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# Biomass Burning and Resulting Emissions in the Northern Territory, Australia

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**Abstract.** The extent of biomass burning in the Northern Territory, Australia, during 1992 (a year of low fire activity) was estimated using NOAA-AVHRR satellite imagery and was subsequently used to calculate the emission of gaseous compounds from biomass burning for that year. A total of 73,729 km² was determined to have been burnt, representing 5.5% of the total Northern Territory area. The extent of biomass burning in different vegetation units in the Northern Territory was also estimated, with eucalypt communities comprising 72% of the total area burnt. An estimated 29.5 x $10^6$ tonnes of biomass was consumed by burning, resulting in the production of an estimated :

1. 11.3 Tg C as carbon dioxide,
2. 1.02 Tg C as carbon monoxide, (3) 5.23 x $10^{-3}$ Tg C as total particulate matter,
4. 26.1 x $10^{-3}$ Tg N as nitrous oxides,
5. various other trace gases.

The calculated release of $CO_2$ in this study accounts for only 41% of the estimated Australian contribution to global emmissions from biomass burning, indicating that the Australian contribution may be overestimted.

**Keywords:** NOAA-AVHRR; Biomass burning; Australian tropics; Remote sensing; Trace gas and aerosol emissions.

## Introduction

It is known that much of northern Australia is burnt annually by fires that occur primarily between May and October, the dry season in the annual monsoon cycle (Figure 1).

Fire is an integral part of northern Australia's ecology and natural history (Haynes et al. 1991). Traditionally, both pastoralists and aborigines have systematically burnt large tracts of land each year (Griffin et al. 1983).

Fire frequency in the north of the Northern Territory (NT) is particularly high, with most areas burnt at least every two to three years and some areas burnt annually. On a global scale, biomass burning is considered to be a major source of aerosol and trace gas production (Robinson 1991). It is hypothesised here that emissions from biomass burning in the NT contribute significantly to global gross trace gas emissions to the atmosphere. However it should be noted that the net emissions will be moderated by assimilation of material in the subsequent vigorous seasonal regrowth typical of the seasonally wet parts of the NT. The study of biomass burning emissions is important in the study of anthropogenic modification of climate and the atmosphere. Such modifications include the greenhouse effect, acid rain, oxidative chemistry, aerosol-related changes in visibility, radiant energy balance, nutrient transport, cloud

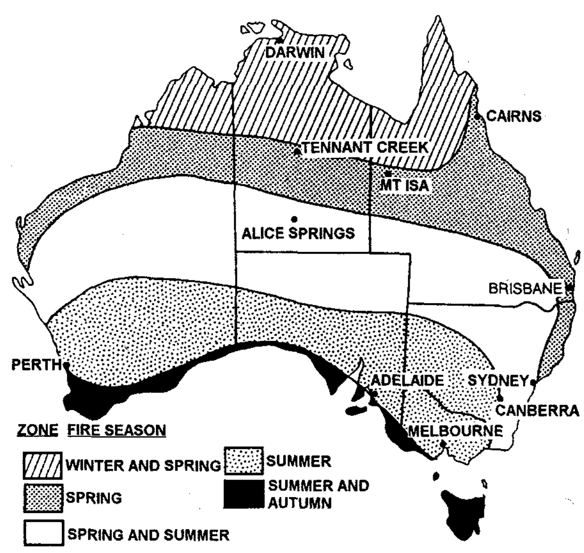


**Figure 1.** The seasonal fire zones across Australia (After Luke and McArthur 1978). The Northern Territory is located in northern-central Australia with Darwin, Alice Springs and Tennant Creek as major centres.

formation and precipitation (Robinson 1991). Fire is also locally important because it strongly affects the distribution and abundance of plant species, and hence ecological systems and land surface properties (Bowman 1986).

Emissions of carbon dioxide ($CO_2$), nitrogen oxides ($NO_x$), and methane ($CH_4$) from burning have the potential to contribute to the atmospheric greenhouse effect by their absorption of atmospheric radiation (Crutzen et al. 1979). Other trace gases, such as carbon monoxide (CO), and other reactive atmospheric gaseous compounds and aerosols can provide catalytic surfaces for the destruction of photochemical products. These reactions can cause changes in the planetary climate and atmospheric chemistry, including the production of tropospheric ozone (Delany et al. 1985; Kaufman et al. 1990).

