mass in the burned area is volatilised.

3.2.5 Classification of fires

Finally the question of how to classify savanna fires was addressed in detail when the methodology was developed (Workbook 5.0 NGGI, 1994) and has been retained through subsequent revisions. The issue was what proportion of savanna fires could be classed as anthropogenic, and which were wildfires. Anthropogenic fire were defined as fires for the purpose of pasture management, fuel reduction and traditional aboriginal land management, and it was recognised that in the absence of these fires, uncontrolled wildfires, either lit by man, or by lightning would probably occur instead. However consistent advice from fire authorities was, and continues to be given that there is currently no practical method to identify the ignition source, or intended purpose of most of the savanna fires. As a result the decision was made to class all fires in the savanna region as anthropogenic.

This conclusion was consistent with the 1995 IPPC inventory guidelines (IPCC, 1995) and the 1996 Revised Guidelines (IPCC, 1996) definitions of Savanna burning.

The 1995 IPCC common reporting framework defined savanna burning as

> “Emissions of CH_4, CO, N_2O and NO_x from the burning of savannas. Savannas are burned to control the growth of vegetation, remove pests and weeds, promote the nutrient cycle and to encourage the growth of new grass for animal grazing. CO_2 from savanna burning is noted for information but is not included in the inventory total since it is assumed that an equivalent amount of CO_2 is removed by regrowing vegetation in the following year. Savannas are tropical and subtropical formations with continuous grass cover, occasionally interrupted by trees which exist in Africa, Latin America, Asia and Australia.
>
> … The burning of savannas also releases gases other than CO_2, including methane, carbon monoxide, nitrous oxide and oxides of nitrogen. Unlike CO2 emissions these are net anthropogenic emissions and should be accounted for.”
> ”

The definition was elaborated but not significantly altered in the revised 1996 IPCC guidelines which describe savanna burning as follows:

> “The term savanna refers to tropical and subtropical vegetation formations with a predominantly continuous grass cover, occasionally interrupted by trees and shrubs (Bouliere and Hadley 1970). These formations exist in Africa, Latin America, Asia, and Australia. The growth of vegetation in savannas is controlled by alternating wet and dry seasons: most of the growth occurs during the wet season; man-made and/or natural fires are frequent and generally occur during the dry season. The global area of savannas is uncertain, in part due to lack of data and in part due to differing ecosystem classifications. Estimates of the areal extent of savannas range from 1300-1900 million hectares world-wide, about 60 per cent of which are humid savannas (annual rainfall of 700 mm or more) and 40 per cent are arid savannas (annual rainfall of less than 700 mm) (Bolin et al., 1979; Whittaker and Likens, 1975; Lanly, 1982; Lacey et al., 1982; and Hao et al., 1990). Large-scale burning takes place primarily in the humid savannas because the arid savannas lack sufficient grass cover to sustain fire. Humid savannas are burned every one to four years on average with the highest frequency in the humid savannas of Africa (as cited in Hao et al., 1990).”
>
> “Savannas are intentionally burned during the dry season primarily for agricultural purposes such as ridding the grassland of weeds and pests, promoting nutrient cycling, and encouraging

> the growth of new grasses for animal grazing. Savanna burning may be distinguished from other biomass burning activities like open forest clearing because there is little net change in the ecosystem biomass in the savanna after the vegetation regrows during the wet season. Consequently, while savanna burning results in instantaneous gross emissions of CO_2 , it is reasonable to assume that the net carbon dioxide released to the atmosphere is essentially zero because the vegetation typically regrows between burning cycles. Savanna burning does release several other important trace gases: methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O), oxides of nitrogen (NO_x i.e., NO and NO_2) and non-methane volatile organic compounds (NMVOCs)."

The key feature of both the NGGI and the IPCC definitions is the emphasis on land management for food production but not specifically commercial agriculture, and recognize that the activity mostly occurs in natural as distinct from strictly agricultural ecosystems. Further, the IPCC definitions imply that all savanna fires other than those associated with land clearing are included. This is even less equivocal than the NGGI definition, which allowed for the possibility that future information might provide a means for stratifying savanna fires into anthropogenic and non-anthropogenic classes.

In conclusion, the current NGGI methodology was developed as a practical approach to a complex problem with limited data sources. The quality of activity data in particular has continued to improve substantially leading to an inconsistency in timeseries. It is well known, that combining inconsistent timeseries can produce errors, particularly in estimates of trends. This issue has being explicitly addressed in the development of the 2006 IPCC Inventory Guidelines. Therefore it is appropriate and timely to review components of the methodology and its underlying assumptions in the light of recent data.

4 Fire scar areas for the baseline year

4.1 Fire history 1990 to 2003

The Satellite Remote Sensing Services Group of the Department of Land Information, WA (formerly known as DOLA) were contracted to estimate the areas of firescars in the Northern Territory and Western Australia for the financial years 1989/90, 1990/91 and 1991/92 which correspond to the inventory years 1990, 1991 and 1992. Coverage was restricted to NT and WA partly by budgetary limitations but principally by time schedule. The required satellite images for WA and NT were received at the Perth satellite receiving station and were archive by DOLA. To map the Eastern states required images received at Melbourne or Townsville, which were unavailable within the tight time schedule. Firescars were detected by change in surface reflectance between successive, cloud free images at nine-day intervals, using the same standard methods by which the 1996 to 2004 were determined. Monthly firescars were provided as polygons in Arcview shapefile format (ESRI, Redlands Ca, USA), using the AGC 1994 datum.

The inventory year is out of phase with the northern Australian fire season; the first half of the inventory year encompasses the late fires season of the first calendar year and the early fire season of the next. It is vary rare that any area will burn twice in any single season. Overlapping firescars within a single fire season are most likely due to small errors in mapping rather than real fire events. However it is quite possible that an area that was burned in the late fire season of one year burns again in the early fire season of the following year. This is because the fuel removed in the first fire may be replaced by grass production during the subsequent wet season. In order to remove coincident firescars within a single season but to account for coincident firescars in successive fire seasons, the standard process used in the NGGI was applied.

Firescar polygons for January to June and for July to December were merged into six-monthly files. Each file was then transformed using Albers equal area projection with the central meridian 1320E, the first parallel 180S and the second parallel 36oS and converted to a 1km x 1 km grid in which the grid cells were assigned values of 0 or 1 corresponding to unburned or burned areas respectively. This removed overlapping fire scars.

The firescar area in the two grids was summed to give the annual area for the inventory year. This step allows for the same area to be burned in successive fire seasons within the same inventory year.

The savanna region defined in the NGGI is currently specified in terms of the agroecological zones (AEZ) of the IBRA 4.1 regionalisation (Fig 4.1). The IBRA regionalisation is well defined and readily available and adds to the transparency to the inventory methodology. There are other, perhaps better definitions of savanna boundaries based on vegetation structure and annual mean rainfall, but for inventory purposes, the differences are small. The current inventory methodology uses as working definition of savanna and tropical grassland all of the Northern Territory and AEZ1 and AEZ11 of Western Australia. The “Top End”, i.e. the savanna woodlands corresponds approximately to AEZ 1 and AEZ 2. The regions AEZ 5 and AEZ 11 comprise the arid zone of Central Australia.

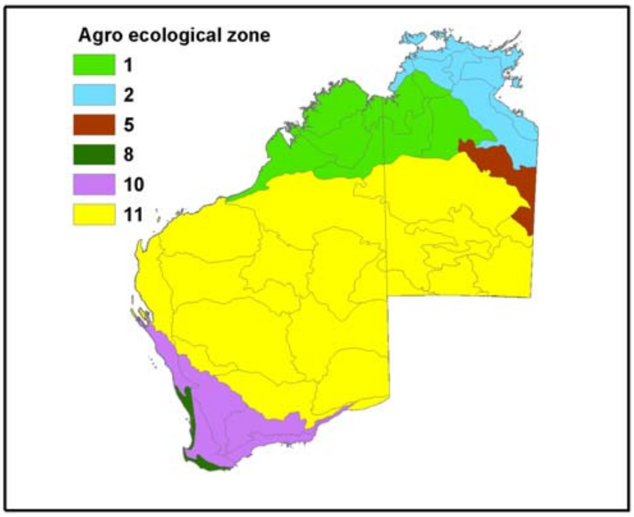


Figure 4.1 Agroecological zones of NT and WA from IBRA 4.1.

The 1990 to 1992 firescar data were combined with the existing firescar data, also estimated from AVHRR satellite imagery by the same methodology, to form a consistent timeseries. This existing data consisted of:

- The Kimberly region, May to November, 1993
- All Western Australia, March to December, 1994 April to December, 1995 and all 1996
- WA and NT, 1997
- All states 1998 to 2003.

The annual firescars for the inventory years NTWA 1990-1992, and 1997-2003, and WA 1994-1996 are shown in Figures 4.2, 4.3, 4.4.and 4.5.

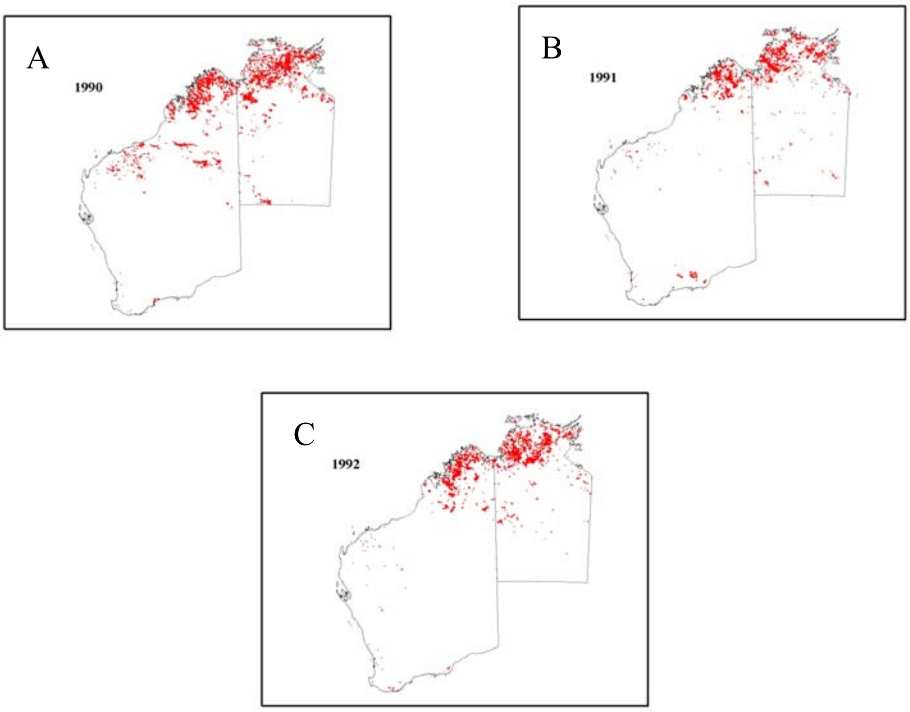


Figure 4.2 **Savanna fires in NT and WA. (a) 1990, (b) 1991 and (c) 1992.**

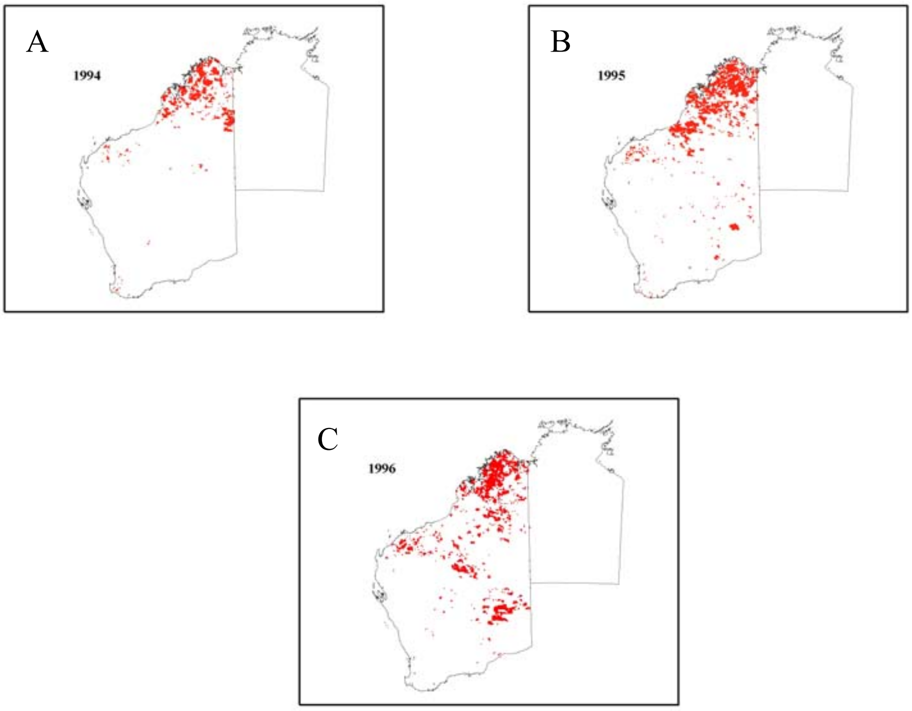


Figure 4.3 Savanna fires in WA. (a) 1994 (b) 1995 and (c) 1996. The 1994 area estimate include the Kimberley region only for July to December 1993 and all WA for May to June 1994 only.

