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Climate change and carbon management in the Monsoonal North

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Executive summary

This report forms part of a study of the impacts of climate change on the Monsoonal North Natural Resource Management Region of Australia. It focusses on carbon sequestration and emissions abatement using the savanna fire methodology under the Emissions Reduction Fund and Carbon Farming Initiative. It was originally intended that the latest climate change projections would be used to parameterise a vegetation dynamics model to examine scenarios for future carbon stocks and the consequences for fire management. However the simulations were not available in time to conduct vegetation modelling. Furthermore, the projections would not have been suitable due to a lack of sensitivity in the critical area of rainfall seasonality. Therefore, following discussions, it was agreed that we should provide a review of the drivers of carbon dynamics in the Monsoonal North in the context of the savanna fire methodology and apply models based on a number of possible rainfall scenarios.

The savanna fire methodology presents default parameters to calculate the emissions abatement that is deemed to occur as a result of changing the fire regime in defined project areas. Although climate change may alter the value of these parameters, they will remain as the default values until a revised or new methodology is produced. Consequently land managers will be most concerned with how climate change affects their ability to manage fires rather than any effects on the calculation of abatement. The savanna fire methodology is based on the use of early dry season controlled burning to reduce overall fire frequency and fuel consumption and thereby reduce emissions and potentially increase carbon sequestration. Under likely climate change scenarios, the opportunity to use careful fire management in the early dry season will continue.

For the monsoonal north, changes in rainfall seasonality are potentially of great significance to carbon dynamics. There is evidence of increasing dry season length in North Queensland and decreasing length in the south Kimberley region of Western Australia. Unfortunately, current climate models cannot robustly model the isolated storm events that determine the transitions between the dry and wet seasons and thus the length of the dry season. Therefore we produced a range of scenarios of possible changes in seasonality and modelled their effects on vegetation and carbon stocks.

Increasing the length of the dry season could have a marked impact on vegetative carbon stocks. This would be greatest if this occurred in the Charters Towers region of Queensland, which currently has the greatest likelihood of winter rainfall across the Monsoonal North. Such changes would alter the tree-grass balance and thus the makeup and amount of the fuel for savanna fires. If it could be demonstrated that such changes were permanent, then future versions of the savanna fire methodology would need to be reparametrized.

Management for greenhouse gas abatement is still practical under climate change. Regardless of the exact period, there will still be windows of opportunity in which controlled fires can be used to reduce late dry season fires. As the vast majority of ignitions are produced by people, there is still great opportunity to modify fire frequency. A decrease in fire frequency is likely to have positive impacts for carbon stored in fine fuels and coarse woody debris pools, resulting in additional carbon sequestration above baseline regardless of future climate.

Part I Background

1 The management of carbon stocks and greenhouse gas emissions in the Monsoonal North

This report addresses the potential effects of climate change on the management of carbon stocks and greenhouse gas emissions in Australia's Monsoonal North. In 2012, a methodology was released that provides an approach to quantify the abatement in greenhouse gas emissions from changing fire regimes. It applies to tropical Australian areas that receive more than 1000 mm mean annual rainfall. This methodology has recently been expanded to include areas wetter than 600 mm. The high rainfall methodology has been widely adopted (Figure 1), with projects to the end of 2014 occurring across more than 30 % of the applicable area. This methodology under the Carbon Farming Initiative/ Emissions Reduction Fund has provided support for improved fire management across vast and remote landscapes for which land management resources are often scarce (Cook *et al.*, 2012, Russell-Smith *et al.*, 2013). These projects have delivered about 1.2 Mt of carbon-dioxide equivalent (CO_2-e) greenhouse gas abatement.

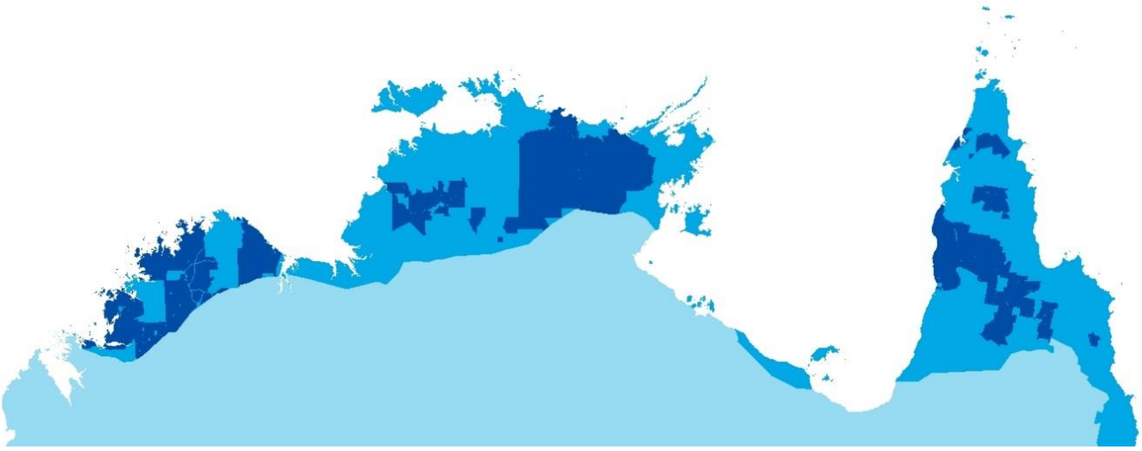


Figure 1 The areas in which savanna burning projects were operating under the Carbon Farming Initiative and Emissions Reduction Fund as at January 2015 (dark blue). Areas with more than 1000 mm annual rainfall are in mid blue.

The most recent version of the methodology for Emissions Abatement through Savanna Fire Management (the Savanna Fire Methodology) was approved in March 2015 (https://www.comlaw.gov.au/Details/F2015L00344, last accessed 28 August 2015). This methodology provides an approach for calculating the effect of changing fire regime on emissions of the greenhouse gases methane and nitrous oxide in high and low rainfall savannas of northern Australia. The calculation has three main components: (1) the frequency of early and late dry season fires; (2) the fuel loads; and (3) the proportions of combusted carbon and nitrogen from each fuel class that are emitted as methane and nitrous oxide. Each of these components could possibly be affected by changes in climate and atmosphere as a result of increasing concentrations of greenhouse gases. However, the current methodology has default values for each of these parameters. If any of the three components were to change in the future, then a revised methodology with new default values would be required. Under the current methodology, project managers only have to aim to reduce overall frequency and / or increase the proportion of early dry season burning.

