# The impacts of *Andropogon gayanus* (gamba grass) invasion on the fire danger index and fire management at a landscape scale

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**Summary** Effective fire management relies on the ability to assess the potential risk that a fire event poses to the community so that fire managers can ensure sufficient resources are available to respond to unplanned fires. Fuel loads are a major contributor to fire risk and any significant changes to fuel load should be incorporated into fire risk models. An example is the invasion of Australia's tropical savannas by the high biomass African grass *Andropogon gayanus* Kunth (gamba grass). Fine fuel load (grass and twigs <6 mm) in a heavily invaded landscape has increased from 6 to 10 t ha$^{-1}$. Consequently, in 2010, the Bureau of Meteorology created two 20 km$^2$ radius 'primary response zones', which are defined areas of dense invasion in the greater Darwin region in which fire risk is assessed using an estimate of increased fuel load. In this paper, we quantify the effect of the increased (invaded) fuel load on the assessment of fire risk. We do this by modelling the daily McArthur Mark 4 Grassland Fire Danger Index (GFDI) for the fire seasons in 2012 and 2013 using both native (6 t ha$^{-1}$) and invaded fuel loads. We show that the number of days with GFDI >50 (the threshold for fire weather warnings and fire bans) has increased and the length of the severe-risk fire season has extended, resulting in substantial increases in fire management costs. This has safety and resource implications for fire management agencies as the area of invasion increases across northern Australia.

**Keywords** *Andropogon gayanus*, exotic grass, strategic weed management, management costs.

## INTRODUCTION

Tropical savanna ecosystems are characterised by frequent burning (every one to three years) because profuse production of native herbaceous plants during the wet season results in large amounts of fine fuel available annually to carry fire (Andersen *et al.* 2005). Non-native grass invasion is considered a significant ecological threat to the world's savannas, particularly in the neotropics and Australia (Foxcroft *et al.* 2010, Hutley and Setterfield 2008) due to impacts on fire regimes. An example is the African grass *A. gayanus*. Spread of *A. gayanus* has been rapid since the 1990s but it is considered to still be in the relatively early stages of invasion across its potential range (Rossiter *et al.* 2003, Brooks *et al*. 2010) with modelling predicting that most of the country's vast area of savanna is suitable for invasion, including approximately 380,000 km$^2$ of the Northern Territory (Northern Territory Government 2008), as well as large savanna areas in Queensland and Western Australia (Hutley and Setterfield 2008). *Andropogon gayanus* invasion greatly alters the fuel bed characteristics of savanna communities, replacing the short (approximately 0.5 m) native grass fuel bed (up to 6 t ha$^{-1}$) (Gill *et al*. 2010), with a tall (approximately 4 m) dense fuel bed of up to 30 t ha$^{-1}$ (Rossiter *et al*. 2003, Setterfield *et al.* 2010, Rossiter-Rachor *et al.* 2009). As a result, fire intensity (the product of the available heat of combustion per unit of ground area and the forward spread of the fire, measured in kilo or megawatts per metre) increases significantly, from typically 1–3 MW m$^{-1}$ in native grass fires to 16 MW m$^{-1}$ in *A. gayanus*-fuelled fires in the early dry season (Setterfield *et al.* 2010).

Setterfield *et al.* (2013) showed that in the area of dense invasion around the township of Batchelor, approximately 100 km south of Darwin, Northern Territory, the estimated landscape fuel load in 2010 had increased from the standard 6 t ha$^{-1}$ (native grass fuel load), to approximately 10 t ha$^{-1}$ and 8 t ha$^{-1}$ respectively within 10 km and 20 km radius of Batchelor. This is a substantial increase in the fuel load at a landscape scale, particularly given fuel load is be predicted to further increase markedly in a short-time period given the high rate of invasion and increase in density within the study region. Consequently, in 2010, Australia's Bureau of Meteorology (BOM) created two 20 km$^2$ radius 'primary response zones' which are defined areas of dense invasion in the greater Darwin region in which fire risk is assessed using an estimate of increased fuel load (Setterfield *et al.* 2013).