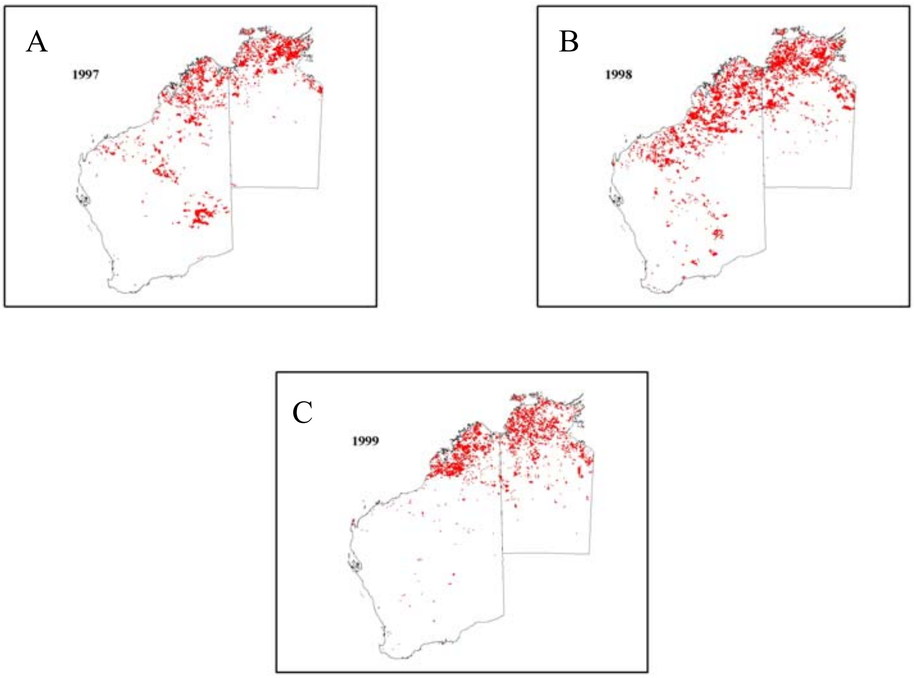


Figure 4.4 Savanna fires in NT and WA. (a) 1997, (b) 1998 and (c) 1999.

In all years, there was substantial fire activity in the Kimberly region of WA and the western half of the Top End of the Northern Territory (AEZ 1) and Central Arnhem Land (AEZ 2). Fire activity in Western Arnhem Land to the Gulf of Carpentaria, and Inland Western Australia and NT were less fire prone. The period 1990 to 1992, which covers the IPCC inventory reference year of 1990, had the least fire activity in the 1990 to 2003 timeseries. Firescar data from DOLA for 1994 to 1996 was available only for WA (Figure 4.3) with mapping in the first half of 1994 restricted to the Kimberleys and therefore must underestimate the complete fire extent to some degree. However, increased fire activity in central Australia is clearly evident from 1995 onwards peaking in 2001 when a large proportion of northern and central NT and WA were impacted.

The timeseries of firescar areas, aggregated by AEZ, are presented in Table 4.1 and Figures 4.6 and 4.7. The total fire area for NT and WA (including data for NT from 1993 to 1996 from the NGGI which was originally sourced from the NT Bushfires Council see Allan and Southgate, 2002), increased from the minimum in 1992 of 14 Mha to the peak in 2001 of 76Mh. The increasing trend from 1991 to 2001 was evident in both the northern ("Top End") and central Australian region. The contribution from central Australia exceeded that from the Top End only in 2001 (Figure 4.6).

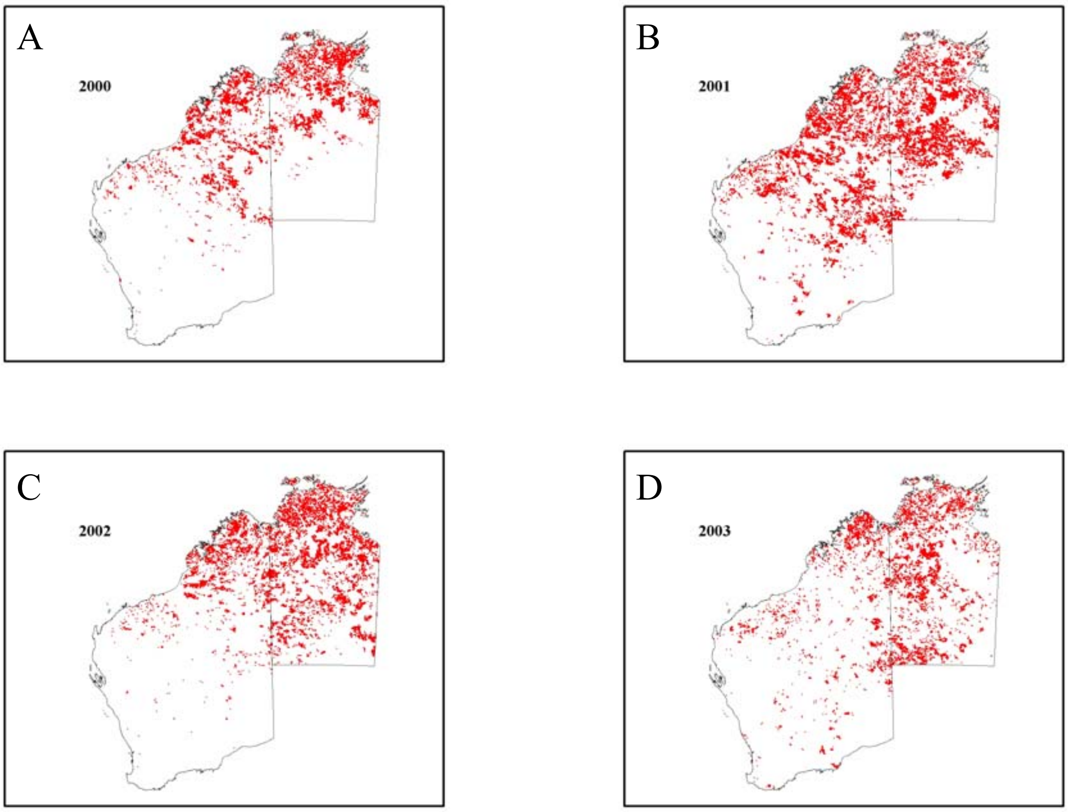


Figure 4.5 Savanna fires in NT and WA. (a) 2000, (b) 2001, (c) 2002 and (d) 2003.

Table 4.1 Firescar areas in Northern Territory and Western Australian Savanna 1990 to 2003.

Year	NT				WA		Total*
	AEZ 1 (Top End)	AEZ 2 (Top End)	AEZ 5 (Centre)	AEZ 11 (Centre)	AEZ 1 (Top End)	AEZ 11 (Centre)	
1990	4,194,900	7,364,600	0-	829,100	7,033,200	3,029,200	22,451,000
1991	3,014,500	5,520,600	500	714,000	4,356,900	335,600	13,942,100
1992	4,099,600	5,544,900	46,500	584,000	5,710,200	786,400	16,771,600
1994					6,697,200	1,826,300	27,223,500[a]
1995					11,618,700	5,918,000	40,436,700[a]
1996					7,812,600	7,605,000	40,417,600[a]
1997	2,827,900	8,457,800	2,500	185,800	7,008,800	6,415,900	24,898,700
1998	6,426,900	10,429,400	92,600	1,425,500	10,710,400	11,378,700	40,463,500
1999	5,361,000	7,995,500	76,200	1,211,400	9,139,900	1,089,000	24,873,000
2000	6,657,300	11,601,900	26,200	2,396,400	9,766,300	11,440,900	41,889,000
2001	8,310,100	9,420,600	385,900	16,257,400	13,523,300	28,081,900	75,979,200
2002	10,215,900	13,381,000	1,427,700	11,962,000	9,861,800	7,046,900	53,895,300
2003	6,679,900	7,223,400	157,100	12,249,000	6,499,200	7,857,200	40,665,800
Mean	5,778,800	8,693,970	221,520	4,781,460	8,441,423	7,139,308	35,685,154
CV	0.41	0.29	1.98	1.28	0.31	1.03	0.47
Max/min	3.6	2.4	>100	88	3.1	84	5.4

[a] Includes estimates of NT areas burned from the 2002 NGGI (AGO, 2004). Data sourced from Bushfire Council of NT

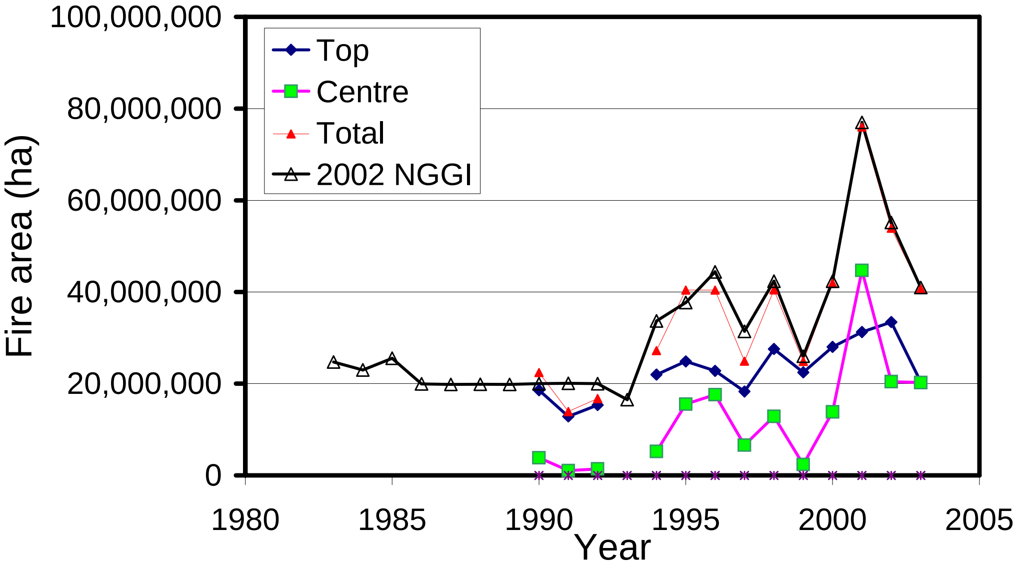


Figure 4.6 Timecourse of fires in NT and WA combined,

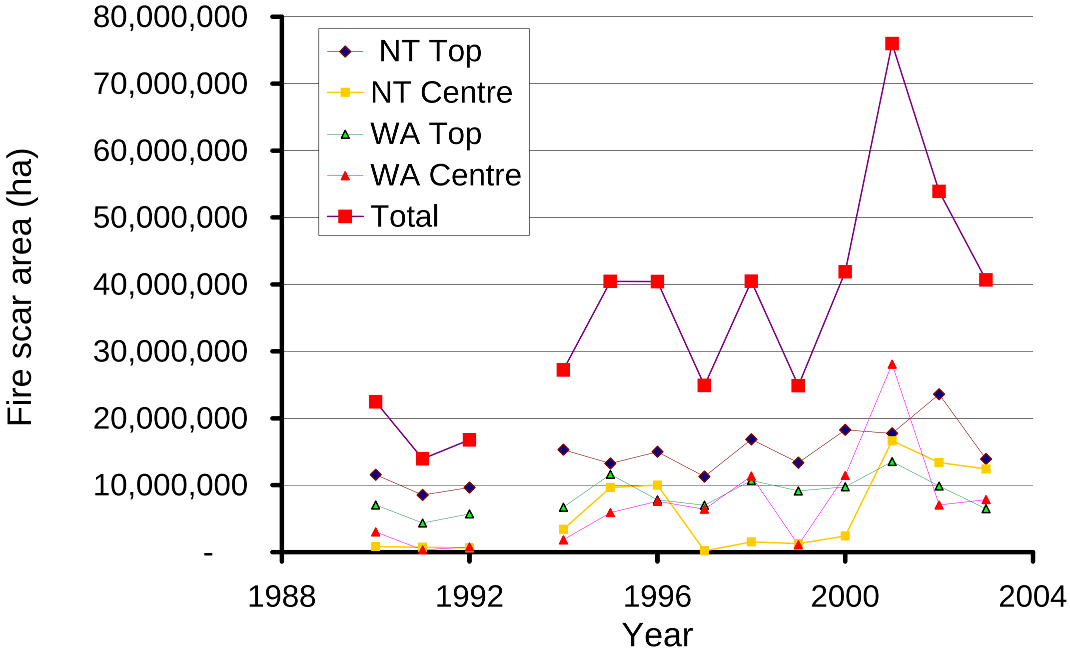


Figure 4.7 **Timecourse of fires in NT and WA 1990 to 2003.**

The inter-annual variation in fire area between 1990 and 2003 is substantial. In the Top End of both NT and WA the coefficients of variation for NT, WA and NT and WA combined are respectively 28%, 31% and 26%, and the relative range (maximum/minimum) is a factor or 3. However the year-to-year variation in central Australia is far greater with coefficients of variation of approximately 100%, and the range a factor of approximately 85 for NT and WA and 45 for NT and WA combined. The year-to-year variation in the Top End and central regions of NT and WA is shown in Figure 4.7. In general, the area burned top-end of WA and NT vary similarly from year-to-year, as do the total areas burned in the central Australia in both states, suggesting that large-scale rather than local factors were probably causing the year-to year changes.

Comparing the revised data set with the NGGI timeseries (Figure 4.6), it is clear that the apparent trend in firescar area from 1990 to 2003 first identified in the NGGI is, in fact a real phenomenon and not, as previously suspected, an artefact caused by combining inconsistent timeseries. However the key question for emissions policy is whether it is a continuing trend, or a component of a longer-term cycle.

4.2 Variability in fire activity

The causes of year-to-year variability have been, and continue to be actively researched (eg Allan and Southgate, 2002). It is generally considered that in the savanna woodlands, and particularly in the Spinifex country of central Australia, fire spread is determined by fuel density, in contrast to the forests of southern Australia where the rate of fire spread is mostly determined by extreme weather events. For a fire to propagate sustainably from the point of ignition, it must generate sufficient heat to raise surrounding unburned fuel to ignition point. In northern Australia, air temperatures humidity and fuel moisture in the dry season are invariably favourable for fire spread, and ignition sources typically common, either lightning or human action. However whether the fire will propagate depends on whether sufficient fuel has accumulated since the previous burn.