Smoke emitted from biomass burning may also affect the radiation budget by increasing the reflection and absorption of solar radiation. Changes in radiant energy balances from modification of surface albedo, atmospheric scattering and reflectance may occur with implications for meso-scale and larger atmospheric circulations (Kaufman et al. 1990). Ground temperatures have been noted to be significantly cooler during episodes of smoke cover (Ward 1990). Particles emitted could also be a major source of cloud condensation nuclei (CCN) which would affect cloud formation and precipitation (Kaufman et al. 1990).

In the 1920s aerosols of Australian origin were believed to be possible contributors to regional haze over the Indonesian archipelago (Braak 1929). Following a number of serious regional haze events in the early 1990s, there have been further questions regarding the possible contribution of Australian emissions from biomass burning to the 'ASEAN Haze' problem (Tapper 1995). Assessment of an Australian contribution to ASEAN Haze would require trajectory analysis and satellite verification of such transport, and will form an important component of the forthcoming Southeast Asia Fire Research Experiment (SEAFIRE) which seeks to assess the extent and impacts of biomass burning in the region (Goldammer 1994). Recent analysis of dry season trajectories from northern Australia shows that approximately 10% of trajectories originating at 900 hPa would impact on the Southeast Asian region, but actual long distance transport has yet to be proven (Wain et al. 1995 in press). Certainly satellite measurements of smoke transport in Canada and the Amazon Basin and aircraft measurements over southern Africa have traced smoke over thousands of kilometres from the source region (Andreae et al. 1988; Ferrare et al. 1990; Fraser et al. 1984).

Biomass burning and resultant emissions in the NT may contribute to perturbations of the atmosphere as described above. Mapping the extent of biomass burning in the NT allows us to calculate the possible contribution to global emissions. Remote sensing provides a tool for collecting spatial and temporal data on various aspects of fires including fire detection, rate of spread, fuel moisture, fuel load, fuel type and vegetative recovery. Certainly the determination of the areal extent of biomass burning in northern Australia, and an estimate of the resulting emissions is a first step in determining possible regional impacts.

## Methods

### *Study Area*

The Northern Territory of Australia consists of 1,347,224 km² of sparsely populated (170,500 persons) land area (ABS 1993). The capital city, Darwin, is located in the north west corner (Figure 2).

Broadly, three fire seasons are represented in the NT (Figure 1). The distribution of vegetation types is closely related to the amount and distribution of rainfall.

Most of the terrain is covered with open forests of *Eucalyptus sp.*, *Acacia sp.* and *Callitris sp.* Below the open canopy, perennial grasses form the primary fuel source for burning (Figure 3).

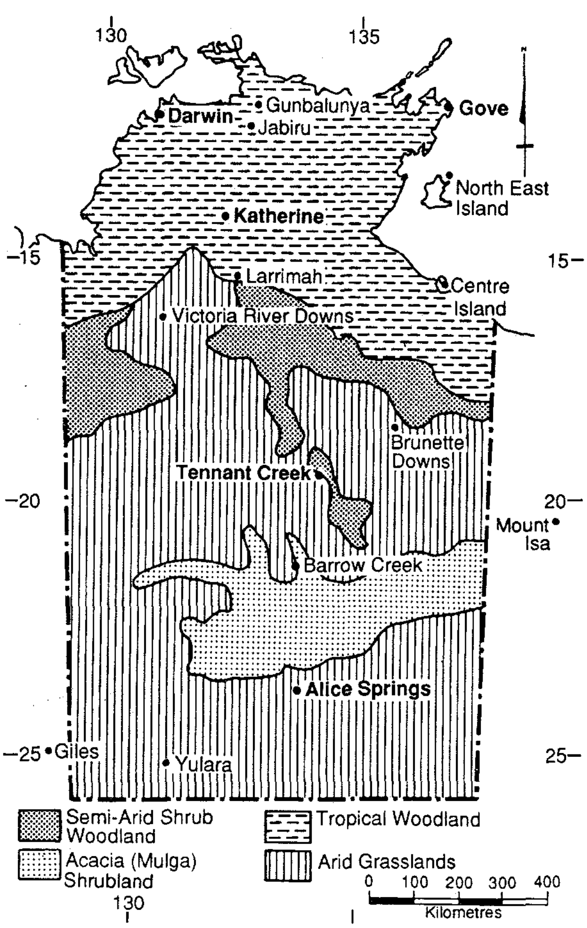


**Figure 2.** Major vegetation units in the NT (After Tapper et al. 1993).

Wilson et al. (1990) have documented the vegetation of the Northern Territory in detail, describing 112 vegetation types. A broader classification is provided here (Figure 2). A detailed study of the climatology and meteorology of high fire danger in the NT is provided by Tapper et al. (1993), whilst a good overview of the study area is given by Haynes et al. (1991).