This report aims to investigate some of the possible changes in carbon and greenhouse gas dynamics in the Monsoonal North and how management could adapt in the context of the Emissions Abatement methodology and potential complementary carbon sequestration methodologies (See for example: Cook *et al.*, 2015b). Firstly, the drivers of emissions and carbon balance are considered, followed by a number of case studies focusing on the potential effect of changes in dry season length.

1.1 Climate and the drivers of emissions and carbon balance

1.1.1 Fire

The Monsoonal North Natural Resource Management region has the highest fire frequency in Australia and is one of the most fire-prone regions of the world. Many parts have fires on average every one in four to one in two years. These fires emit methane (CH_4) and nitrous oxide (N_2O) and also affect carbon stocks. The methane and nitrous oxide emissions from these fires represented about 2 % of Australia's accountable greenhouse gas emissions in 2012.

Fires in the Monsoonal North region are overwhelmingly lit by people both accidentally and for a wide variety of reasons (Russell-Smith *et al.*, 2007). Most fires occur during the dry season, typically from mid-April to late October. An important paradigm throughout much of the region is the distinction between early dry season fires and late dry season fires. Early dry season fires tend to be more patchy and of lower intensity than late dry season fires (Figure 1). Less of the available fuel is consumed at a landscape scale due to the patchiness. In burnt patches less is consumed in early dry season fires due to more incomplete combustion as a result of lower fire intensities and often incompletely cured grassy fuels (Cook & Meyer, 2009). This distinction between early and late dry season fires provides the basis for the methodologies to reduce greenhouse gas emissions. These methodologies provide a means to quantify the effects of changing fire regimes on emissions (Russell-Smith *et al.*, 2013).

The key aspects of the fire regime are the overall fire frequency as estimated for a large area using remote sensing and the proportion of fires that are early and late. Reducing the overall fire frequency or shifting to a greater proportion of early fires or both can decrease the amount of fuel burnt and increase the amount decomposed biologically. This leads to reduced emissions of greenhouse gases (Cook & Meyer, 2009).

For the Monsoonal North, climate change is not expected to directly affect fire frequency, but there is a high confidence that fire behaviour will become more extreme (Moise & others, 2015). This high confidence derives from the dependence of fire weather on temperature and humidity. "*By late in the century (2090), for a high emission scenario (RCP8.5) the projected range of warming is 2.8 to 5.1 °C. Under an intermediate scenario (RCP4.5) the projected warming is 1.3 to 2.7 °C*" (Moise & others, 2015). There is also a medium confidence in a decrease in relative humidity by late in the century.

In Figure 2 and Figure 3, we examine the potential effect of changing temperature, humidity and wind speed on the maximum rate of spread of fires assuming that the fuel is 100 % cured. This is calculated following the approach of Luke and McArthur (1978). As the rate of spread increases, fire intensity increases and the proportion of trees killed increases. Faster moving fires are also much harder to control. An increase in temperature of 5°C (the maximum predicted) from 31°C to 36°C at the time of the fire increases the maximum rate of spread by about 9 %. The maximum rate of spread would increase by a similar amount if relative humidity decreased from 35 % to 25 % (Figure 4). In contrast, changing wind speed over the range of diurnal and seasonal variation seen across the Monsoonal North has a much greater effect (Figure 3). Wind speeds are difficult for climate models to predict, but clearly are an important contributor to variation in fire behaviour.

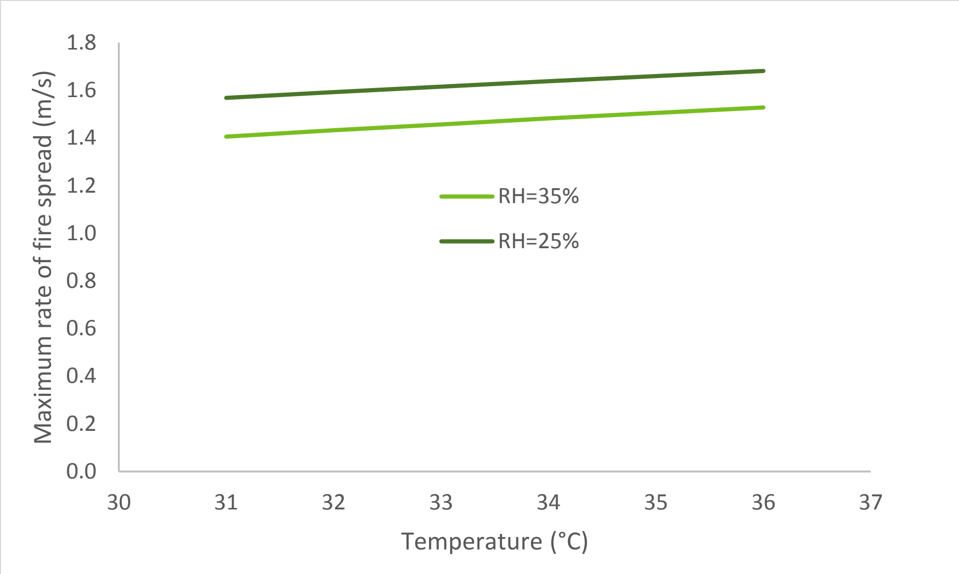


Figure 2 The effect of temperature and humidity on the maximum rate of spread of fires assuming a wind speed of 20.5 km hr^{-1}

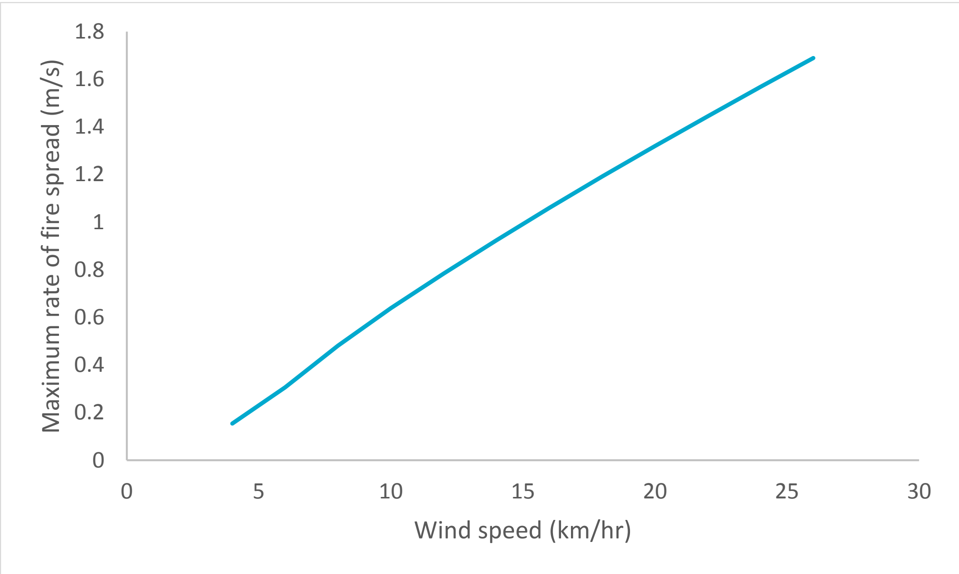


Figure 3 The effect of wind speed on the maximum rate of spread of fires assuming a temperature of 36°C and a relative humidity of 48 %