The fire frequency for each 1 km^2 grid cell from the 1990-2003 timeseries and is shown in Figure 4.8. Fire frequency (f) is expressed as the percentage of years in the timeseries in which the grid cell registered a fire. Alternatively it can be expressed as a fire return interval (R) where R =100/f

Fire frequency in the Top End ranges from 25% to almost 100%, that is, most areas will be burned at least once in 3-4 years, some annually. In central Australia many, perhaps most cells were burned only once in the 14 year record.

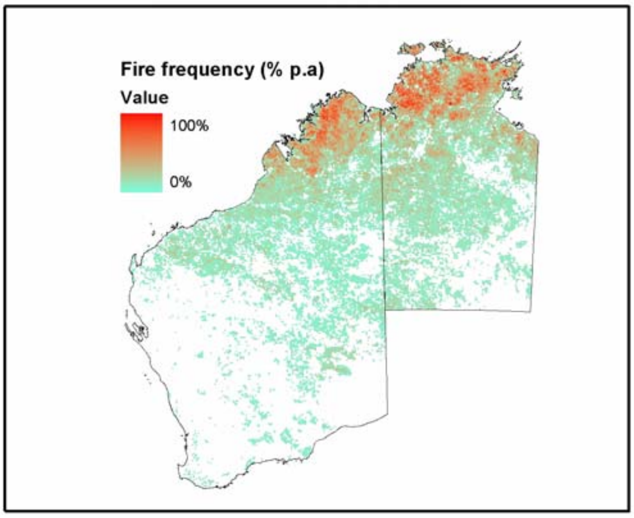


Figure 4.8 Frequency of fires in NT and WA 1990 to 2003.

This pattern is well known, and well understood; it is discussed at length by Allan and Southgate (2002). In the high rainfall regional of the Top End, plant production occurs during the wet season (December to March) with little activity in the subsequent dry season during which the grass and litter fuel progressively dries out. Fire risk increases as the dry season progresses and the fuel cures. The probability of ignition is extremely high and weather is rarely a limiting factor for fire spread. Fuel accumulation rates, and the maximum fuel load are determined by the rate of grass production, litter fall and decay rate, and grazing by vertebrates, and termites. Litter loads in the Top End reach equilibrium in 3-5 years at between 3 and 10 t ha^{-1} As a rough rule, a fuel load of 1.5-2 t ha^{-1} is the minimum that will sustain a fire and, therefore, potentially most areas will burn within 2-3 years of the last fire.

A similar process occurs in Central Australia, however rainfall is increasingly infrequent and episodic with distance inland, and significant plant production occurs only after major and sustained rainfall events. The episodic nature of fires in inland Australia is apparent in the firescar record for the period post 1990 (Figure 2.6). Allan and Southgate (2002) extend the analysis back to the mid 1970s using a combination of LANDSAT and NOAA AVHRR imagery supplemented by NT Bushfire Council records. They found the last extensive fire season (prior to 2000/2001) occurred in the mid 1970s when more than 21Mha burned in central NT. There was sustained but lower fire activity in the wetter, northern districts during the 1980s, with almost no fires in the typically drier southern regions of the Simpson Desert. Apparent fire return intervals in the 1979-1994 period ranged from 11 years in the Tanami desert to 31 years at Uluru-Kata Tjuta National Park to 77 years in the Great Victoria Desert Region in Western Australia.

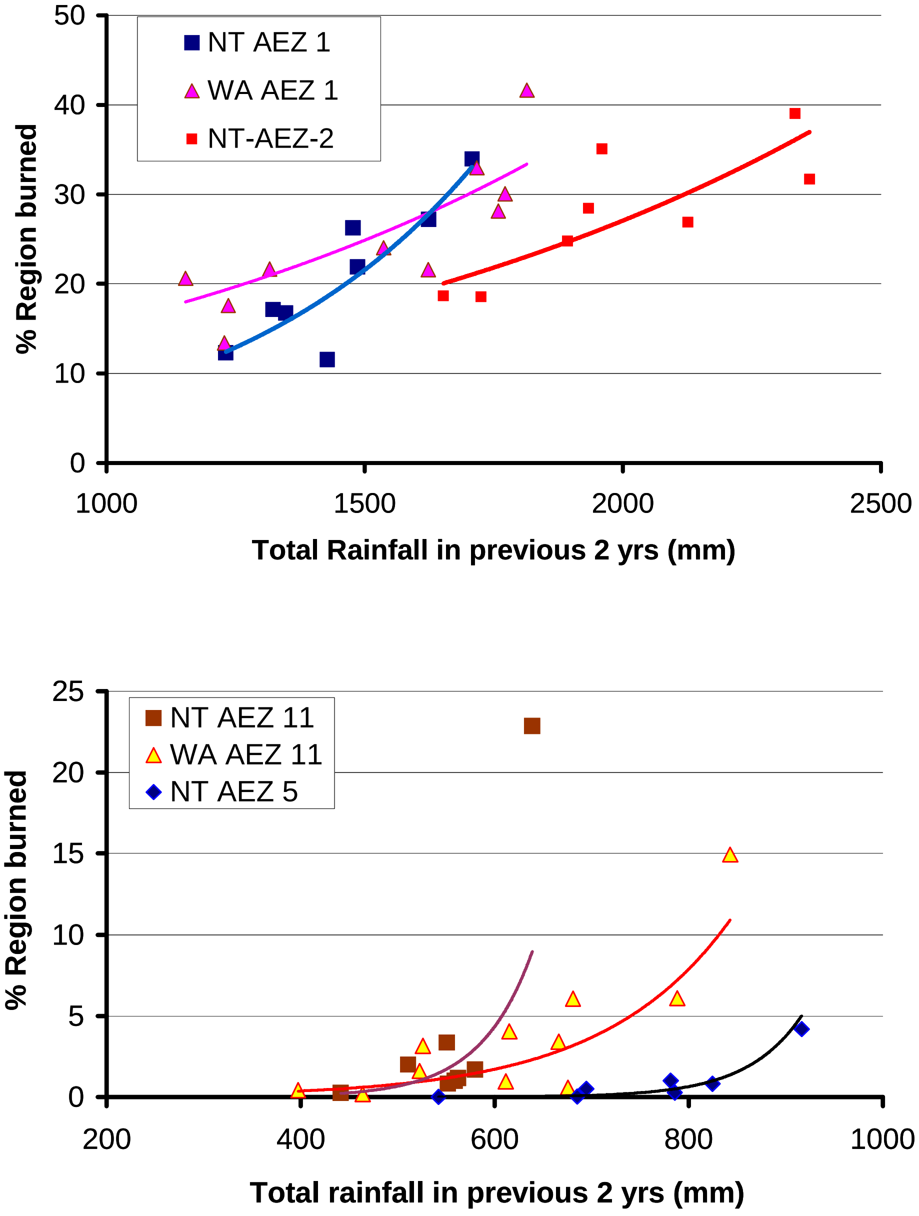


Figure 4.9 Relationship between fire scar area and rainfall in the preceding two seasons.

Extensive fires throughout the region occur only after sustained and very widespread rainfall when production and fuel accumulation is extensive (Walker, 1981). This has occurred only twice in the last 30 years, in mid 1970s leading to the extensive fires in late 1970 (Allen and Southgate, 2002) and again in the late 1990s leading to the peak fire year of 2000/2001.

The relationship between firescar area and rainfall in the preceding seasons was investigated in the current timeseries by combining the DOLA firescar record with the National rainfall grid for 1988 to 2002 (Bureau of Meteorology, 2003), integrated across each of the agroecological zones in WA and the NT (Figure 4.9). Firescar area is normalised by total area of each region.

The most likely form of the relationship between the rainfall and firescar area is a sigmoidal function. Two factors contribute to this. (1) The relationship between seasonal rainfall and fuel load is likely to be nonlinear with little fuel accumulation possible until biomass production is significantly greater than the loss to grazing by vertebrates and termites. (2) Fires are not sustainable until the fuel load increases to the threshold at which the fire produces sufficient energy to ignite adjacent fuel patches. Beyond this threshold, intensity and rate of spread probably increase with fuel load until they are limited other factors such as air temperature, humidity, moisture, windspeed and topography In the domain of the fire area/rainfall relationship where fire spread is fuel-limited, an exponential function is likely to be a good approximation .

Consequently, the timeseries of firescar area in each region each was fitted with simple exponential relation , y = a*.exp(b**x*) where *x* is total rainfall in the preceding two years and y percentage of the region burned (Table 4.2). For the central Australian zones, the exponential regressions were significantly better than linear regressions, while in the top end the goodness of fit for both linear and exponential regressions was similar. In all cases the correlation between fire area and rainfall is highly significant, with more than 50% of the variance in firescar area explained by rainfall. The firescar ranges over which the regressions are valid are also given in Table 4.2.

Table 4.2 Regression coefficients for the relationship between percentage of region burned and rainfall in the preceding two years. (A = a* exp (b *R).

Region	Coefficients A	B	r^2	Upper limit of prediction (% region burned)
NT -1	9.91E-01	2.05E-03	0.70	42
NT- 2	4.83	8.62E-04	0.68	46
NT-5	5.19E-07	1.76E-02	0.84	16
NT-11	5.97E-05	1.87E-02	0.67	23
WA-1	6.13	9.35E-04	0.61	42
WA-11	1.77E-02	7.62E-03	0.58	15

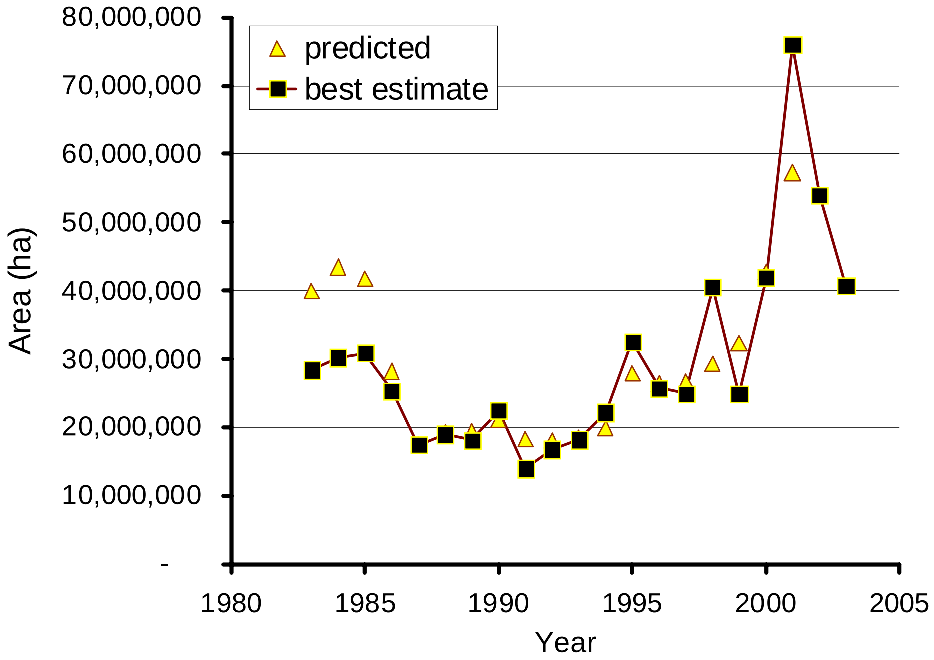


Figure 4.10 Timeseries of fires in NT and WA, fire-scar areas; triangle, fire area predicted from regression equations; squares, best estimate using measured fire areas supplemented predicted areas in regions where data were unavailable.

These regressions can be used to predict the fire areas in years where data are missing or incomplete, allowing the timeseries of fires in NT and WA, to be extended back to 1983 (Figure 4.10). A comparison between predicted firescar area and actual fire scar area in those years when firescar data are complete, 1989-1992 and 1997-2003, shows good agreement between actual and predicted values. Data were not available for WA between 1983 and 1989, and NT between 1993 and 1996, and missing data were estimated using the regressions. The patched timeseries confirms that firescar activity in 1991 was the lowest in 20 years.

The trend in the 1990-2003 timeseries (Table 4.1) therefore appears to be explained, in part at least, by the rainfall cycle. Fires occurred mainly in the Top End, less following dry seasons, more after wet years. However the extreme wet years of 1998-2000 lead to widespread fires in Central Australia as well as in the Top End causing a major peak in fire activity in 2000/2001. This peak was 2.1 times the 1990 to 2003 average.

5 Classification of savanna fires by location or cause

The question was explored of whether savanna fires could be usefully stratified beyond the current level of State to categories that might describe how much of the savanna fires could be ascribed to anthropogenic purposes or causes. Potential parameters include:

- commercial grazing density;
- land use classifications; or
- ignition source

5.1 Land use masks

Commercial grazing density was investigated as a potential mask, but was considered unsuitable, because although livestock production in these regions is substantial, animal densities are extremely low. The definition of boundaries of the mask would inevitable rely on a value judgement of what constituted a viable agricultural grazing density and consensus would be unlikely. It was decided instead to investigate three masks which were well defined and which had potential for stratifying the regions by land classifications relevant to IPCC inventory guidelines. These masks, vegetation type, land tenure and land-use are available as attributes in the National Land & Water Resources Audit 1996/97 Land Use of Australia Version 2 (Stewart et al., 2002). This layer was developed using a wide range of data sources including the Australian Bureau of Statistics Agriculture Census. Full descriptions are available from http://audit.ea.gov.au/

The land use layer is provided as 0.01° grid in geographical coordinates (AGC94). In this analysis, each layer was converted to vector format using Arcview V3.2, and projected using Albers Equal Area Conic projection as described in section 4.1.

The vegetation mask (Figure 5.1) classifies vegetation in to five structural classes based on projected foliage cover:

1.	Grassland	Non-forest: crown cover between 0% and 20%;
2.	Woodland	Native forest with crown cover between 20% and 50%;
3.	Open forest	Native forest with crown cover between 50% and 80%;
4.	Closed forest	Native forest with crown cover between 80% and 100%;
5.	Plantation	Softwood or hardwood plantation forest.