*Techniques*

NOAA-AVHRR imagery of the NT were retrieved from the North-east Australian Satellite Imagery System (NASIS) archives, James Cook University, Townsville, Australia, for 22 dates at approximately 18 day intervals during 1992. The images, selected for their low cloud cover, were geometrically rectified to a latitude and longitude map base (decimal degrees) and satellite bands were radiometrically calibrated to produce channels of physical values (Table 1). The pixel size of the remapped images was 1.1 km². Image processing took place using MicroBRIAN™ version 3.1 (MPA Communications 1993).

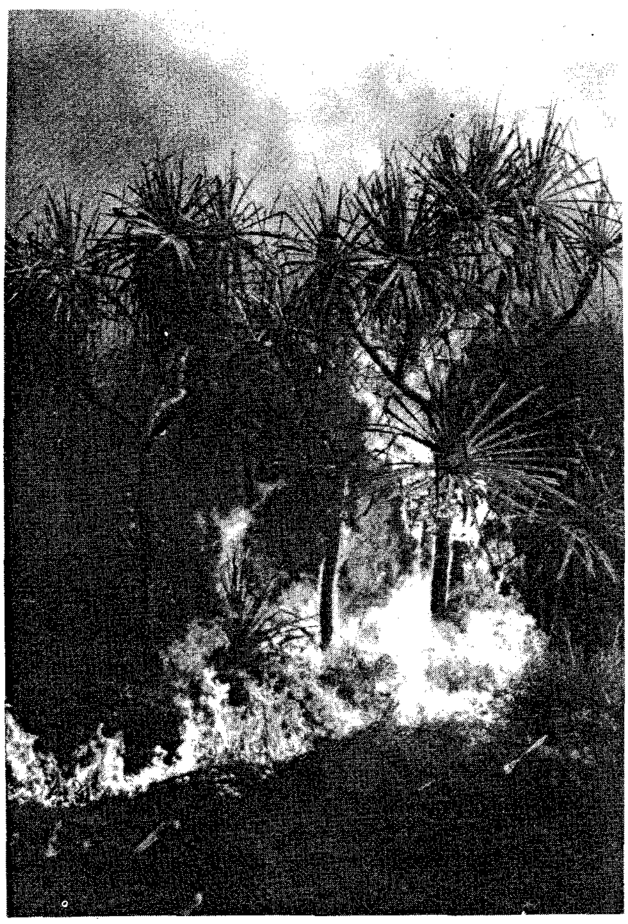

**Figure 3.** A typical burn comprised of Pandanas sp. and perennial grass fuels (Photograph courtesy of Greg Miles — Australian Nature Conservancy Agency).

**Table 1.** AVHRR satellite bands and the derived image channels and descriptions.

| AVHRR Satellite band | Processed image channel and physical description |
|---|---|
| 1 | Albedo(1) |
| 2 | Albedo(2) |
| 3 | Radiance(3) |
| 3 | Brightness Temperature(3) |
| 4 | Brightness Temperature(4) |
| 5 | Brightness temperature(5) |
| 1 and 2 | Normalised Difference Vegetation Index (NDVI) |

Active fires were easily detected due to their high Radiance(3). A comparison of Brightness Temperatures(3) and (4) was used to confirm active fire areas as described by Matson et al. (1987). These areas could also be distinguished by the associated smoke plumes. A good combination for visual enhancement of active fires and smoke plumes was found using Albedo(1), Albedo(2) and Radiance(3) in the blue, green and red wavelength bands respectively

Images subsequent to those displaying active fires showed distinct fire mosaics where active fires had once been. Fire mosaics were visible as lower (dark) values in Albedo(2) and NDVI. The decreased response is due to the low reflectance of the blackened, burnt surfaces. Lower values in NDVI occur because green vegetation has been reduced.

Ratios of channels were chosen to highlight contrasting spectral responses for fire mosaics (Table 2). Whilst the ratioing of image channels is a simple operation, it is an effective way of highlighting the differences between two channels. Moreover, ratioed channels allow comparsion between multiple images. These fire mosaics were used as training areas for classification.