The diurnal and seasonal variation in maximum rate of spread provides an opportunity for land managers to manage fires at times of day, and times of year when rates of spread and intensities can be minimised. There is a window of opportunity between the end of the wet season and the start of severe fire weather when fires can be managed and are likely to be patchy and of low intensity. Although the timing and duration of this window may be affected by climate change, at this stage we have no ability to predict such changes.

Figure 4 Burnt landscape after early patchy fire (left) and late less patchy fire (right)

The more severe fire weather of the late dry season in the Monsoonal North is a result of intense subtropical ridges in the south producing a strong and dry surge of south-east trade winds (Tapper *et al.*, 1993). By this time of year, fuel loads can still be high and the fuel highly cured with little moisture. Any fires that occur can spread rapidly and consume much of the available fuel under the hot, dry and windy conditions. It is these fires that are likely to become more intense under climate change. Early dry season burning is a valuable tool to provide burnt fire breaks in the landscape and reduce the likelihood of late season fires spreading.

The proportions of nitrogen and carbon in the fuel that are emitted as nitrous oxide and methane during combustion – the emission factors - are determined largely by the proportions of dry grass, leaf and twig litter from trees and coarse woody debris (Meyer *et al.*, 2012, Meyer & Cook, 2015, Smith *et al.*, 2014, van Leeuwen *et al.*, 2014). These values are only likely to alter under climate change if there is a large change in the tree-grass balance. This is considered in Part 2 of this report, but at this stage there is no ability to produce a robust prediction of changes to the emission factors of methane and nitrous oxide.

Under most climate change scenarios, it is likely that the opportunity will remain to use early dry season fires to reduce the probability of uncontrollable late dry season fires and to reduce the overall fire frequency. Increasing temperatures could lead to an increase in the number of fire ban days and thus decrease the length of the permitted burning season and the ability to undertake management burns. Nevertheless, the potential effect of climate change on the behaviour of late dry season fires could still be avoided through improved fire management. For this reason we do not consider the issue of direct climate change effects on fire regimes further in this report. Nevertheless, in future versions of the savanna burning methodology the possible changes in severity of late dry season fires under climate change may need to be accounted for.

1.1.2 Rainfall

A defining feature of the Monsoonal North is the strong seasonality of rainfall (Cook & Heerdegen, 2001). For much of the region, less than 10 % of the annual rainfall occurs in the six driest months. Only in the far south-east of the Monsoonal North region, in the vicinity of Charters Towers is there a greater winter rainfall influence.

Williams *et al.* (2009) concluded that "*The effect of climate change on the savannas* [i.e. the Monsoonal North] *may appear relatively small compared with other parts of Australia where altitudinal gradients are strong, topographic complexity is high and the dispersal capacity of the biota is limited…. Because water is in fact a limiting resource for a considerable part of the year any climate change driven variation in the amount and seasonal distribution of rainfall in this region has the potential to significantly affect native flora and fauna."*

The amount and seasonal distribution of rainfall is a major driver of the overall density of trees and their productivity in the Monsoonal North. Murphy *et al.* (2014) argued that the available evidence suggests that water stress is more important than fire in determining the dynamics of the dominant eucalypt tree stands. The total basal area of trees generally declines with decreasing mean annual rainfall (Cook *et al.*, 2002, Williams *et al.*, 1996). The mechanism for that decline appears to be an increasing length of the dry season rather than decreasing total rainfall *per se* (Liedloff & Cook, 2007). Young trees are suppressed by older trees, with water stress as a result of competition for water in the late dry season being the mechanism of suppression (Fensham & Bowman, 1992, Prior & Eamus, 2000). Further, decreasing rainfall also causes trees to be shorter for a given stem diameter, with dry season length being the likely causal factor (Cook *et al.*, 2015a).

"*Providing confident rainfall projections for the Monsoonal North cluster is difficult because global climate models offer diverse results, and models have shortcomings in resolving some tropical processes. Natural climate variability is projected to remain the major driver of rainfall changes in the next few decades*" (Moise & others, 2015).

"*By late in the century, rainfall projections have low confidence. Potential summer rainfall changes are approximately -15 to +10 per cent under an intermediate emission scenario (RCP4.5) and approximately -25 to +20 per cent under a high scenario (RCP8.5). Per cent changes are much larger in winter in some models, but these changes are less reliable because average winter rainfall is very low*" (Moise & others, 2015).

A recent study found that on all continents except Australia, the length of the fire season had increased between 1979 and 2013 (Jolly *et al.*, 2015). Globally, the mean length of the fire season in tropical and subtropical grasslands, savannas and shrublands increased by more than a week over the 35 years considered. Within Australia, the median length of the fire season in this biome decreased by 21 days but the variation differed across the continent. North Queensland showed an increase in the frequency of years with long fire seasons, while the southern Kimberley in Western Australia showed a decrease. The Northern Territory showed negligible change. The fire seasons reflect variation in wet season length. Clearly there is evidence of changes in fire season length, but the effects are variable due to the high degree of influence of the El Niño Southern Oscillation and the Indian Ocean Dipole (Jolly *et al.*, 2015). The long-term trends cannot be predicted using current knowledge and modelling tools.

As discussed above, we believe that the dry season length is a key determinant of tree stocks in the Monsoonal North. The transitions from both the end of the dry season to the start of the wet and from the end of the wet season to the start of the dry are marked by isolated storms (Cook & Heerdegen, 1998). Their ecological importance derives from their timing rather than from their contribution to total wet season rainfall. Therefore we decided to focus on changes to rainfall seasonality and dry season length as a key process potentially affecting carbon stocks and dynamics. Unfortunately, changes in occurrence of these isolated storms cannot be modelled currently with any precision. Following discussions with climate modellers, we generated a number of scenarios with varying dry season length to examine the potential effects of changes to dry season length.