The savanna region of the Top End (AEZ 1 and 2) consists predominantly of open woodland, with smaller areas of open forest and grassland ("no forest"), while the central Australian region is classified as "no forest" i.e. grassland. The distribution of firescars by these vegetation classes is presented in Tables 5. 1a and 5.1b and Figure 5.1.

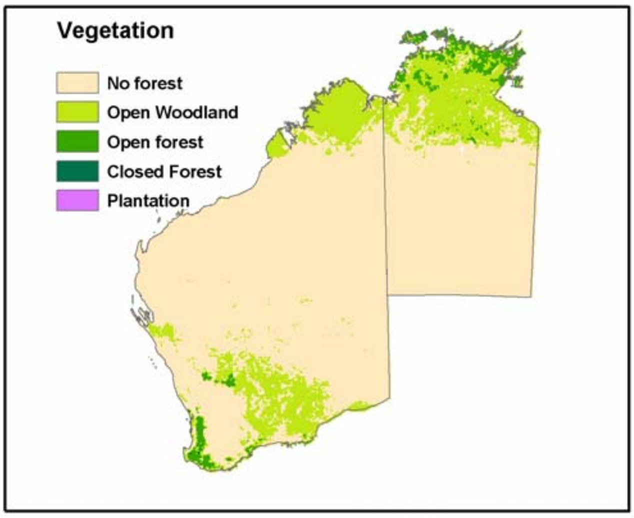


Figure 5.1 Distribution of grassland, woodland and forest in NT and WA. From the National Land & Water Resources Audit 1996/97 Land Use of Australia Version 2.

In the Top End almost two thirds of fires occur in open woodland, 30% in grassland and 10% in open forest. The fires areas in open woodland and grassland follow the increasing trend discussed in Section 4.1, however there was no trend in fires in open forest.

Firescars in central Australia occurred entirely in grassland with the variability described in Section 4.1.

Table 5.1a. Firescar areas (ha) in Northern Territory and Western Australian savanna, 1990 to 2003, stratified by forest type.

Year	Grassland	Open woodland	Open forest	Closed forest	Plantation
1990	8,398,900	11,980,400	2,007,100	27,000	1,100
1991	2,633,600	9,198,400	2,078,400	12,700	1,000
1992	4,225,400	10,829,900	1,687,700	6,500	900
1997	11,171,200	10,693,700	2,927,200	28,300	2,700
1998	22,773,600	14,938,400	2,680,900	26,700	1,500
1999	9,780,700	13,164,100	1,842,800	17,500	3,100
2000	22,547,800	16,170,200	3,086,600	32,000	2,300
2001	57,689,400	16,334,300	1,882,400	10,300	800
2002	31,791,600	19,011,700	3,010,500	26,200	2,100
2003	25,798,200	12,453,900	2,379,500	11,300	100

Table 5.1b. Average firescar distribution (%) 1990 to 2003 in Northern Territory and Western Australian savanna 1990 to 2003 stratified by forest type. Standard deviations are enclosed in brackets.

	Grassland	Open woodland	Open forest	Closed forest	Plantation
Top	29 (9)	60 (6)	11 (3)	0 (0)	0 (0)
Centre	99 (1)	1 (1)	0 (0)	0 (0)	0 (0)
Total	47 (17)	44 (14)	8 (3)	0 (0)	0 (0)

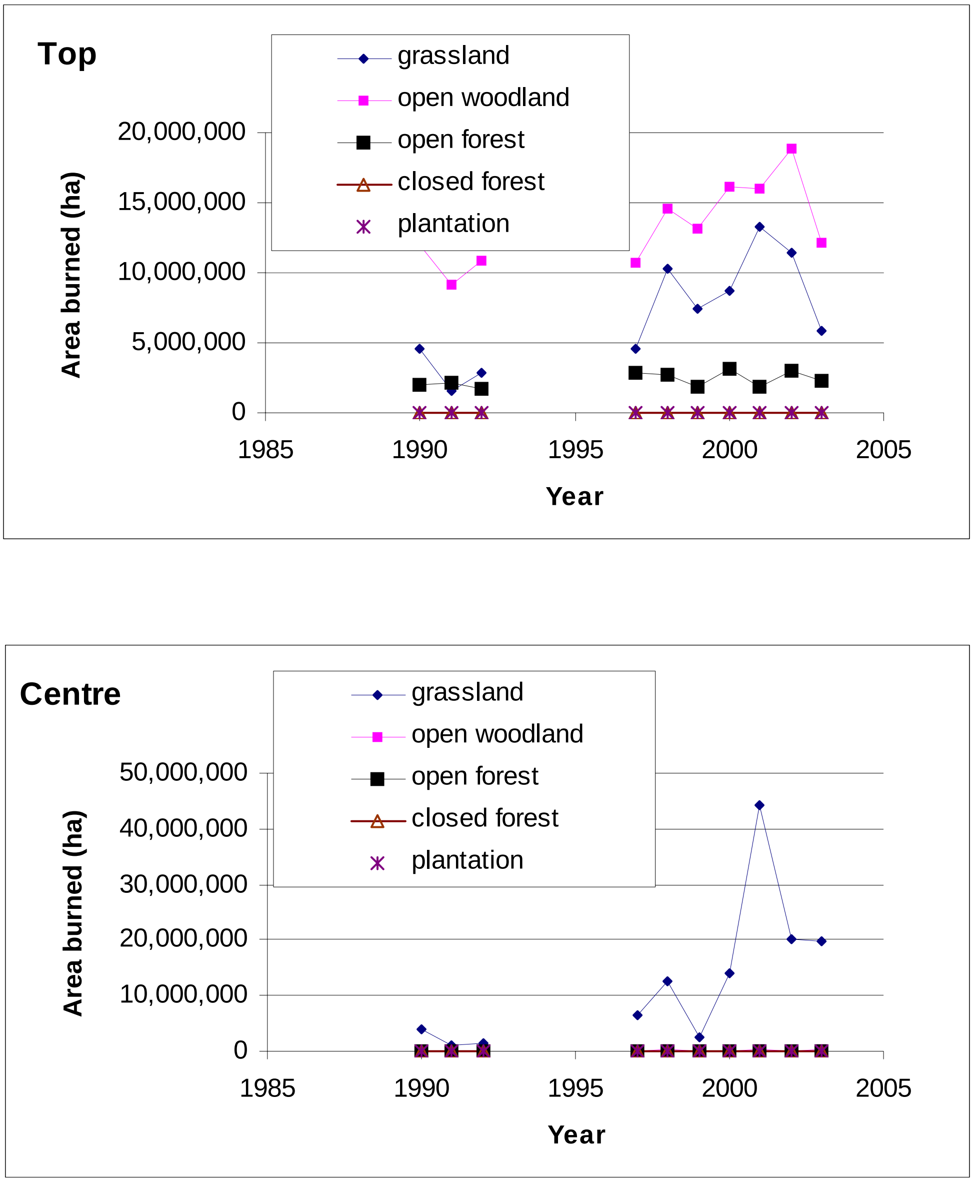


Figure 5.2 Timecourse of firescar areas in NT and WA 1990 to 2003 by forest type.

The categories of the land tenure layer were aggregated into five classes from the 16 categories in the landuse theme, namely:

1.	Freehold/leasehold,	(classes 6,7 and 22 of the attribute “topo_features”);
2.	Indigenous lands	(classes 8,9,18,19 and 21);
3.	Crown land,	(classes 10 and 14);
4.	Conservation	(national parks, military areas, mining tenements etc i.e. classes 4,11,12,13 and 25); and
5.	Forestry	class 1).

The mask is shown in Figure 5.3.

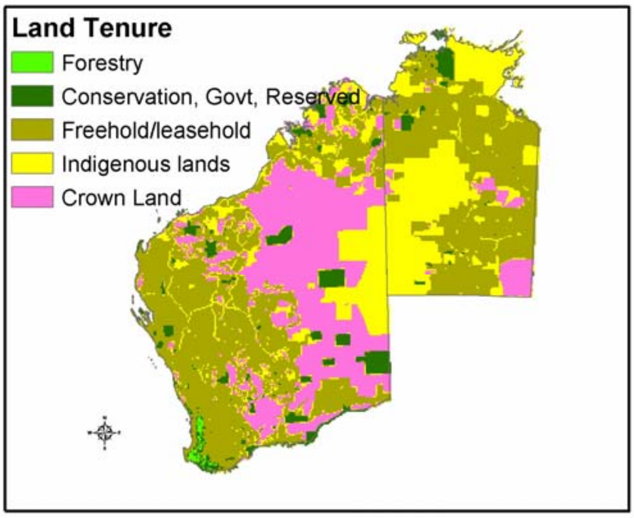


Figure 5.3 Land tenure classification for NT and WA.

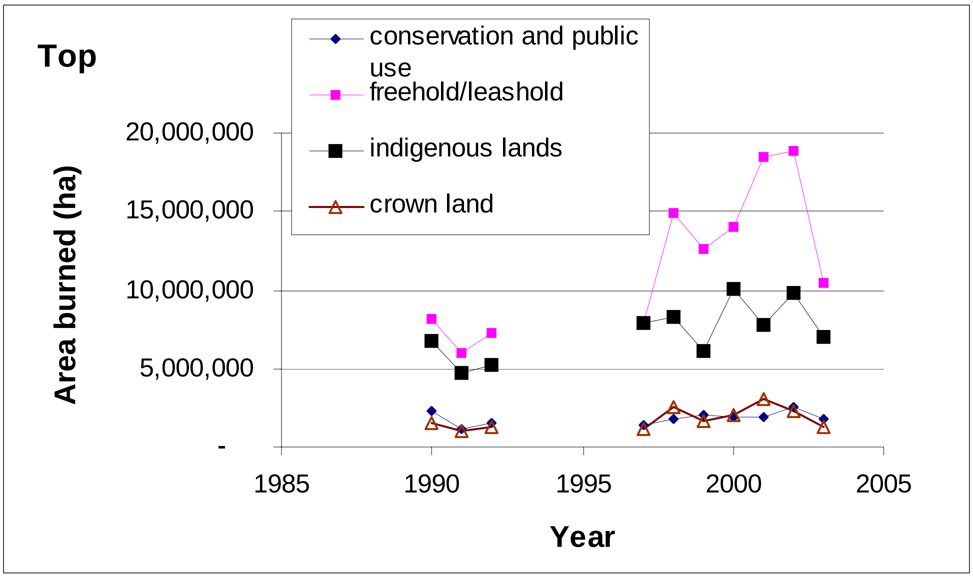
On average, approximately 50% of fire activity occurred on freehold and leasehold tenures in the Top End, one third in indigenous lands and 8% in crown land and conservation and other reserves. In central Australia, fires were evenly divided between crown land, indigenous lands and freehold/leasehold tenures (Table 5.2b). In the Top End there was a 3-fold increase in fire area on freehold/leasehold and crown land and a 2- fold increase indigenous lands between 1991 and 2001. In central Australia the variability was substantially greater (Figure 5.4): with fire areas increasing on freehold/leasehold, indigenous lands and crown land from the minimum in 1991-1993 to the maximum in 2001 by factors of 30, 43 and 68 respectively. Clearly, none of these tenure classes was free from either fire or fire variability.

Table 5.2a. Firescar areas (ha) in Northern Territory and Western Australian savanna, 1990 to 2003, stratified by land tenure.

Year	Forestry	Conservation, military and other reserves	Freehold and leasehold	Indigenous lands	Crown land
1990	1,800	2,305,800	9,026,500	7,667,900	3,432,700
1991	-	1,247,500	6,263,600	5,095,800	1,314,000
1992	100	1,546,200	7,771,600	5,623,500	1,819,100
1997	600	2,119,100	8,652,400	8,301,400	5,818,000
1998	1,600	2,578,000	18,661,600	9,511,300	9,691,500
1999	-	2,126,300	13,376,200	7,199,200	2,159,500
2000	1,700	2,493,700	16,092,000	13,435,500	9,848,800
2001	9,600	3,678,500	28,092,100	24,858,600	19,331,700
2002	500	2,949,900	26,798,800	16,694,500	7,424,400
2003	2,300	2,202,100	16,399,000	17,412,300	4,628,200

Table 5.2b. Average firescar distribution (%) 1990 to 2003 in Northern Territory and Western Australian savanna 1990 to 2003 stratified by land tenure. Standard deviations are enclosed in brackets.

	Forestry	Conservation, military and other reserves	Freehold and leasehold	Indigenous lands	Crown land
Top	0 (0)	8 (2)	51 (5)	33 (5)	8 (1)
Centre	0 (0)	5 (3)	28 (10)	30 (13)	38 (20)
Total	0 (0)	7 (2)	43 (6)	33 (5)	17 (6)



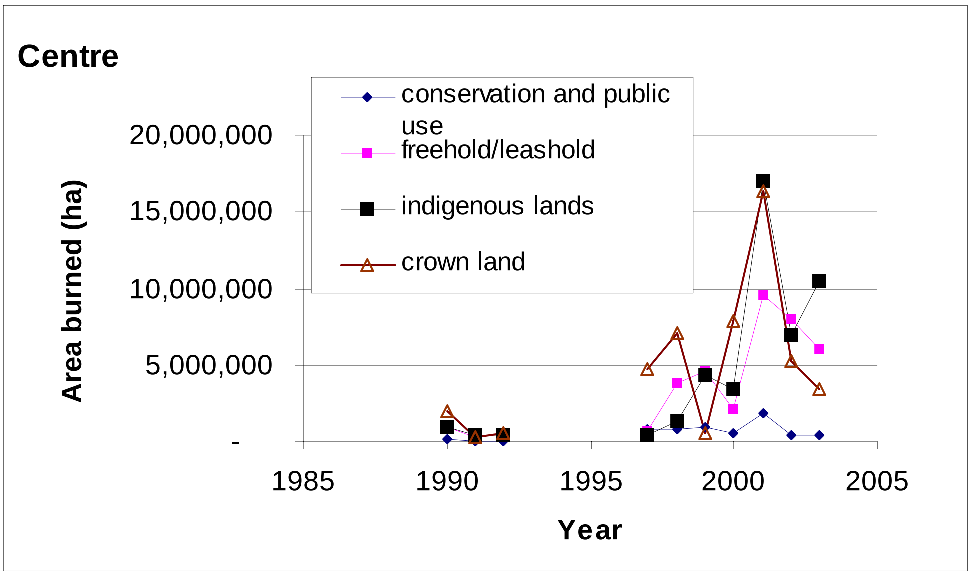


Figure 5.4 Timecourse of firescar areas in NT and WA 1990 to 2003 by land tenure.