In this paper, we model the impact of this change on the daily McArthur Mark 4 Grassland Fire Danger Index (GFDI) for the 2012 and 2013 fire seasons, using both native (6 t ha$^{-1}$) and invaded fuel loads. GFDI is calculated daily by BOM based on weather conditions and characteristics of the fuel (e.g. quantity, moisture content).

## MATERIALS AND METHODS

**GFDI** To determine the effect of increases in regional fuel load resulting from invasion by *A. gayanus*, we used Purton's (1982) modification of GFDI, which is defined as:

$$\log_{10}GDFI = (0.661 + 1.027\log_{10}FUEL_{t}) - 0.004096(100 - CURING)^{1.536} + 0.01201TEMP + 0.02789\sqrt{(WIND)} - 0.9577\sqrt{(RH)}$$

where

$FUEL_t$ is fuel load (t ha$^{-1}$);

*CURING* is degree of curing (0–100%);

*TEMP* is air temperature (degrees Celsius);

*WIND* is wind speed (km h$^{-1}$ at 10 m height in the open); and

*RH* is relative humidity (%).

GFDI calculations were made for each day of two fire seasons (1 May to 31 October, 2012 and 2013) with $FUEL_t$ equal to 6 t ha$^{-1}$ (the historical native grass fuel load) and also 13 t ha$^{-1}$ (currently used by the BOM to calculate the daily GFDI for the 20 km$^2$ radius 'primary response zones' around Batchelor). Calculations were made using hourly *TEMP*, *WIND* and *RH* data from the BOM weather station at Batchelor. Daily *CURING* data was provided by Bushfires NT (the Northern Territory Government's fire authority) for the study period.

**Quantifying the effect of increased fuel load on fire management costs** On any date in which GFDI is calculated to be greater than 50, Bushfires NT must ensure that additional fire fighting equipment and staff resources are put on 'standby', that is, they are available for immediate call-out in the event of a wildfire. This includes aerial fire-fighting equipment such as water-bombing planes. Using Setterfield *et al*.'s (2013) costing of the equipment required on stand-by, we calculated the economic cost of increasing stand-by resources under two different scenarios: the actual number of fire ban days in the 2012 and 2013 season ($FUEL_t$ equal to 13 t ha$^{-1}$) and the predicted number of fire ban days (GFDI >50) using $FUEL_t$ at 6 t ha$^{-1}$.

## RESULTS AND DISCUSSION

The nature of the fire season changed following increases in $FUEL_t$ (Figure 1a,b). In the primary response zone, the increase in $FUEL_t$ to 13 t ha$^{-1}$ resulted in the GFDI being in the 'very high' (25–49) and 'severe' (50–74) category for most of the fire season, and exceeded GFDI 75 ('extreme') on several occasions, in both years (Figure 1.) By contrast, if $FUEL_t$ had remained at 6 t ha$^{-1}$, the GFDI at the Batchelor weather station would not reach the 'severe' category during the entire season, instead remaining in the low-moderate (GFDI <12) or high (GFDI 12–24) category for most of the fire season in both years (Figure. 1).

In both years, an increase in $FUEL_t$ from 6 t ha$^{-1}$ to 13 t ha$^{-1}$ resulted in a substantial increase in the number of days with GFDI >50. When $FUEL_t$ = 6 t ha$^{-1}$, the *predicted* number of days with GFDI >50 at Batchelor was zero, whereas when $FUEL_t$ = 13 t ha$^{-1}$, the *actual* number of days with GFDI >50, was 38