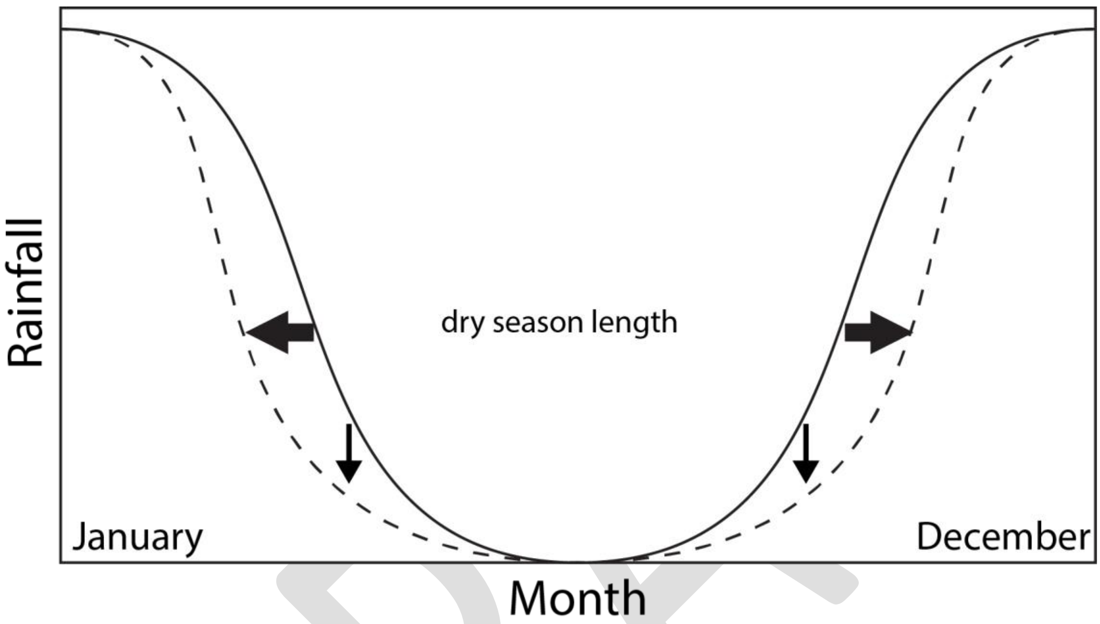


Figure 5 Conceptual diagram of predicted changes in rainfall pattern from current (solid line) to future (dashed line) showing increase in dry season length and declines in monthly rainfall.

1.1.3 Current tree carbon stocks

Cook *et al.* (2015a) showed that, in the Northern Territory, the height of trees for a given stem diameter decreases with decreasing rainfall. The most likely mechanism was the effect of the concurrent increase in dry season length rather than decreasing rainfall amount *per se*. Using existing data on the variation in total basal area of trees against rainfall and soil type, they were able to estimate the carbon stocks in trees across northern Australia (Figure 6). They also estimated the potential gains in carbon stock from changing fire regimes. They showed that while the relative gains were greatest in drier parts of northern Australia, the potential for absolute increases in carbon stocks were greater where rainfall was greatest.

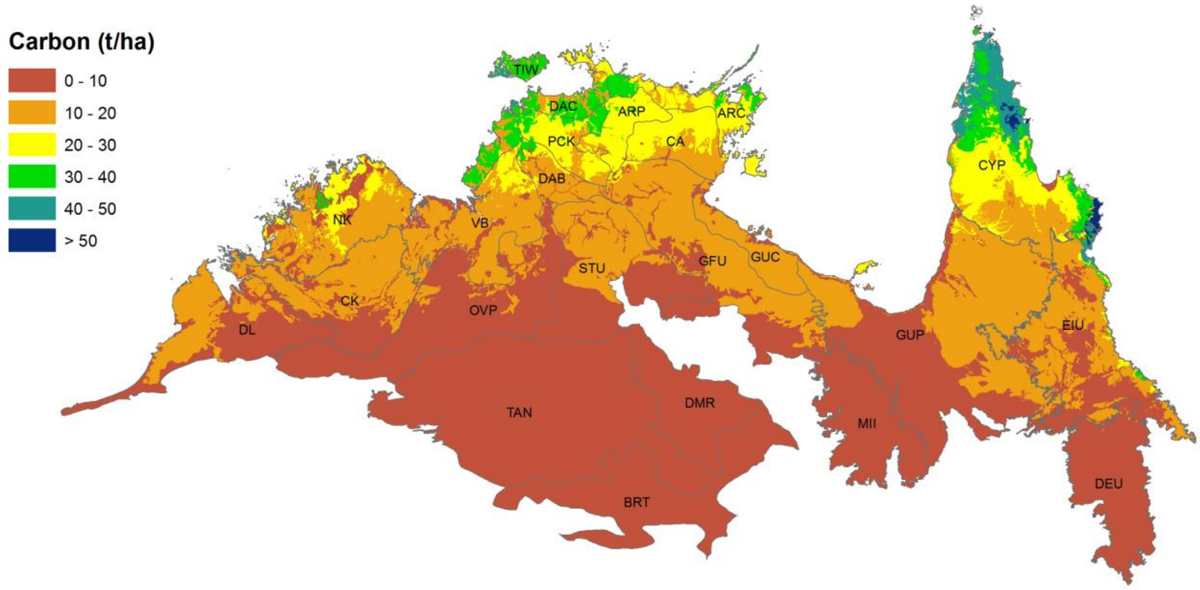


Figure 6 Estimated above ground tree carbon stocks (source: modified from Cook et al. 2015)

Part II Case Studies

In this study we used a tropical savanna tree stand model (Flames) to investigate the potential changes in above ground carbon stocks in both living and dead pools with a range of possible climate change scenarios. We start by looking at the current conditions and then present the modelled results under climate change before considering some management options for maintaining and/or improving above ground carbon stocks in the northern NRM area of each state. Each case studies is designed to be stand alone and read by relevant natural resource managers in conjunction with the background material.

Within each region we simulate both high and low rainfall locations. At each location we consider a shallow (40 cm) and a deep (120 cm) Kandosol soil (>20% clay) typical of much of northern Australia to help provide local comparisons from the simulations. The results will not be applicable to cracking clay soil areas.