The land use mask (Figure 5.5) has many similar features to the land tenure mask. There are six categories:

1.	Conservation	land used primarily for conservation purposes, based on the maintenance of the essentially natural ecosystems present.
2.	Rangeland production	land used primarily for primary production based on limited change to the native vegetation.
3.	Dryland production	land used mainly for primary production, based on dryland farming systems.
4.	Irrigated production	land used mostly for primary production, based on irrigated farming.
5.	Intensive uses	land subject to extensive modification, generally in association with closer residential settlement, commercial or industrial uses.
6.	Mangroves/water	water features. Water is regarded as an essential aspect of the classification, but it is primarily a cover type.

The indigenous lands and the crown lands are largely classified as predominantly natural, although some of the indigenous lands support active pastoral businesses and conversely some freehold/leasehold areas are classed as relatively natural.

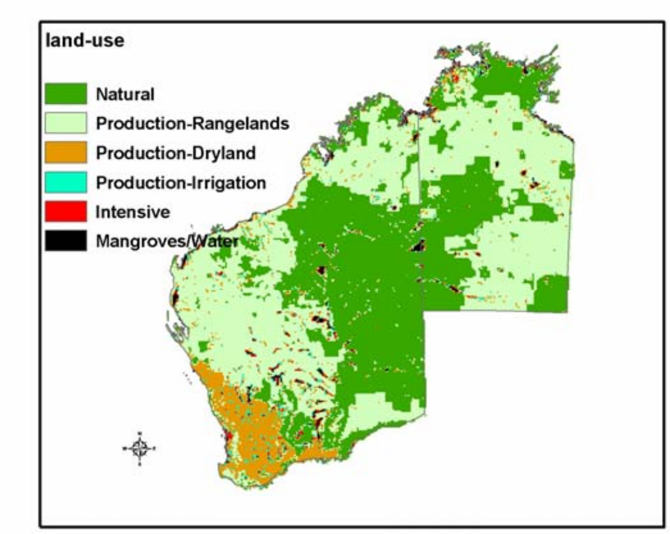


Figure 5.5 Land use in NT and WA (1993).

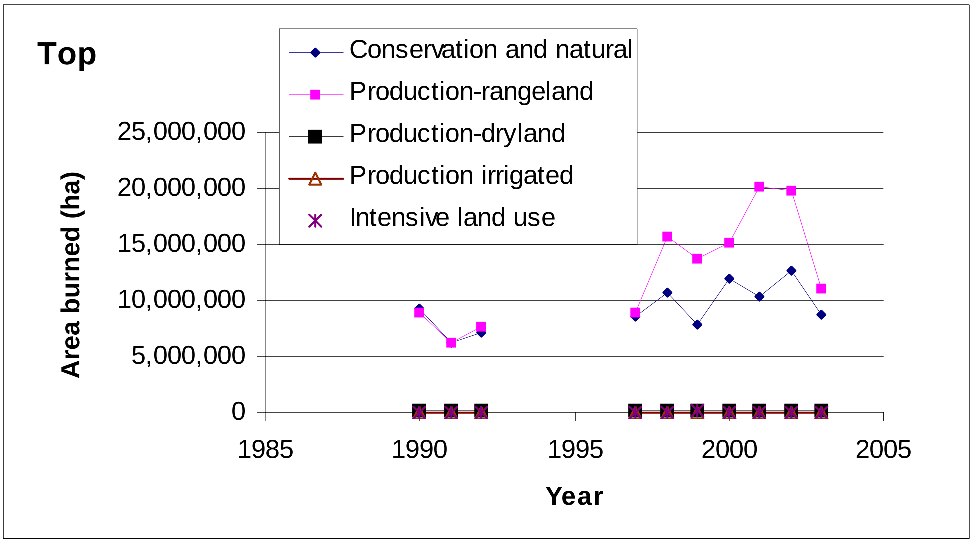
Fire activity is slightly higher in the rangelands (55%) than in the relatively natural area (42%), while in central Australia the pattern is reversed with approximately 70% of the fires in relatively natural regions (Table 5.3b). The trends in fire activity with land use class are almost identical to those in the land tenure classification (Table 5.3a, Figure 5.6).

Table 5.3a. Firescar areas (ha) in Northern Territory and Western Australian savanna, 1990 to 2003, stratified by land use.

Year	Relatively natural lands	Production-rangeland	Production-dryland	Production-irrigated	Intensive land use	Wetlands
1990	11,956,800	9,982,600	96,100	5,300	46,200	363,200
1991	6,885,500	6,572,600	100,700	1,500	67,900	313,800
1992	8,086,500	8,223,600	100,800	1,100	56,800	302,300
1997	14,316,700	9,705,600	95,000	2,600	54,700	721,500
1998	19,135,900	20,081,200	132,700	6,700	81,900	1,024,500
1999	9,333,100	14,605,300	146,400	400	99,200	685,800
2000	22,972,100	17,804,900	144,800	5,900	74,100	886,500
2001	44,140,500	30,797,000	142,200	2,600	81,000	810,700
2002	24,482,900	28,289,000	157,500	2,000	81,200	878,800
2003	22,487,300	17,423,800	106,300	2,200	68,600	571,600

Table 5.3b. Average firescar distribution (%) 1990 to 2003 in Northern Territory and Western Australian savanna 1990 to 2003 stratified by land use. Standard deviations are enclosed in brackets.

	Relatively natural lands	Production-rangeland	Production-dryland	Production-irrigated	Intensive land use	Wetlands
Top	42 (5)	55 (6)	1 (0)	0 (0)	0 (0)	2 (1)
Centre	69 (9)	30 (8)	0 (0)	0 (0)	0 (0)	1 (1)
Total	51 (6)	47 (6)	0 (0)	0 (0)	0 (0)	2 (1)



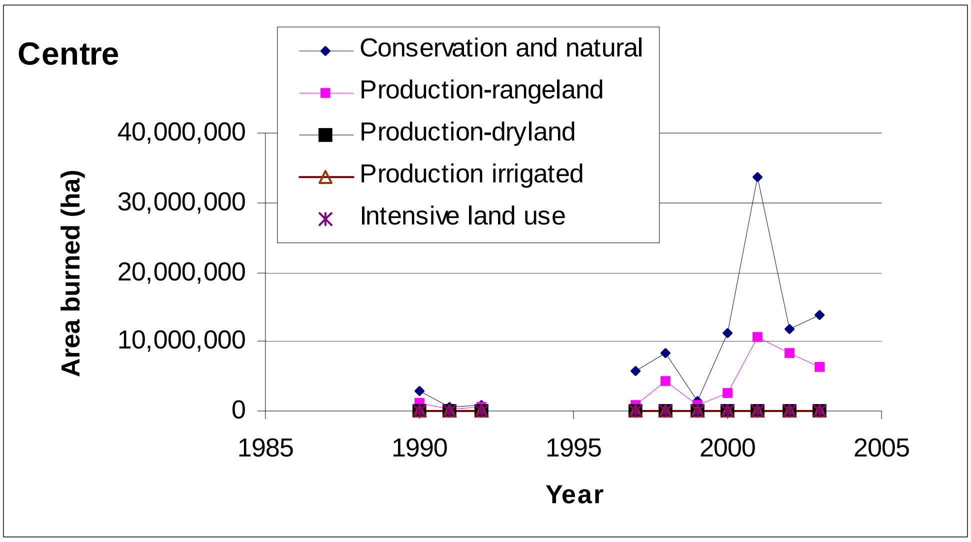


Figure 5.6 Timecourse of firescar areas in NT and WA 1990 to 2003 by land use.

5.2 Discussion

One purpose for exploring the fire distribution by a land classification was to determine whether the fires were confined predominantly to particular classes, and therefore whether the definition of savanna currently used in the inventory should be reassessed to account specifically for land use. Clearly, fires are distributed across all tenure and land use classes, and the trends in fire area through the 1990s are broadly similar in all classes. Whether all land use classes should be included in sector 4E, however is still open to debate. The question of what classes of land use and fires should be considered to be anthropogenic has never been fully resolved. Given the ambiguities and limited data availability both the NGGIC and the IPCC continue to take the pragmatic approach of including all sources.

In the current study the advice of two expert groups, the Bushfire Council of the NT and WA Department of Agriculture was sought. The Bushfire Council presented a strong consensus that, at a minimum, both traditional aboriginal and pastoral land use should be defined as anthropogenic. While many traditional aboriginal land management actives do not directly lead to commercial agricultural products, the activities are clearly sustainable subsistence agriculture underpinning and providing the raw materials for other commercial activities.

5.2.1 Aboriginal land management

The following consensus was prepared by Peter Whitehead (Tropical Savanna CRC).

> Use of fire by Aboriginal people serves many purposes, including meeting ceremonial and other non-utilitarian obligations (Yibarbuk 1998). But for the contemporary Aboriginal societies active in many parts of northern Australia, burning is also a critical feature of their customary economies. The customary (subsistence) economy remains large and in some areas comprises about 30-50% of total cash and non-cash incomes (Altman 1987; Altman 2003).
>
> Fire is used to maintain populations of the wildlife species that are most important in the customary economy, by promoting or protecting the habitat features that favour their abundance, as well as facilitating wildlife capture or foraging for plants (Yibarbuk et al. 2001; Whitehead et al. 2003). The customary economy is fundamentally dependent on continued, purposeful, regular use of fire.
>
> Aspects of the market economy in remote areas also depend on skilled use of fire. For example, the arts market is one of the few areas where Aboriginal people maintaining customary lifestyles have interacted successfully with the mainstream Australian and global economy. Arts production in the Northern Territory exceeds $30 million pa and in remote areas arguably provides private employment for more Aboriginal people than any other single activity. Plant populations providing the raw materials used in this production, such as trees for carvings and plants for dyes, are maintained by use of fire to protect rainforest patches.
>
> Under these circumstances, use of fire is undeniably a critical contributor to sustained economic activity on Aboriginal lands, and often outside them where various levels of customary activities are maintained. Whilst such production has not appear to have been routinely recognised as “agricultural”, fire use is no less significant economically in such landscapes than in sugar-growing regions or pastoral lands where burning is employed to maintain favourable grass to tree ratios.

5.2.2 Fires in pastoral lands management

The WA Department of Agriculture experts saw the issue to some degree in terms of fire categories analogous to the fire management classes for temperate forests; prescribed fires for management purposes and wildfire from arson, accident or natural causes primarily lightning strikes. The following consensus view was prepared by Paul Novelly.

> Fires in Western Australia's savannas can be divided into four groups:
>
> 1. Prescribed burning for fire control.
>
> Annually, in association with Western Australia's Fire & Emergency Services Authority, many landholders (both industry and government) institute a program of prescribed aerial burning. The major purpose of this burning is the creation of broad firebreaks designed to limit the spread of the other types of fire listed below. These activities are generally conducted within a few weeks of the "end" of the wet season (April / May) as soon as fuels are sufficiently cured. Aerial burns are plotted using GPS and the areas burnt can be estimated, with some limitations, from fire scar mapping. While prescriptions are designed to achieve extinguishment overnight, the actual extent of fires is not subject to close control. Land managers carry out some ground-based burning, particularly along roads and tracks, for the same purpose. These fires are less well documented.
>
> 2. Prescribed burning for pastoral management.
>
> Pastoralists (graziers) and their "agents" (contract musterers and others) light fires for either land management or animal management purposes. This latter relates to the desire to produce areas of "green pick" of better value for cattle, or to aid in cattle mustering by attracting cattle to limited areas of more attractive feed, enabling a more efficient and economical operation. These fires are generally lit early in the dry season (for "green pick" purposes while there is still some moisture in the ground) or during the mid dry season more for cattle mustering purposes. By the second half of the year management fires are relatively limited through fears that that fires will become uncontrollable. However, some burning is carried out after the early storms that precede the arrival of the wet season, to remove rank pastures or rejuvenate spinifex country. Careful planning is needed to limit the extent of all prescribed fires, although the skill of landholders varies in this respect.
>
> 3. Deliberate burning, in some cases for traditional purposes unrelated to "agriculture", or accidental fires related to visitor activity in the region.
>
> Significant areas of pastoral leasehold land are burnt annually by persons not associated with the lease or the pastoral enterprise, and often in direct contravention of the leaseholder's wishes. Most of these fires are deliberate others accidental. However, despite mostly occurring on leasehold land, in no way can these fires be ascribed to an "agricultural" (in the broadest sense) purpose, and they are often very detrimental to pastoral operations and pastoral infrastructure. These fires are liable to occur at any time during the dry season. They may burn over extensive areas until restricted by natural barriers (watercourses), broad firebreaks developed by early dry season prescribed burning, or by active fire suppression efforts involving back-burning from graded tracks or temporary lines prepared by the lessee. Active fire suppression is not feasible in the rugged terrain found within many pastoral leases.
>
> 4. Lightning induced fires.

> These fires occur as a result of lightning strike in the late dry season and the build up to the wet season (generally post mid October). As for deliberate fires, there is no limit to their extent unless they encounter natural barriers, prepared firebreaks, low-fuel areas resulting from previous burns earlier in the season or active fire suppression efforts.

However it was concluded that classifying fires by ignition source was not currently practical due to the almost complete absence of statistics. Both the IPCC and NGGIC came to similar conclusions.