**Table 2.** Channels used in classification and their ratio.

| Channel ratios used in classification |
|---|
| Brightness Temperature 3 / Brightness Temperature 4 |
| Albedo 1 / Albedo 2 |
| Brightness Temperature 3 / NDVI |
| Radiance 3 / Albedo 2 |
| Albedo 2 / NDVI |

Several classes of fire mosaics as well as many vegetation classes, water and cloud were used in the classification. Classification was best achieved using a Maximum Likelihood classifier (Lillesand and Kiefer 1987). Each of the 22 images taken throughout 1992 were classified and the pixels classified as burnt were cumulatively added to form an image of total area burnt for 1992 (Figure 4). No ground truthing of the results has yet been undertaken which results in a potential for error.

The total extent of fire mosaics was compared to vegetation types of the NT using a comprehensive vegetation map (Wilson et al. 1990). The fire mosaic map and vegetation map were registered and formed two channels which were cross-tabulated to achieve the comparison. This produced figures for the area of individual vegetation units burnt during 1992. Broad figures on the productivity of Australian savanna vegetation have been estimated by Walker (1981). These were used in conjunction with the figures of area burnt to calculate the biomass burnt. Subsequently it was possible to extrapolate these figures to calculate gross gaseous emissions. Emission factors for Australian savanna vegetation have been used in the calculation of gaseous emissions (Hurst et al. 1994).

## Results and Discussion

From the cumulative image of fire mosaics (Figure 4), a total of 66821 pixels ($7.3729 \times 10^6$ ha) were classified as burnt in 1992, representing 5.5% of the total land area. It is interesting to compare the total area burnt in the NT in 1992 (a year in which there was less burning than usual because of a continuing drought that reduced available vegetation) to global and continental estimates of the extent of annual burning. The $7.3729 \times 10^6$ ha burnt in the NT makes up 1.2% of the estimated area of global savanna and bushland burnt of $600 \times 10^6$ ha (Seiler and Crutzen 1980). In contrast, the burning in the NT comprises 91% of the estimated annual area of Australian biomass burning of $8 \times 10^6$ ha (Setzer and Perreira 1991). Biomass burning from the NT is of the same order as estimates for the entire United States ($1 \times 10^6$ ha; Albini 1984) and Canada ($1.3 \times 10^6$ ha; Chung 1984).

Figure 4. The total extent of biomass burning in the NT during 1992.

Examination of the series of 22 images from 1992 shows little fire activity occuring until May. A general trend of fire activity starts on the east coast of the NT and progresses toward the central 'Top End' in July and August, continuing westward until November. It appears that the peak burning time in the south was slightly later than in the north. The area of fire mosaics was determined for each of these images and a graph of seasonal fire activity is shown in Figure 5.

It can be seen that there is a peak in activity in July (the height of the dry season) which then declines until mid-November. There is some residual burning at the end of the season in November-December, which may be related to lightning strikes at the onset of the wet season.

Through cross-tabulation of the fire mosaic image and the digital NT vegetation map, the area of each vegetation group burnt was determined (Table 3). Vegetation types with the greatest area burnt were the *Eucalyptus sp.* with grass understorey and *Eucalyptus sp.* with hummock grass understorey groups. These groups respectively comprised 56% and 16% of the total area burnt during 1992. The Eucalyptus communities therefore comprised 72% of all burnt areas in the NT during 1992. These communities have had a long history of dry-season burning and are generally composed of fire tolerant species (Bowman et al. 1988). Fire is encouraged in both wet and dry Eucalyptus forests as natural regeneration is controlled by fire through seedbed preparation and the temporary removal of competition (Bowman 1986). It is therefore not surprising to find that the largest proportion of the total area burnt in 1992 in the NT was in *Eucalypt* communities.

The total weight of biomass consumed by burning was calculated by multiplying the total area by the available fuel produced per ha. Available fuel load in the region varies from between 2-10 t/ha with a usual fuel load of 4.0 t/ha (Walker 1981). Specific biomass figures for separate vegetation types were not available, so a figure of 4.0 t/ha of available fuel was assumed for savanna vegetation (Walker 1981). Fuel consumed varies not only with vegetation type but also varies between seasons and with fire intensity. The variation in fuel consumption provides the greatest error in estimating emmissions and should be considered in this light The total biomass consumed was $29.5 \times 10^6$ t (4.0 t/ha x 7372900 ha).