The Flames model simulates the dynamics of individual trees within a stand. It takes account of tree water use, the effect of fire on mortality, and tree growth rates. It has been used to examine variations in rainfall and fire regimes on tree stands and carbon dynamics (Cook & Liedloff, 2000, Cook & Liedloff, 2001, Liedloff & Cook, 2007, Liedloff & Cook, 2011). In this study we do not change the fire frequency as a result of climate change, but consider only changes in rainfall.

2 North Queensland

2.1 Study Sites

Three towns were selected to represent the north Queensland NRM area. These were Normanton, representing a high rainfall location (927 mm yr^{-1}), Mt Isa (420 mm yr^{-1}) and Charters Towers (650 mm yr^{-1}) representing two lower rainfall locations with different rainfall patterns (**Error! Reference ource not found.**). All three locations show seasonal rainfall with the majority of rain falling in the wet season (summer) as a result of monsoon driven events (**Error! Reference source not found.**). harters Towers is more influenced by east coast rainfall and La Niña and El Niño patterns (Chiew *et al.*, 1998). About 17% of Charters Towers' average annual rainfall falls during the dry season (May to August inclusive) compared with <10% and <4% for Mt Isa and Normanton respectively.

2.2 Contemporary situation

An example of the modelled variation in tree stands for two locations is shown in Figure 8. Here the data lines represent 20 simulations showing changes in total basal areas of trees over 100 year periods for Normanton and Charters Towers with either a deep (120 cm) or shallow (40 cm) soil.

These simulated ranges of values should encompass natural variation in tree stands for these soil depths. Tree stands on soils with depths between 40 cm and 120 cm should be of intermediate total basal area. The range of total basal area for deep soils at Charters Towers at about 5 to 10 m^2 ha^{-1} was greater than that at Normanton at about 7 to 9 m^2 ha^{-1}. This was despite Normanton's higher rainfall.

The mean simulated carbon stock of the three locations (Table 2) reflects variation in both mean annual rainfall and rainfall seasonality. Charters Towers is much more likely to have rain during the dry season and has higher mean carbon stocks for both the deep and shallow soils than either Normanton or Mt Isa, despite Normanton's higher mean annual rainfall. The greater spread of rain through the year at Charters Towers allows more trees to be supported for a given level of annual rainfall. However, the greater interannual variability at Charters Towers leads to greater variability in tree stands due to cycles of drought and recovery.

2.3 Future scenarios

The climate projections for rainfall in this region are highly uncertain, but the increasing temperatures and range of rainfall projections suggest that the dry season rainfall may decrease. The daily rainfall projections from climate change scenarios were not available for the tree modelling. Therefore, we simulated the effects of less rain during the dry season by removing rainfall for an increasing period of time from 1 month (July), to 9 months (March to November) and used these as modified rainfall records in our tree stand modelling. This is akin to either an increase in the length of the dry season, and/or a decrease in the amount of rain falling during the dry season (see Figure 5). We assume that the range of scenarios included will represent the outcomes from no change (baseline) to 9 months dry or the worst case of drying. The impact of removing rainfall for various dry season lengths can be seen in average annual rainfall (mm) for each location in Table 1. The relative decline in rainfall is greater for Charters Towers than the other locations due to the greater proportion of rainfall it currently receives during the dry season.

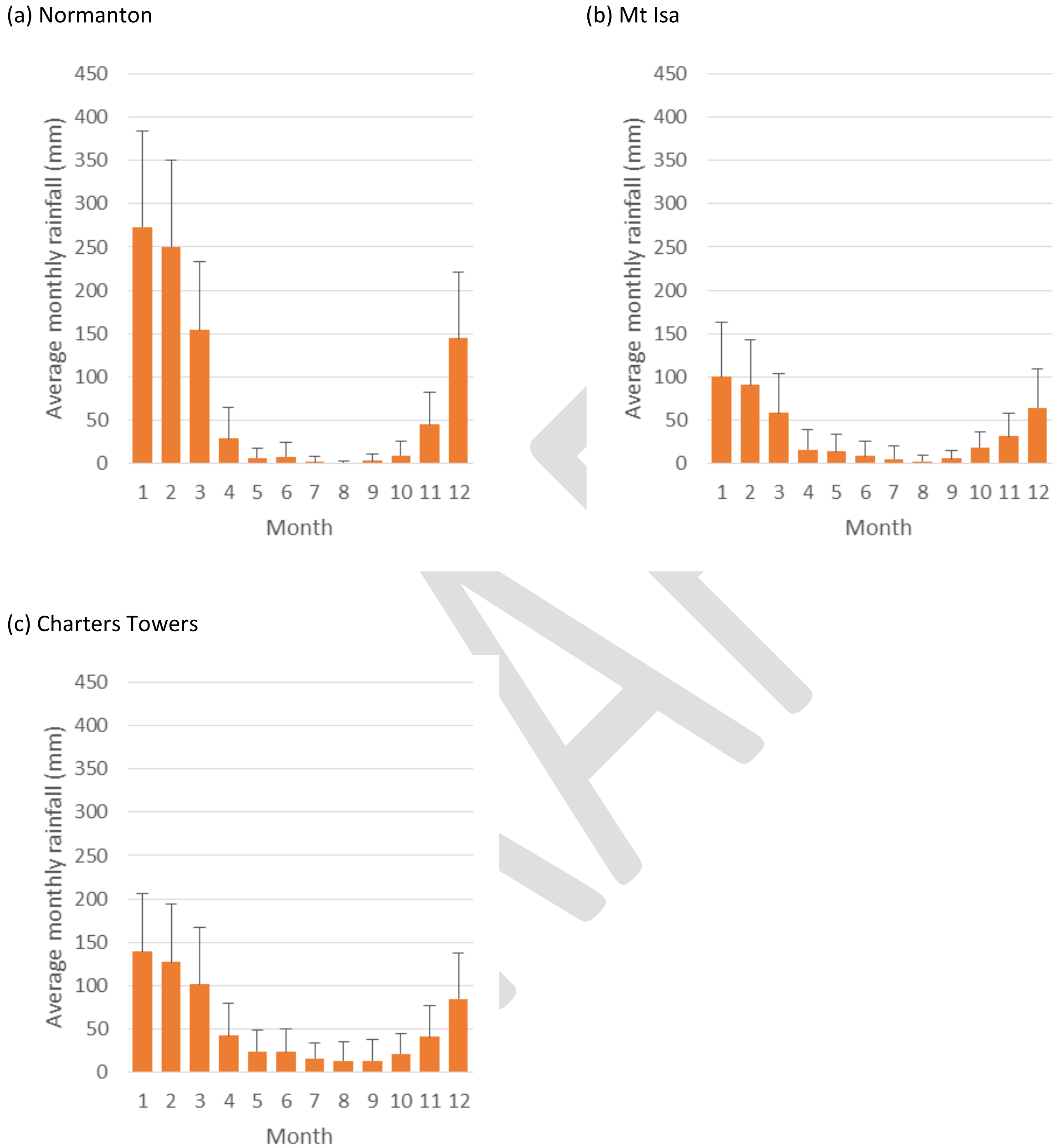


Figure 7 Simulated average monthly rainfall (mm) for (a) Normanton, (b) Mt Isa and (c) Charters Towers based on historic daily rainfall records