The inventory sector 5, Land use, land use change and forestry (LULUCF) accounts emissions from wildfires and prescribed fires in forests. These classes are mutually exclusive to sector 4E and to each other. The classification is explicitly based on ignition class. Prescribed fires are fires ignited by forest and land management authorities for specific land management purposes such as fuel reduction, logging waste removal and seed bed regeneration. Wildfires are fires started by all other ignition sources including arson and lightning. However in the Savanna lands, the distinction between wildfires and prescribed fires is more problematic. In the savanna areas, while fire is used as a land management tool, frequently it is not carried out by prescription by a land management authority. This has led to a view, that has strong currency amongst fire ecologists that the identity of the ignition source is mostly irrelevant because in northern and central Australia the high fire risk and high probability of an ignition source, anthropogenic or natural, always eventually lead to a fire. This view is summarised by the statement,

> *"All land is managed land. You can choose to light the fire with a match or with lightning. It is the land manager's choice. " Garry Cook, CSIRO Sustainable Ecosystems.*

At this stage, therefore, there in no obvious justification for dividing the current savanna regions included in sector 4E into agricultural, and non agricultural regions or firescars into prescribed and non-prescribed fires. The general conclusion is that the trend in fire areas between 1990 and 2001 observed at the aggregated level of the NGGI, and at regional scales occurs in all major land use and vegetation classes. There does not seem to be any landuse category with extensive fire activity is that is unquestionably incompatible with current IPCC definitions of savanna fires.

6 Trends and drivers

Savanna woodland and grassland fires occur predominantly in Africa, South America, India and Australia. A recent analysis of global fire scars using remote sensing (Tansey et al, 2004) reported that in 2000 Africa contributed 64% of all fires compared to Australia (16%), Asia (14%), South America (3%), North America (2%), and Europe (1%). Australia is the only Annex 1 Party with substantial emissions from savanna fires, and the only Annex 1 Party for which savanna fires is a key source. Sector 4E, Emissions for burning of savannas, also has some unusual characteristics in comparison to other sectors of the inventory.

As a general rule, all inventory algorithms suggest that the main anthropogenic changes appear in the activity. In most cases, other parameters and emission factors are held to be constants or slowly changing and consequently are minor sources of year-to-year variability. In the energy, transport, industrial processes and waste sectors, changes in activity are unequivocally anthropogenic. In the agricultural and land use sectors, natural sources of variability, predominantly climatic, are important but are rarely the cause of major changes in activity that outweigh the anthropogenic ones. Where non-anthropogenic seasonal variation is an issue in agriculture, the IPCC allows (although it doesn't recommend) averaging over a 3-yr interval centred on the inventory year. In the land use change sector, most of the carbon fluxes affected by non-anthropogenic drivers are calculated from changes in relatively long-lived pools (e.g. soil carbon), where extensive averaging is required in the measurements of the stocks to remove the extremely high sample variability. Given either clarity in the anthropogenic nature of the activity or the smoothing of activity estimates either directly by aggregation or averaging or indirectly by the methods used to measure stocks it is possible to compare emissions between any two inventory years and be reasonably confident that the difference can be interpreted in terms of anthropogenic activity.

This is clearly not the case for vegetation burning and particularly for savanna fires. As discussed above, it is clear that climate variability produces variation in emissions that are substantially greater than any other sector. In Australia's case, year-to-year variation of a factor of 5 at national level or by factors of 100 or more at regional scale makes comparison of pairs of years impossible. The signal simply disappears within the noise of the timeseries. The simplest way to remove random noise is by averaging over a suitably long period.

Savanna fires in Australia are also somewhat anomalous within the definitions of IPCC methodology. The IPCC definition (see Section 3) refers principally to fires in the moist tropics, arguing that desert regions are too dry to produce fuel loads sufficient to sustain a fire. The savanna woodlands, which are mostly subject to regular seasonal patterns and annual productivity sufficient to support near annual fires, fit the IPCC definition. However, fires in the arid grasslands are also major emission sources in Australia, match the IPCC definitions of savanna apart from seasonality of rainfall but are subject to extreme variability with a long cycle length. The 1996 Revised IPCC Guidelines has no methodology explicitly for this class of emission sources.

Currently therefore Australia appears to be left with a conundrum. The inventory baseline year of 1990 is demonstrably at the lowest point of a long-term cycle and therefore comparison of any subsequent season with 1990 will have more information about the rainfall pattern than information on the impacts of land management practice. In order to avoid this, the current practice of smoothing the timeseries using a moving average with a window comparable to cycle length of the regional climate should be retained. The fire return interval is a good starting point. This would lead to a 3-4 year window for the Top End, a practice that is consistent with current IPCC guidelines, and a 10-year average at a minimum for central Australia. The latter is currently outside IPCC practice, however it is also clear, that current guidelines do not cover anthropogenic fires in arid grasslands. This could form the basis for a special case.

A second issue arises because the current trend, uncertainty and magnitude of emissions from savanna burning characterise it as a key source. This normally required the Party to review the key source with a view to using or developing a higher tier methodology to characterise the source in greater detail and ideally with lower uncertainty. The current guidelines are currently under review for the 2006 IPCC Inventory Guidelines.

7 Review of data availability on fuel loads, C:N ratios and burning efficiency

The two inventory emissions algorithms (equations 3.1, 3.2) require respectively four or five parameters apart from the activity (Ajk). The usual convention in inventory methodologies is to consider parameters to be either constant or slowly varying in time. In sector 4E, most of these parameters were poorly determined primarily because of the huge area of savanna woodland and arid grasslands in Northern Australia and the limited pool of staff and funding required for the very labour intensive field sampling required to measure them. Consequently they contribute a large proportion of the uncertainty in the emission estimate. Of the five parameters in equations 3.1 and 3.2, only the fuel carbon content (Cj) is considered to be reasonably well defined.

The three parameters of most concern are the fuel load (Mj), the burning efficiency (ξj) and the carbon to nitrogen ratio (NCj). The current values for these parameters were derived from a very limited body of published data available when Workbook 5.0 was prepared (NGGIC, 1994), modified in subsequent years with advice from regional and state experts. Most data were sourced from the Kapalga experiments in Kakadu National Park, supplemented with some data of fuel loads in Spinifex communities in central Australia.

Since the development of the NGGI methodology in 1994 there have been some significant developments which could improve the current estimates in the short term, and together with more fundamental research, potentially improve the methodology in the future. These are the development of rangeland pasture production models and the pilot programs addressing ecosystem production and litter turnover in savanna woodlands. The two projects providing data of direct relevance for savanna fuels loads are:

1. the development of pasture production using the rangeland management model, Aussie GRASS (Dyer et al 2001; Carter et al, 2002); and
2. the recent study of fuel loads, N:C ratios and burning efficiency (Russell-Smith et al., 2004).

The pasture production models predict pasture biomass and litter in the presence of animal grazing. They do not usually determine the non-grass components of fuels, produced by trees and woody shrubs, i.e. non-grass fine fuels, coarse woody fuel, heavy fuels and combustible shrubs. The latter components can comprise either a significant fraction or the major fraction of fuels in particularly in woodland and forest. A further limitation of current rangeland pasture models is that, mostly, fire is not included in the model and, therefore, litter accumulation rates may be overestimated. In open grassland, however, the pasture biomass is a reasonable indicator of potential fuel loads.

7.1 Fuel loads in the pastoral regions of NT and WA

Development, testing and calibration of rangeland pasture models require comprehensive measurements of pasture production at representative sample sites and widespread spatial sampling of some parameters across the model domain. These data are useful for fire emissions studies. The Aussie GRASS projects followed this pattern and developed a coordinated and wide ranging activity covering Qld, NT and northern WA to measure pasture production in the major pastoral ecosystems in order to test and calibrate the model. This project involved state agricultural authorities in all three states.

The Aussie GRASS model (Carter et al. 2000) is a spatial model with 0.05° resolution which uses the GRASP pasture production model to predict pasture growth and accumulation. This production model is mostly based on empirical descriptions of key processes calibrated against direct measurements at strategically selected reference sites, supplemented by an extensive series of visual estimates of total standing dry matter (TSDM) made from vehicles which in turn were calibrated against daily spot measurements of pasture biomass; the “spider mapping” project. The model was calibrated for WA and NT rangelands by Dyer et al, 2001. The measurements of TSDM and fine grass litter at the reference sites are directly relevant to the current inventory methodology.

7.1.1 Reference sites

With the cooperation of leaseholders, the Department of Agriculture, WA (Andrew Craig, pers. comm.) established a number of 0.13 ha plots for studying the effects of fire on the Kimberley rangelands, beginning in 1993. The layout followed the standard WARMS layout for grasslands. In most cases these studies have involved documenting vegetation characteristics through a series of landscape fires, and were not controlled experiments.

Estimates of total standing dry matter and litter in these plots were made on an annual basis, usually during April-August. As part of the standard sampling protocol, 15 samples of ground storey vegetation were clipped as closely as possible to ground level within a 70 x 70cm square quadrat. Any woody resprouts arising from ground level, and less than 2m tall, were included. On some occasions, unincorporated litter within the quadrats was also (separately) collected. On cracking clay soils carrying open grasslands, it was generally considered impractical to collect reliably the low levels of surface litter that were present. Data have been collected from 60 plots distributed over 20 properties, mainly pastoral stations. Site locations and their sampling history are listed in Table 7.1.

Table 7.1. Location of study plots and period of data collection.

Property	IBRA Bioregion	No of Plots	Data Period
Beverley Springs	Northern Kimberley	2	1994-96
Doongan	Northern Kimberley	2	1994-2000
Drysdale River	Northern Kimberley	3	1994-2000
Gibb River	Northern Kimberley	1	1996-2002
Home Valley	Northern Kimberley	2	1994-2001
Kalumburu	Northern Kimberley	3	1994-2000
Theda	Northern Kimberley	1	1995-2000
Carlton Hill	Victoria Bonaparte	2	1994-2004
Ivanhoe	Victoria Bonaparte	3	1994-2004
Ellenbrae	Central Kimberley	3	1996
Moola Bulla	Central Kimberley	1	1996-2004
Napier Downs	Central Kimberley	4	1994-97
Springvale	Central Kimberley	5	1995
Flora Valley	Ord-Victoria Plains	8	1995-2003
Ord Regen. Reserve	Ord-Victoria Plains	6	1996
Texas Downs	Ord Victoria Plains	2	1994-2000
Spring Creek	Ord Victoria Plains	2	1994-96
Dampier Downs	Dampierland	6	1994-2000
Kilto	Dampierland	2	1996-2000
Shamrock	Dampierland	4	1996-99

The data on total standing dry matter are summarised by pasture type in Table 7.2. Average TSDM values for each pasture type were within the range 2 to 4 t ha^{-1}, although the range in individual quadrats was larger (0.2 to 13 t ha^{-1}. The lower values were for two pasture types with very low plot numbers - Curly Spinifex Annual Sorghum Hill (1) and Buffel Grass (2).

Table 7.2. Summary of total standing dry matter estimates (t ha^{-1}) by pasture type (n = total no. of estimates, p = no. of plots).

Pasture type	TSDM (av)	Max	Min	n	p
ASGP[1]	2.29	3.66	1.26	6	1
BSGP[2]	2.11	2.62	0.98	5	1
BUGP[3]	1.60	2.21	1.00	2	2
CAHP[4]	0.84	1.35	0.48	3	1
FRGP[5]	2.41	3.57	1.55	5	2
HSHP[6]	3.76	11.42	0.22	6	1
LCSP[7]	2.29	4.06	0.66	15	5
MGAP[8]	2.38	7.08	0.12	86	14
OTHP[9]	3.14	5.57	0.55	13	4
PINP[10]	2.13	4.32	0.72	22	6
PLSP[11]	2.27	5.19	0.83	27	7
RAPP[12]	4.09	5.72	1.56	11	1
SSPP[13]	3.91	13.06	0.17	28	8
TTGP[14]	3.21	6.09	0.26	14	2
WGBP[15]	3.12	3.92	1.86	5	5
Mean	2.6	5.3	0.8		

[1]Arid Short Grass, [2]Black Speargrass, [3]Buffel Grass, [4]Curly Spinifex Annual Sorghum Hill, [5]Fringing, [6]Hard Spinifex Hill, [7]Lowland Curly Spinifex Annual Sorghum,
[8]Mitchell Grass Alluvial Plain, [9]OTHP = Other, [10]Pindan, [11]Plume Sorghum, [12]Ribbon Grass Alluvial Plain, [13]Soft Spinifex, [14]Tippera Tall Grass, [15]White Grass Bundle-Bundle.

For those plots where litter samples were available, fuel loads were calculated for each pasture type as the sum of total standing dry matter and litter (Table 7.3). Average fuel load values fell mainly within the range 2-5.5 t ha^{-1} although it should be noted that plot and quadrat numbers were quite small.

Table 7.3. Summary of total standing and litter dry matter estimates (t ha^{-1}) by pasture type (n = total no. of estimates, p = no. of plots).

Pasture type	TSDM +LDM (av)	Max	Min	n	p
ASGP[1]	2.73	3.53	1.94	2	1
BSGP[2]	2.97	3.77	1.71	5	1
CAHP[3]	2.50	3.39	1.35	3	1
FRGP[4]	5.12	8.03	2.49	5	2
LCSP[5]	2.34	3.91	0.87	7	2
MGAP[6]	5.11	7.94	2.28	2	2
OTHP[7]	1.29	1.38	1.20	2	1
PINP[8]	3.53	4.93	1.98	12	6
PLSP[9]	3.53	6.13	1.34	17	6
SSPP[10]	5.49	9.29	2.08	8	5
TTGP[11]	2.03	2.96	0.57	4	2
WGBP[12]	4.71	6.14	3.13	5	5
Mean	3.4	5.1	1.7		

[1]Arid Short Grass, [2]Black Speargrass, [3]Curly Spinifex Annual Sorghum Hill, [4]Fringing,, [5]Lowland Curly Spinifex Annual Sorghum,[6]Mitchell Grass Alluvial Plain, [7]OTHP = Other, [8]Pindan, [9]Plume Sorghum,[10]Soft Spinifex, [11]Tippera Tall Grass, [12]White Grass Bundle-Bundle.