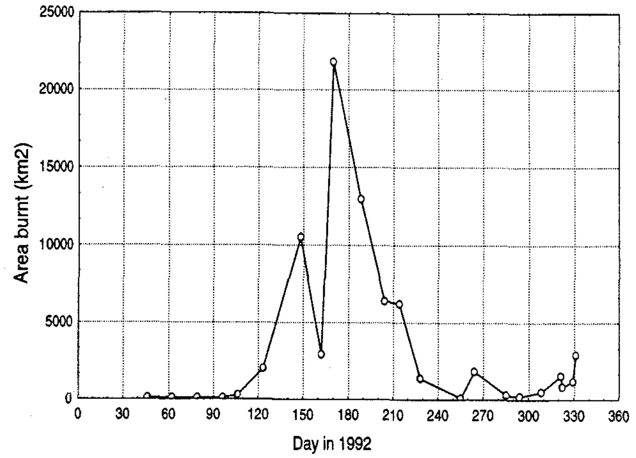


**Figure 5.** Graph of area burnt in km² between images.

Once the amount of biomass consumed by burning has been calculated the resulting gaseous emissions can be broadly estimated. Emission factors were obtained from a recent northern Australian study (Hurst et al. 1994).

The carbon content of fuel exposed to fire was estimated to be 13.57 Tg C (Tg = $10^{12}$ g) using a conversion factor of 46% of dry weight of fuel (Hurst et al. 1994). The nitrogen content of the fuel exposed to fire was estimated to be 0.14 Tg N using a conversion factor of 0.48% of the dry weight of fuel (Hurst et al. 1994).

Hurst et al. (1994) determined that 96 and 89% of the fuel C and N burned was transfered to the atmosphere respectively. Using these figures 13.02 and 0.12 Tg of C and N were released to the atmosphere respectively.

On a global scale annual biomass burning of savanna has been estimated at 1190 Tg C (Seiler and Crutzen 1980) of which biomass consumption in the NT, according to 1992 figures, comprises 1.15 %. This is comparable with the NT contribution to the total global area burnt of between 1.2%.

From Table 4 it can be seen that 11.3 Tg C released as $CO_2$ is estimated to have been emitted to the atmosphere from biomass burning in the NT during 1992.

The global release of $CO_2$ from biomass burning has been estimated at 3460 Tg $CO_2$ annually (Andreae 1991). The NT contribution to this global figure is estimated to be 1.4 % in 1992. It should be noted that 1992 was a drought year in the NT with little vegetation available to be burnt. The estimate of biomass burning and total emissions in a year of high vegetation growth could be expected to be larger. Australia is ranked fourth highest in its contribution to total biomass burning in tropical regions with Africa, Asia and America being the greatest contributors (Andreae 1991). Similar contributions to that provided by the NT could be expected from northern Queensland and northern Western Australia. If similar values are assumed, then an estimated 33.9 Tg C released as $CO_2$ would be emitted from the inter-tropical region of Australia. The $CO_2$ emissions from the NT would account for only 41% of the estimated Australian contribution to global $CO_2$ emissions from savanna fires estimated at 82 Tg C $yr^{-1}$ (Hurst et al. 1994). However the NT does account for 91% of the total Australian area burnt. This indicates that on these figures Australia's contribution to global emissions may be overestimated. The calculated emissions may be locally significant, especially when it is realised that the releases are seasonal phenomena, concentrated during the middle of the dry season.

Production of ozone for instance, could be locally significant, with levels approaching that lethal to native plant and animal life (Levine 1991). Levels of CO in these ecosystems may also be greater than in highly industrialised areas (Levine 1991).

Acid deposition appears to be a problem in the NT with a mean rainwater pH ranging from 4.2 - 4.3 for sites such as Groote Eylandt, Katherine and Jabiru (Andreae 1991).

Recent evidence shows that the levels may be derived to a large extent from direct emissions of acetic acid from biomass burning and the photochemical formation of formic and acetic acid in the plumes (Andreae 1991).

Burning also appears to significantly enhance the microbial production and emission of $NO_x$ and $N_2$ from soil and methane from wetlands (Andreae 1991).

It must be realised however that these figures are gross emissions and net emissions would be significantly moderated due to the assimilation of material in the subsequent vigorous seasonal regrowth.