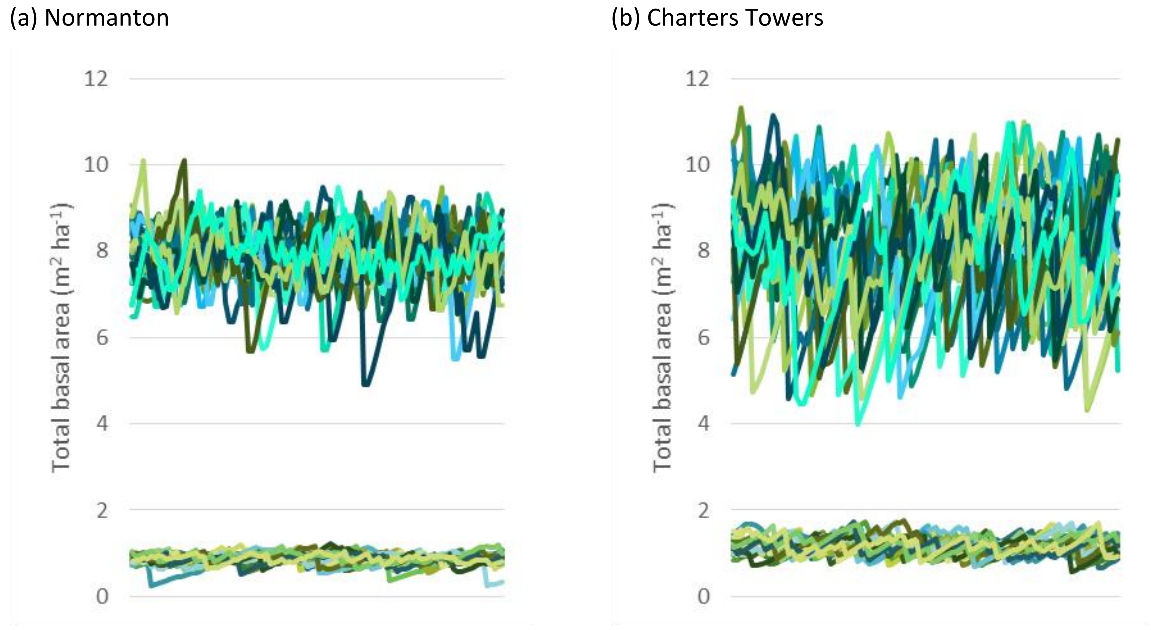


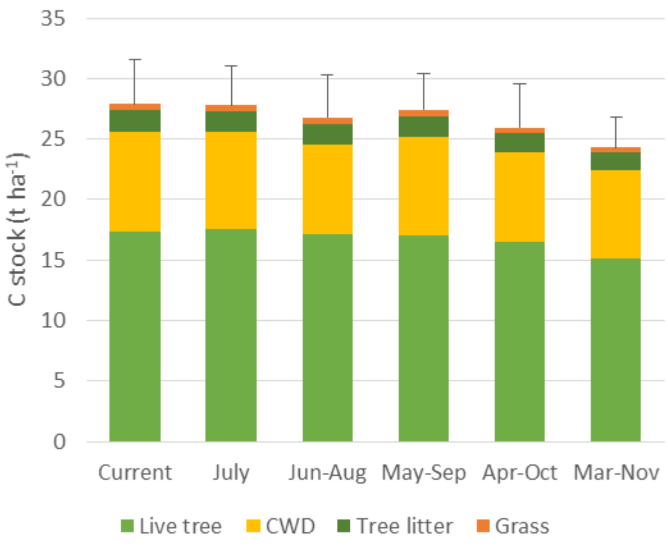
Figure 8 Simulated total basal areas of tree stands for 20 initial populations over 100 years for 120 cm (top) and 40 cm (bottom) soil depths for (a) Normanton and (b) Charters Towers

Table 1 The average simulated annual rainfall (mm) for north Queensland NRM locations given current historic rainfall patterns and increasing dry season length with no rainfall from 1 to 9 months.

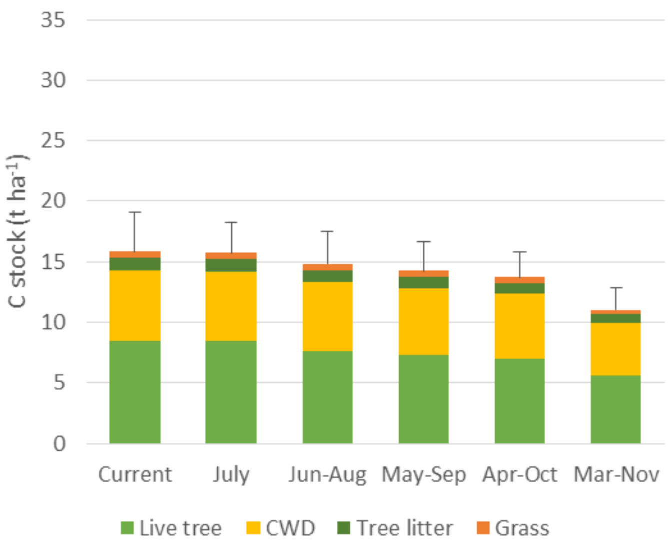
DRY SEASON LENGTH	NORMANTON	CHARTERS TOWERS	MOUNT ISA
Current rainfall	927	650	420
Dry July	925	631	420
Dry June-August	923	589	399
Dry May-September	899	557	375
Dry April-October	865	513	352
Dry March-November	696	382	282

This leads to the impact of increasing dry season length and severity on carbon stocks being greatest for Charters Towers (Table 2 and Figure 9). This was expected as the tree stands in Charters Towers under current conditions are in equilibrium with a system receiving more winter or dry season rainfall than Normanton or Mt Isa.