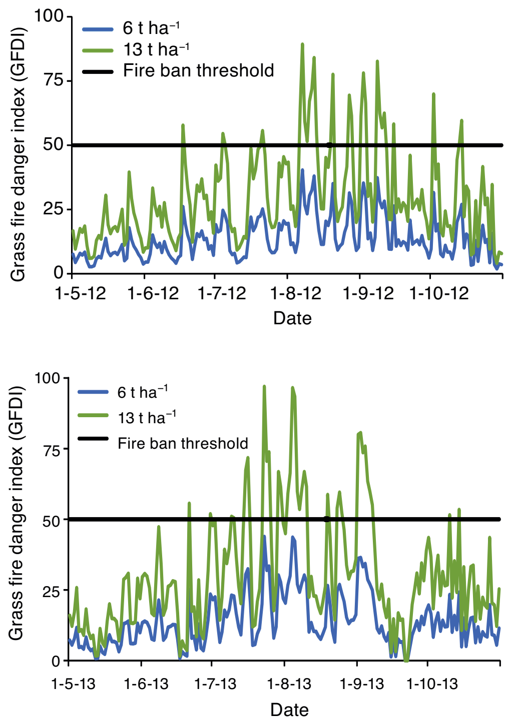


**Figure 1.** Daily maximum GFDI in (a) 2012 and (b) 2013, at Batchelor weather station, Northern Territory, Australia (BOM data) for two fuel load ($FUEL_t$) scenarios: 6 t ha$^{-1}$ (blue line), and 13 t ha$^{-1}$ (green line). GFDI of 50 is represented by the black line and is considered 'severe' fire weather and fire management authorities must declare fire ban days.

and 48 days for the years 2012 and 2013 respectively (Figure 1, Table 1).

Historically the fire season in the 'Top End' of the Northern Territory extended from 1 May to 31 October each year, with the highest fire danger in the late dry season (August – September). The duration of the severe fire season has extended considerably following *A. gayanus* invasion (Figure 1). If $FUEL_t$ = 6 t ha$^{-1}$, no days had a GFDI >50. By contrast, with the increase in $FUEL_t$ to 13 t ha$^{-1}$, the severe fire season commenced early in the fire season, with the first fire ban declared in early June in both years (17 and 21 of June in 2012 and 2013 respectively). Severe fire conditions now continue to the end of the fire season, with the last fire ban of the season declared in late October (14 and 11 of October in 2012, and 2013 respectively). Extending the length of the severe risk fire season has resulted in substantial increases in fire management costs (Setterfield *et al*. 2013).

The increase in the number of fire ban days has significant resource implications for fire management agencies across northern Australia. For every day that a fire ban declaration occurs, the suite of extra resources required to be on standby costs \$11,442 day$^{-1}$ (data in 2010 dollars and includes GST; Setterfield *et al*. 2013). *A. gayanus* invasion has clearly increased the cost of fire management. The 38 actual fire bans in 2012 equates to an estimated increased cost of \$436,796 compared to no cost (due to no fire bans) if $FUEL_t$ remained at 6 t ha$^{-1}$ (Table 2). Similarly, in 2013, the 48 actual fire bans equates to an estimated \$549,216 compared to no cost if $FUEL_t$ remained at 6 t ha$^{-1}$ (Table 2). This is a substantial increase in cost of fire management activities, in addition to increased cost of wildfire control. Clearly, widespread *A. gayanus* invasion has had major safety and resource implications for fire management agencies in northern Australia which demonstrates that increased effort is needed to limit spread and contain the area of increased fire risk.

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**Table 1.** Actual and modelled fire bans in the 2012 and 2013 fire season for the Batchelor region (Northern Territory, Australia) for two fuel scenarios (a) current *A. gayanus* fuel loads (13 t ha$^{-1}$) and (b) historical, native grass fuel loads (6 t ha$^{-1}$).

| Year | (a) 13 t ha$^{-1}$ *A. gayanus* fuel | (b) 6 t ha$^{-1}$ native fuel |
|---|---|---|
| 2012 | 38 | 0 |
| 2013 | 48 | 0 |

**Table 2.** Cost of fire management stand-by equipment in 2012 and 2013 for the Batchelor region (Northern Territory, Australia) for two fuel scenarios: (a) current *A. gayanus* fuel loads (13 t ha$^{-1}$) and (b) historical, native grass fuel loads (6 t ha$^{-1}$). Data are provided in 2010 dollars and include GST.

| Year | (a) 13 t ha$^{-1}$ *A. gayanus* fuel | (b) 6 t ha$^{-1}$ native fuel |
|---|---|---|
| 2012 | \$436,796 | \$0 |
| 2013 | \$549,216 | \$0 |

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