7.1.2 Aussie GRASS data

Collected of TDSM data for model calibration and validation of the Aussie GRASS Project was carried out in 1998-99 by staff of the NT Department of Primary Industries and Fisheries and the Department of Agriculture, Western Australia (Dyer, Cafe and Craig, 2001). Data collection ('spider-mapping') involved continuous vehicle-based estimation of standing pasture biomass while driving along roads and tracks. Each day, operators clipped and weighed pasture samples at >5 calibration sites and regression relationships were developed between estimated and actual biomass values. These were used to adjust each day's visual estimates. Pasture type, grazing pressure and recent fire were also recorded as ancillary information. The most comprehensive and useful data set was collected in June-July 1999, during which some 10,635 visual estimates were made. Grazing was rated as slight or nil for the majority of observations.

A summary of total standing dry matter (TSDM) by bioregion is provided in Table 7.4. Estimates of litter was not included in these data. Values overall appear to be somewhat lower than for the fire ecology study sites.

Table 7.4. Average total standing pasture biomass (t ha^{-1}), based on Table 10 of Dyer, Cafe and Craig (2001); n = no of observations, se = standard error of mean.

IBRA Bioregion	TSDM (av) (t ha^{-1})	N
Central Kimberley	2.3	812
Dampierland	2.0	5330
Ord Victoria Plains	2.2	3536
Tanami	0.9	170
Victoria Bonaparte	1.6	787
Mean	1.8	

A similar study to Dyer et al., (2001), conducted in Queensland. TDSM was estimated by "spider mapping" along representative transects. Litter loads corresponding to these observations were estimated using Aussie GRASS. The summarised in an internal report by Carter and Henry (2003) are reproduced in Table 7.5. Average TDSM for Queensland was estimated at 2.8 t ha^{-1} and total pasture biomass and litter at 3.2 t ha^{-1} (Table 7.5).

Table 7.5. Average total standing pasture biomass (t ha^{-1}) from "spider mapping" in Queensland. From Carter and Henry (2003).

Study Name	Date	Observations	TSDM (t ha-1)	TSDM+ litter
All Queensland	Jan 1994- June 1995	367	2.2	2.7
Victoria River Downs	Oct-98	272	3.3	4.0
Monkira	Apr-99	50	2.9	3.5
South	May-99	278	2.4	3.0
North	Jun-99	1033	2.6	3.1
North Queensland	Jul-99	552	2.3	2.9
SW Queensland	Aug-99	60	3.4	4.1
Central Queensland	Sep-99	2569	2.6	3.2
Cape York	Oct-99	1671	2.8	3.5
North West	Jul-01	234	3.7	4.5
Silo	Oct-01	1209	3.1	3.8
Mean			2.8	3.2

In summary, the field measurements at the reference sites Aussie GRASS project suggest that the while the fuel load currently used in the NGGI methodology for Queensland (3 t ha^{-1}) is appropriate, the values for NT (5.8 t ha^{-1}) and WA (7.7 t ha^{-1}) are probably significantly higher than the actual fuel loads in the pastoral area. The reference site data for Kimberly suggests an average fuel load of 3 to 4t ha^{-1} would be more appropriate.

7.2 Fuel loads in the savanna woodlands.

Russell-Smith et al. (2004) have recently completed a pilot study of fuel loads, burning efficiencies and N content in the savanna woodlands of Central Arnhem Land. This study assessed all fuel classes including the heavy fuels, not just the fine fuels (fuel < 6mm thick) in all the major vegetation communities in this region of NT. It also addressed the impact of fire return interval on fuel accumulation. A summary of the data weighted by fire frequency is presented in Table 7.6. This study adds substantially to the body of ecological data for the savanna woodlands and is particularly useful for large scale inventory methodologies such as NGGI. However, as the authors recognize, it provides guidance, rather than the unequivocal data required for emissions accounting resolved at fine spatial scale and seasonal timescales. It is reviewed here solely in terms of its contribution to large-scale inventory accounting.

The mean fuel load in each fuel class was calculated by weighting by the percentage area in each vegetation type. The fine fuel load was comparable to the estimates derived from the Kapalga study and used originally in the NGGI methodology (5 and 4.1 t ha^{-1}, Table 3.1), but lower than the value of 5.8 t ha^{-1}currently used in the NGGI methodology. The heavier fuel fractions substantially increase the total fuel load to 12.7 t ha^{-1}.

Table 7.6. Fuel loads from Central Arnhem Land Study (Russell-Smith et al. 2004). Fuel loads for each fuel age class were weighted by fire frequency.

Forest type	%total area	*Fuel load (t ha^{-1})*			
		Fine fuel	Coarse fuel	Heavy fuel	Shrub
Eucalypt open forest	6%	5.9	1.3	18.9	0.6
Eucalypt open woodland	52%	3.9	1.1	4.0	0.9
Sandstone woodland	20%	6.0	1.0	12.9	0.6
Sandstone heath	23%	4.0	0.4	4.0	0.7
Weighted mean		**4.4**	**0.9**	**6.6**	**0.8**

7.3 Burning efficiency.

The burning efficiency is the product of two parameters, the pyrolysis efficiency, (defined here as the fraction of fuel exposed to flame that is volatilized) and the fraction of fire scar area that is burned i.e. the fire patchiness. The pyrolysis efficiency is routinely measured bushfire studies, particularly in SE and SW Western Australian forests, mostly for fuel reduction burns, and occasionally in fire studies in Savanna regions. Fire patchiness is less commonly estimated.

The NGGI estimate for burning efficiency, 0.72 was provided by Tolhurst (1994) using the limited data available the time. The figure is the product of the average combustion efficiency measured in *Themeda* grassland in Victoria (0.86) and

Kapalga study, NT (0.94) and the patchiness of tropical and temperate grass fires (0.8, range 0.7-0.9).

These data are consistent with the pyrolysis factors reported for African savannas and in South America. The study of O'Shea, et al. (1996) from the 1992 SAFARI Campaign in Southern Africa report pyrolysis efficiencies for fine litter, live grasses and wood debris from 8 sites in savanna grassland and woodland which average, respectively, 0.93, 0.99 and 0.4. The overall pyrolysis efficiency for all fuel was 0.85. The South American values were mostly measured in studies of biomass burning during forest clearing for agriculture by research teams in Brazil using similar methods to O'Shea at al. (1996). These are conveniently summarized by Ito and Penner (2004). The pyrolysis efficiencies average 0.93 for fine fuels and 0.27 for coarse woody fuel.

The most recent and comprehensive Australian study for savanna woodland is Russell-Smith et al. (2004) summarized in Table 7.7. This also shows that pyrolysis efficiency is very high for the fine fuels (0.92) and live shrubs (0.67) and low for the coarse and heavy fuels (0.2). Patchiness of fires in Northern Australian Woodlands varied with fire intensity varying from 0.71 for early season fires to 0.8 for mid season fires to 0.84 for late season fires. The seasonally weighted patchiness is 0.83. These two terms are combined in the combustion efficiency. The seasonally weighted combustion efficiency for fine fuel, in the recent study is 0.76, a 5% increase from the NGGI estimate. The new study however, shows that the heavier fuels also contribute significantly to emissions, at least in the savanna woodlands adding a further 50% (2 t ha^{-1} (Table 7.7) to the fine fuel fraction. The overall combustion efficiency, weighted by season, for all woodland fuel components is 0.39.

Table 7.7. Pyrolysis efficiency from Central Arnhem Land Study (Russell-Smith et al. 2004). Mean efficiencies were weighted by the fraction of annual fires occurring in each season

Pyrolysis efficiency	% annual fires	Patchiness	*Pyrolysis efficiency*			
			Fine fuel	Coarse fuel	Heavy fuel	Shrub
Early fires	5%	0.71	0.70	0.03	0.05	0.45
Mid season fires	20%	0.8	0.70	0.03	0.05	0.45
Late season fires	75%	0.84	1.00	0.25	0.25	0.75
weighted mean		0.83	**0.92**	**0.19**	**0.20**	**0.67**
Seasonally weighted burning efficiency			0.76	0.16	0.17	0.55
fuel volatilised (t ha^{-1})			**4.1**	**0.2**	**1.3**	**0.5**

In summary, the pyrolysis efficiency used by Tolhurst for fine fuels is consistent with more extensive and more recent work, and the patchiness estimate of 0.8 is consistent with the recent study of Russell-Smith et.al. Therefore the burning efficiency currently used in the NGGI (0.72) is a reasonable estimate for the fine fuels (i.e. fine litter and grass) and appropriate for the pastoral areas and the grassy fuels in the savanna woodlands. However, the study by Russell-Smith et al. (2004)

shows clearly that coarse and heavy woody fuels should also be included in the emissions estimates.

7.4 Nitrogen content.

The N:C ratio currently used in the NGGI is 0.02 however it is now clear that this is certainly an overestimate (see 3.2.3), and that a value of 0.01 or 0.011 was more appropriate.

More recent and extensive work on Queensland pastures (Table 7.8, Henry and Carter, 2003) report nitrogen content of dry pasture and grass litter ranging from 0.28 to 1.18% dry weight, averaging 0.56% ± 0.1% across all reference sites. This compares with the slightly lower values reported for grass fuels in the NT of 0.42% from Kapalga (Hurst et al., 1994a) and 0.38% (Russell-Smith et al., 2004). The nitrogen content of tree leaf fuels in the NT was higher than that of the grass fuels; 0.73% from Kapalga, and 0.58% from Central Arnhem Land.

All these studies agree that a mean carbon content of fine fuel of 0.46 is appropriate, Therefore the Queensland N:C ratio for pasture grasses is 0.012± 0.002 while the NT, leaf litter N:C varies between 0.008 and 0.016 although when the coarse woody fuels are included, both Hurst et al., 1994 and Russell-Smith et al. (2004) recommend an N:C ratio of 0.01 to 0.011.

In the light of these new data, consideration should be given to reducing the N:C ratio from the current (rounded) inventory value of 0.02. It is suggested that the N:C ratio be revised to 0.011% for savanna woodlands and 0.012% for arid and savanna grasslands. Given that the error bounds on these estimates are probably at least ±20%, there is probably no significant difference between the two estimates.

Table 7.8. Fuel loads and nitrogen content of pastures in Queensland DPI study areas. From Carter and Henry (2003).

Dominant grass species	TSDM (t ha $^{-1}$)	mean N (% dry weight)	N
Bothriochloa	2.31	0.58	23
Dichanthium	2.19	0.52	5
Themeda	2.48	0.45	9
Aristida	1.99	0.63	11
Sporobolous	5.34	0.69	1
Sorghum	2.51	0.34	11
Heteropogon	2.57	0.49	23
Cenchrus	1.87	1.18	4
Triodia	6.37	0.56	14
Enneapogon	1.32	0.53	3
Dactyloctenium	1.40	0.73	1
Eragrostis	1.51	0.91	3
Whiteochloa	2.12	0.41	2
Chrystopogon fallax	2.50	0.47	2
Zygochloa	3.42	0.61	1
Plectranthe	3.02	0.28	2
Sehima	1.25	0.28	1
Eriachne	1.35	0.36	2
Mean	**2.5**	**0.56**	

7.5 Summary.

Confidence in the estimates of fuel loads, burning efficiency and nitrogen-to-carbon ratios have improved substantially since the development of the NGGI methodology in 1994. While data is still sparse, the savanna grasslands and woodlands are no longer the data void that existed in 1994. Recent studies indicate that the fuel loads for the pastoral regions of WA may have been overestimated in the current NGGI methodology and a good case can be made for reducing the fuel load from the current 7.7 t ha^{1} which is essentially a to 3-4 t ha^{-1}. The Queensland fuel load of 3 t ha^{-1} appears to be reasonable.

The fuel loads in the savanna woodlands clearly should include the coarse and heavy fuels, however this will require modification to the current algorithm. To allow for difference in burning efficiency between fuel size classes it will be necessary calculate emission rates in the savanna woodlands by fuel class.

The current estimates for burning efficiency for fine fuels used in the NGGI are consistent with international and recent Australian studies. The estimate derived from the recent Study of Russell-Smith et al., (0.76) is based on more comprehensive data than the current NGGI estimate (0.72) and consideration should be given to using it in preference in subsequent inventories. However the difference between the two is probably within the bounds of uncertainty of current knowledge.

Both the recent study of Russell-Smith et al., (2004) and the South African and Brazilian studies indicate that coarse woody fuels should also be included in emission estimates. In the Australian study, the heavier fuels account for 65% of total available fuel and 33% of total emissions. Consideration, therefore, should be given to revising the woodland fuel load from the current value of 5.8 t ha^{-1} for NT or 7.7 t ha^{-1} for WA to the seasonally-weighted value suggested by Russell-Smith et al. (2004) of 12.7 t ha^{-1}. This will require a change to the combustion efficiency from the current value of 0.72, which accounts only for fine fuels, to a new value of 0.39, which accounts for both fine and woody fuels.

The N:C ratio currently used in the NGGI is imprecise due to rounding errors and should be revised in future inventories from the current value of 0.02 to the current best estimates of 0.011 for savanna woodlands and 0.012 for arid grasslands.

8 Reassessment of emission rates from Australian savanna fires

The previous sections have established that a number of the parameters used in the current NGGI methodology could be revised, and that there is now sufficient information available to consider extending the methodology to a higher level of spatial disaggregation.

At one end of the spectrum the current algorithm could be applied at the resolution of the fire scar mapping, using one of the current biomass production models (eg. Aussie GRASS, VAST (Barrett, 2003) or others which are in development). The disadvantages of this approach are the complexity, the lack of validation of the biomass production models for all fuel types, particularly the coarse woody fuels, and the continuing uncertainty in the greenhouse gas emission factors and burning efficiencies. With these uncertainties, it is unlikely that a highly detailed spatial model would reduce overall uncertainty in emission estimates.