(a) Normanton



(b) Mt Isa



(c) Charters Towers

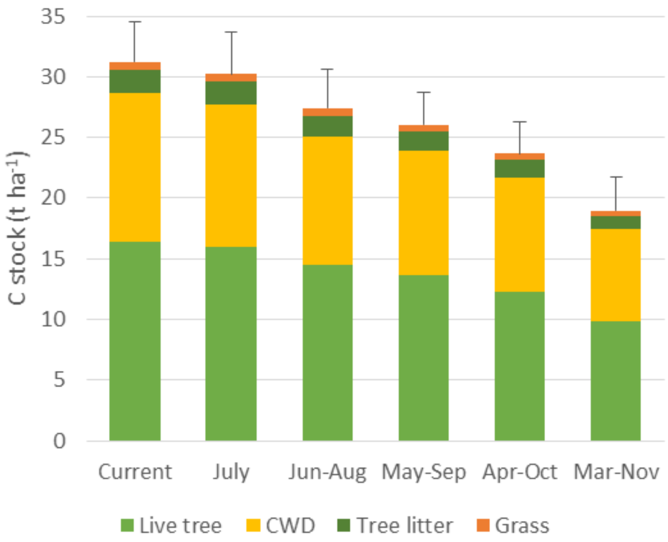


Figure 9 Average simulated carbon stock (100 years) of live above ground tree, coarse woody debris (CWD), tree litter and grass (t ha^{-1}) for 120 cm of soil at (a) Normanton, (b) Mt Isa and (c) Charters Towers based on current and increasing dry season severity scenarios from 1 month to 9 months with total stock standard deviation as error bars

Table 2 The average predicted change in total above ground carbon stock (t ha^{-1}) from the current baseline with increasing length of dry season with no rainfall for north Queensland NRM locations with shallow and deep soils

Location	Current C stock (t ha^{-1})	Change in C stock with no rain (t ha^{-1})				
		July	Jun-Aug	May-Sep	Apr-Oct	Mar-Nov
Shallow soil (depth = 40 cm)						
Normanton	3.9	-0.1	-0.1	-0.2	-0.4	-0.7
Mt Isa	3.4	0	-0..1	-0.4	-0.4	-1.0
Charters Towers	5.4	-0.3	-0.9	-1.4	-1.6	-2.1
Deep soil (depth = 120 cm)						
Normanton	27.9	-0.1	-1.1	-0.5	-1.9	-3.6
Mt Isa	15.9	-0.1	-1.0	-1.6	-2.1	-4.8
Charters Towers	31.2	-1.0	-3.8	-5.2	-7.5	-12.2

The changes in carbon stock reported are primarily the result of a decrease in live above ground tree biomass, which in turn results in a decline in coarse woody debris (CWD).

Under the most severe drying scenario (120 cm soil with a 9 month drought from March to November) the modelled declines in the average potential above ground carbon stocks were 3.6, 4.8 and 12.2 t ha^{-1} for Normanton, Mt Isa and Charters Towers respectively. This equates to significant decreases in the stored landscape carbon stock.

2.4 Management options.

If climate change leads to reduced rainfall during the dry season, then the predicted declines in the carbon stored in tree stands are highly likely to follow. This means that the upper carbon stock storage capacity for the region would decline. If a reduction in dry season rainfall extended southwards into the Charters Towers region and beyond where significant winter rainfall currently occurs then the impact on carbon stocks will be substantial.

Such a decline in carbon stock would not be the result of any land management practice, but would need to be taken into account in carbon farming methodologies. These would need to reflect altered baselines and potential greenhouse gas benefits from management actions. It would be necessary to demonstrate a sustained change in dry season rainfall to start to take the impacts into account.

Regardless of predicted negative trends in tree populations under climate change, managers will still aim to manage landscapes for the lowest reasonable emissions and highest reasonable carbon storage to maximise abatement. While a decrease in tree stands and associated carbon stocks would appear to reduce the economic return from abatement, shifts in the tree/grass balance and decomposition versus combustion pathways of coarse woody debris add complexity to predicting the outcome.

While the carbon stock graphs suggest both live and dead biomass pools will decline under an increase in dry season length, the simulations do not account for management options to change fire frequency. Fire frequency may have a greater impact on the stores of fuel loads, particularly coarse woody debris, than some of the changes in rainfall have on the overall tree stand. For this reason managing fire for fuel loads as well and tree populations is still very important. It may also be found that reducing the current fire frequency from that used in the model simulations may actually mitigate the predicted losses due to changes in rainfall. There is also a period where the management of coarse woody debris from trees as they die from water stress or other causes may be beneficial.

Management options to improve tree stands in this region, such as reforesting degraded areas, may also counteract any decline due to rainfall patterns.

3 Top End of Northern Territory

3.1 Study Sites

Two towns were selected to represent the Top End of the Northern Territory NRM area. These were Darwin, representing a high rainfall location (1602 mm yr^{-1}) and Katherine (965 mm yr^{-1}) representing a low rainfall location (Figure 10). Both locations show seasonal rainfall with the majority of rain falling in the wet season (summer) as a result of monsoon driven events with <4% and <2% of the annual rainfall occurring between May and August inclusive in Darwin and Katherine respectively.