**Table 3.** Burnt area in 1992 by vegetation community (after Wilson et al. 1990).

| Major vegetation communities | Area burnt (km²) | % of total burnt area |
|---|---|---|
| Closed forest | 229 | 0.31 |
| Eucalyptus with grass understorey | 40770 | 56.10 |
| Eucalypt with hummock grass understorey | 11828 | 15.80 |
| Mixed species low open-woodland with grass understorey | 282 | 0.38 |
| Misc. shrubland | 142 | 0.19 |
| Melaleuca (Paperbark) | 1559 | 2.35 |
| Flood plains | 2052 | 2.83 |
| Acacia with grass understorey | 11249 | 14.3 |
| Hummock Grassland | 2380 | 3.27 |
| Grassland | 1726 | 2.38 |
| Littoral | 1461 | 2.02 |
| Chenopod low sparse-shrub/forbland | 51 | 0.07 |
| Totals | 73729 | 100 |

Table 4. Calculation of total emissions from biomass burning in the NT during 1992.

| Emission | Emission factor[a] | Total emissions from NT in 1992[b] |
|---|---|---|
| $CO_2$ | $0.87 \pm 0.03$ | $11330 \pm 390.6$ |
| $CO$ | $0.078 \pm 0.023$ | $1016 \pm 299.9$ |
| $CH_4$ | $0.0035 \pm 0.0012$ | $46 \pm 15.62$ |
| $C_2H_2$ | $0.00011 \pm 0.00007$ | $1.43 \pm 0.9114$ |
| $C_2H_6$ | $0.000089 \pm 0.000075$ | $1.156 \pm 0.98$ |
| $C_3H_8$ | $0.00020 \pm 0.00012$ | $2.6 \pm 1.56$ |
| $CH_3CHO$ | $0.00055 \pm 0.00034$ | $7.16 \pm 4.4$ |
| $NO_x$ | $0.21 \pm 0.08$ | $26.1 \pm 10.0$ |
| $NH_3$ | $0.23 \pm 0.13$ | $28.66 \pm 16.2$ |
| $N_2O$ | $0.0077 \pm 0.0021$[c] | $0.96 \pm 0.26$ |
| $HCN$ | $0.0025 \pm 0.0024$ | $0.31 \pm 0.30$ |
| $CH_3CN$ | $0.0070 \pm 0.0042$ | $0.87 \pm 0.52$ |
| TPM 2.5[d] | $0.0042 \pm 0.0030$ | $5.23 \pm 0.37$ |

[a] Emission factors from Hurst et al. (1994) except where noted. Emission factors represent the fraction of burned fuel C or N emitted as each species. Emission ratios are given as mean ± one standard deviation.
[b] Estimated total emissions are given in units of $10^{-9}$ g C or N.
[c] Emission data from Lobert et al. (1991).
[d] TPM 2.5 is emissions of particulate carbon < 2.5 μm in diameter

## Conclusions

This study has quantified regionally significant amounts of gaseous and particulate emissions to the atmosphere through biomass burning in the NT. The results show a possible Australian contribution to global $CO_2$ emissions of around 34 Tg C. Based on this the contribution to the global emissions from biomass burning is underestimated by over half.

It should be noted that there are substantial sources for error in these calculations resulting from the lack of ground truthing, the unavailablity of specific biomass production figures, limited temporal data and the extrapolation of NT figures to other states. These tasks may form the basis for improved accuracy in estimating emissions.

However figures calculated using contemporaneous spatial data sets such as the ones in this project give a much more accurate indication of Australia's contribution to global biomass burning emissions than other methods of estimation on which other estimates are based. These figures help quantify the perturbation of the atmosphere associated with emissions from the NT and will assist in quantifying the effect emissions have on ecosystems within the region and beyond. Further work should be aimed at reducing the level of unceratinty associated with the biomass yields for different plant communities.

Fire mosaic detection techniques may be used to assist in the regional monitoring of fire activity in the NT. Mapping of fire activity by satellite provides a fast, reliable and inexpensive method of regional monitoring. This method may in some cases even replace the use of expensive and resource intensive aerial and ground surveying. The production of fire maps is important for land managers to achieve an appropriate burning frequency. In addition, coupling vegetation data with fire mosaic maps allows a comparison of vegetation types burnt and may give an insight for fire ecologists into susceptibility and resilience of vegetation communities.

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