An alternative and perhaps more practical, approach is to disaggregate the current methodology to a spatial scale which matches the currently available detail in all parameters in the emissions algorithm. In this section I present a series of scenarios to investigate the impact of potential modifications of parameter values and form of the emission algorithm on greenhouse gas emission estimates for NT and WA. Two issues are explicitly addressed:

(1) the impact of the 10-year smoothing of firescar areas currently used in the NGGI, compared with alternative averaging intervals

(2) the impact of revised fuel loads, burning efficiencies and nitrogen content indicated by recent measurement programs.

8.1 Averaging intervals.

This review has established consistent timeseries of firescar areas for 1983 to 2003 disaggregated by state and by agro-ecological zone into the tropical savanna and the arid zone. Two features to emerge were :

- there appears to be a genuine trend in emissions between 1990 and 2001 driven primarily by rainfall; and
- there is extreme inter-annual variability in fire activity in Central Australia consistent with a long fire return period in excess of 10 years.

It was concluded in section 6 that, because of the extreme inter-annual variability, it could be argued that the timeseries should be smoothed by averaging over a window comparable to the fire return interval to remove noise from natural inter-annual viability in order to determine the trend.

The following scenarios were suggested:

1. no smoothing;
2. smoothing all data by the current 10-year moving average;
3. smoothing all data by a 3-year moving average. This is consistent with practice in other agricultural sectors and avoids issues caused by phase differences between fire seasons in tropical and temperate Australia.; and
4. A combination of 2 and 3. A 10-year moving average is used for Central Australia and a 3-year moving average is used for the Top End. These intervals approximate the return interval for fires in these regions.

Greenhouse gas emissions were estimated for these scenarios using the firescar timeseries prepared for this report, with missing data estimated from rainfall regressions (Fig 4.10). All other parameters are taken from the 2002 NGGI (AGO,2004). The scenarios are compared with the 2002 NGGI estimates (for NT and WA) in Figure 8.1.

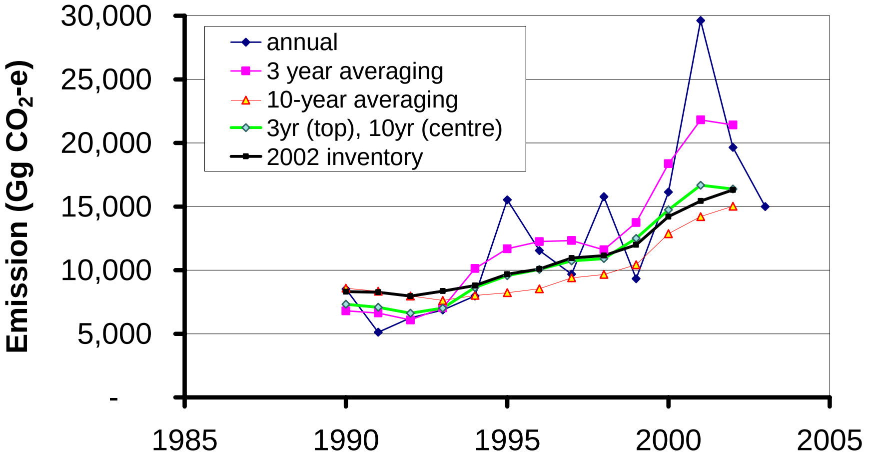


Figure 8.1 Effect of smoothing period on estimated emissions from savanna fires in NT and WA. Firescar areas are sourced from the patched 1983-2003 timeseries. All other parameters are from the 2002 NGGI (AGO, 2004).

Comparison of the NGGI (AGO, 2004) timeseries with the revised timeseries suggests that the new data analysed for this report lead to a slight reduction in emission estimates.

The 10-year averaging window used in the NGGI is not centred on the inventory year but on the year three-years previously. This is a practical issue caused by the need to prepare emissions inventories close to the current year, but it has the effect of introducing a lag to the trend. While this does not affect the magnitude of the trend, it puts the time series significantly out of phase with the annual data. Applying 3-year averaging removes most of the inter-annual variability but significantly increases the apparent trend, while a combined 3-year and 10-year window produces a trend intermediate between the 3-year and 10-year scenarios.

Good arguments can be developed to support the use of each scenario; however an obvious consequence of using annual data is that the rank of savanna fire emissions in the IPCC key source analysis could change significantly from year to year. This is not a preferred outcome.

8.2 Parameter revisions.

The second set of scenarios to be explored is the trend analysis described above combined with the best estimates of all other parameters indicated by this review (section 7.6). Specifically the parameter revisions are:

- Set the N:C ratio for woodlands and grasslands to 0.011 and 0.012 respectively;
- Set the fuel load for pastoral and grassland areas to 3 t ha^{-1} ;
- Set the fuel load for savanna woodland to 12.7 t ha^{-1} to account for coarse and heavy fuels; and
- Set the burning efficiency for grassland and woodlands at 0.76 and 0.39 respectively.

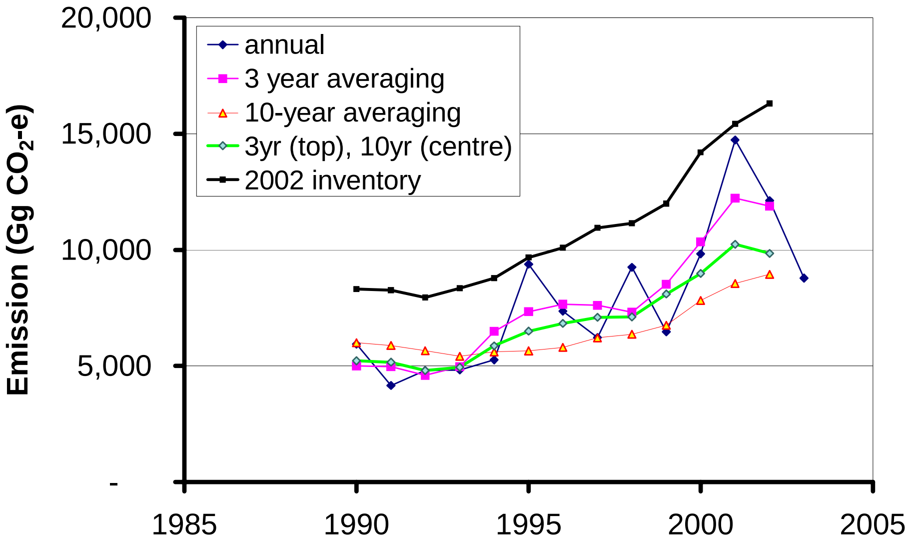


Figure 8.2 Comparison of savanna fire greenhouse gas emission estimates for NT and WA using revised fire scar data, emissions parameters and smoothing periods with 2002 NGGI emission estimates.

The combined effect of these parameter revisions on emission estimates is shown in Figure 8.2. The revised firescar areas and parameters reduce the emission estimates by approximately 38% when compared to the current data and parameters used in the 2002 NGGI (AGO, 2004) for all scenarios. A brief sensitivity analysis (Table 8.1) shows the source of this change. Revising fire scar estimates for 1989 to 1996 using DOLA firescar estimates supplemented by values estimated from regional rainfall records produces 10% reduction in emissions from the 2002 NIGGI estimate; correcting the N:C ratio increases the reduction to 26%; and revision of fuel loads and burning efficiencies using newly released field data results in a further reduction of 12%.

Table 8.1. Cumulative sensitivity of emission estimate to changes in emission parameters.

Revision	Old	New	Change from NGGI (2004)
1. Fire areas	NGGI (2004)	Revised DOLA	-10%
2. N:C	0.02	0.012	-26%
3. Revised grassland burning efficiency	0.72	0.76	-23%
4. WA fuel load	7.7	3	-31%
5. Disaggregate to woodland/grassland fuel loads, burning efficiencies and N:C ratio	WA fuel=7.7 NT fuel=5.8 BE=0.72	Woodland fuel=12.7 Grassland fuel =3 Woodland BE= 0.39 Grassland BE = 0. 76 Woodland N:C= 0.011 Grassland N:C = 0. 012	-38%

8.3 Comparison of NGGI estimates with international studies

The final issue for this review is whether these revisions lead to more accurate emissions estimates. New regional and global estimates of biomass burning emissions have been published within the last few years. Some of these studies use emissions algorithms similar to equation 3.1 applied at the spatial resolution of the firescar mapping. The first national estimate of emissions in Australia (Galbally et al., 1992) was 298 Mt biomass burned annually, 237 Mt from savanna woodlands and grasslands. These were derived from work of Walker (1981) using regional area, fuel load and fire return frequency.

The first detailed study which explicitly covered the Australian savanna was Meyer et al., (2001). This analysis combined the spatial firescar data used in the NGGI with spatial estimates of fuel loads derived from the biospheric model VAST (Barrett, 2003). Both grass and fine litter and coarse woody residue were included in the fuel load. Burning efficiencies were estimated by comparing observations of smoke composition during smouldering and flaming combustion with the composition of a well mixed smoke plume (Cook, unpublished) from which it was concluded that 90% of fine fuel and 30% of coarse woody fuels was burned. This study estimated that 126 Mt biomass was burned in 1999, substantially less than Galbally et al, (1992).

In more recent studies, fire scar areas are sourced from international groups using similar satellite imagery (MODIS, SPOT and AVHRR) although the fire scar areas are measured using algorithms and methods which are quite independent of those used to derive the data used in the NGGI. The study of Tansey et al. (2004) is an example.

In the most recent emissions study, Ito and Penner (2004) estimate global emissions which they report by region one of which is Australia. In this study the fuel loads are derived from biospheric production models. For the Australian region, the steady-state fuel load pools were again derived from the steady state version of VAST while the vegetation classes (forest, woodland, grassland, bare ground) for 2000 or 2001 were sourced from one of three global vegetation models.

A comparison of previous estimates of biomass burning emissions in Australia published in the literature with the estimates of this review is given in Table 8.1. The NGGI estimate for mass emission from biomass burning of savannas in Australia in 2000 is 194 Tg. This is less than all the previous international estimates published using inventory-style methods although it was acknowledged that the uncertainties of these early estimates are very large. In contrast the spatially derived estimates of 125 Tg (Meyer et al., 2001) and 130-180 Tg (Ito and Penner, 2004) are slightly lower than the 2002 NGGI estimate but more comparable to the revised NGGI estimate for NT and WA of 148 Tg.

These comparisons, particularly the latter, therefore suggest that:

1. the NGGI methodology is reasonably well based; but
2. recent studies of fuel loads, N:C ratios and burning efficiencies in the NT and WA indicate that the accuracy of some parameters could be improved. Incorporating these revised parameter estimates could reduce the current emission estimates by up to 38%.

Table 8.2. Estimates of biomass combustion in Australia from regional and global studies.

Study	Year	Biomass burned ((Tg dry matter) yr-1)
Australia		
Galbally et al., 1992	average	298
NGGI (AGO, 2004) 10 yr average	2000	194
Regional or NGGI fuel load estimates		
Hao et al. (1990)		420
Hao and Liu (1994)		290
Hurst et al. (1994)	1990	210
Shirai et al. (2003)	1999	260
Spatial models at 1 km^2 resolution		
Meyer et al., (2001)	1999	126
Ito and Jenner (2004) Veg model 1	2000	130
Ito and Jenner (2004) Veg model 2	2000	180
Ito and Jenner (2004) Veg model 3	2000	140
NT & WA emissions		
Galbally et al., 1992	average	237
NGGI (AGO,2004) 10-yr average	2000	179
This study -annual	2000	148
-10 yr average	2000	118
-3 yr average	2000	156
-3yr top, 10yr centre	2000	135

9 Conclusion

The annual areas of firescars in Northern Territory and Western Australia for 1989 to 1992 measured from AVHRR satellite imagery confirmed that 1989 -1992 were years of low activity. The apparent trend in savanna fire activity between 1990 and 2002 was confirmed, however, it was concluded that most probably this was not a monotonic trend but inter-annual variability within a long-term natural climate cycle. A significant component of the variability could be explained by regional rainfall in the preceding seasons.

In order to remove the impact of inter-annual variability from the trend in greenhouse gas emissions from fires consideration should be given to averaging fire areas across 3 or 10 years, depending on practicality, and the need for consistency with IPCC guidelines.

Savanna fires occur across all land tenure, land use and vegetation categories in the Northern Territory and Western Australia. It was concluded that fires on private pastoral lands and on aboriginal lands both met the current IPCC definitions of savanna burning, and currently there is no reliable basis to classify fires as anthropogenic or natural by ignition source. It is recommended that the current NGGI practice be continued in which all fires in the NT and Northern and Central WA are classified for inventory purposes as savanna fires.

There have been several recent studies that provide substantially basis for revising the values of emissions parameters currently used in the NGGI. It is recommended that consideration be given to revising:

- the N:C ratio for woodlands and grasslands to 0.011 and 0.012 respectively;
- the fuel load for pastoral and grassland areas to 3 t ha^{-1} and the fuel load for savanna woodland to 12.7 t ha^{-1} to account for coarse and heavy fuels; and
- the burning efficiency for grassland and woodlands at 0.76 and 0.39 respectively.

The availability of these new data now justify stratifying savanna regions into two broad vegetation classes: woodlands comprising vegetation with projected foliage cover greater than 20% and grasslands, and that emissions be calculated both by state and by vegetation class. The revised estimates of fire scar area, N:C ratio, and fuel load and burning efficiency combined, lead to reduced estimates of non-CO_2 greenhouse gas emissions, compared to the current NGGI estimates, of 10%, 16% and 12% respectively. The current NGGI methodology may be overestimating by one third the non-CO_2 greenhouse gas emissions from savanna fires.

Finally, both the current NGGI methodology and the proposed revised methodology are consistent with the more recent independent international estimates of biomass burned by savanna fires in Australia.

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