(a) Darwin (b) Katherine

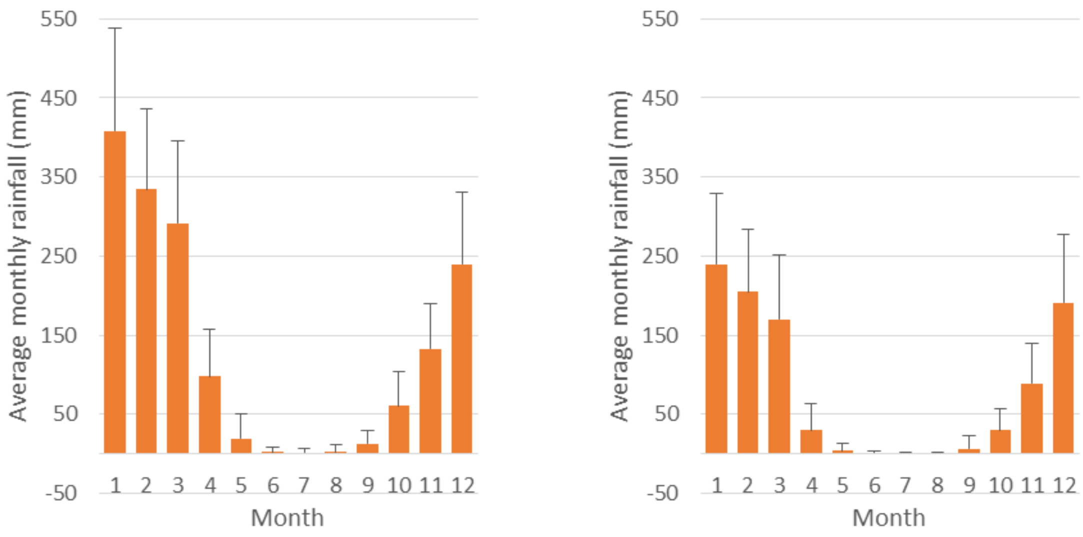


Figure 10 Simulated average monthly rainfall (mm) for (a) Darwin and (b) Katherine based on historic daily rainfall records

3.2 Contemporary situation

An example of the variation in tree stands for the two locations is shown in Figure 11. Here the data lines represent the 20 simulations showing changes in total basal areas of trees over a 100 year periods for Darwin and Katherine with a either a deep (120 cm) or shallow (40 cm) soil.

We would expect that these simulated ranges of values would encompass natural variation in tree stands at these soil depths. Tree stands on soils of with depths between 40 cm and 120 cm should be of intermediate total basal area. The range of total basal area for deep soils at Darwin at about 8 to 12 m^2 ha^{-1} was greater than that at Katherine at about 7 to 10 m^2 ha^{-1}. The mean simulated carbon stock of the two locations (Table 3) reflects variation in mean annual rainfall.

(a) Darwin (b) Katherine

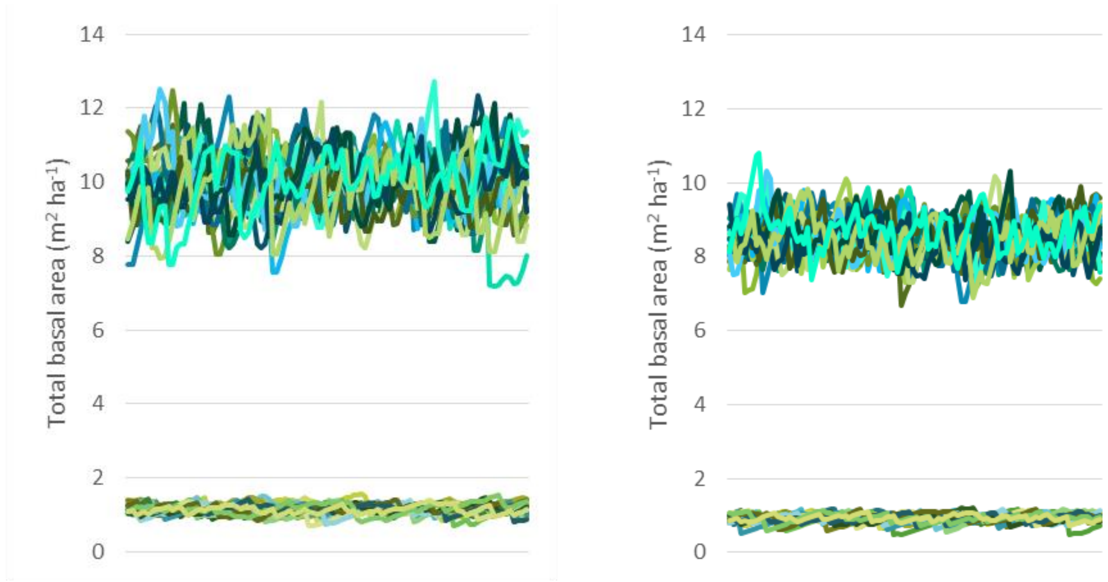


Figure 11 Simulated total basal areas of tree stands for 20 initial populations over 100 years for 120 cm (top) and 40 cm (bottom) soil depths for (a) Darwin and (b) Katherine

3.3 Future scenarios

The climate projections for rainfall in this region are highly uncertain, but the increasing temperatures and range of rainfall projections suggest that the dry season rainfall may decrease. The daily rainfall projections from climate change scenarios were not available for the tree modelling. Therefore, we simulated the effects of less rain during the dry season by removing rainfall for an increasing period of time from 1 month (July) to 9 months (March to November) and used these as modified rainfall records in our tree stand modelling. This is akin to either an increase in the length of the dry season, and/or a decrease in the amount of rain falling during the dry season (see Figure 5). We assume no change in wet season rainfall and that the range of scenarios included will represent the outcomes from no change (baseline) to 9 months dry or the worst case of drying. The impact of removing rainfall for various dry season lengths can be seen in average annual rainfall (mm) for each location in Table 3.

Table 3 The average simulated annual rainfall (mm) for the Top End Northern Territory NRM locations given current historic rainfall patterns and increasing dry season length with no rainfall from 1 to 9 months.

DRY SEASON LENGTH	DARWIN	KATHERINE
Current rainfall	1603	966
Dry July	1597	967
Dry June-August	1591	977
Dry May-September	1559	951
Dry April-October	1466	938
Dry March-November	1115	732

There was minimal impact on tree carbon stocks of increasing dry season length until the dry season was extended from April to October for Darwin and from March to November for Katherine. This is because both locations have little rain during the dry season under contemporary conditions. Katherine in particularly is not affected by reducing rainfall from April to October which represents the current long dry season (Table 4 and Figure 12).

(a) Darwin

(b) Katherine

Figure 12 Average simulated carbon stock (100 years) of live above ground tree, coarse woody debris (CWD), tree litter and grass (t ha^{-1}) for 120 cm of soil at (a) Darwin and (b) Katherine based on current and increasing dry season severity scenarios from 1 month to 9 months with total stock standard deviation as error bars

Table 4 The average predicted change in total above ground carbon stock (t ha^{-1}) from the current baseline with increasing length of dry season with no rainfall for Top End Northern Territory NRM locations with shallow and deep soils

Location	Current C stock (t ha^{-1})	Change in C stock with no rain (t ha^{-1})				
		July	Jun-Aug	May-Sep	Apr-Oct	Mar-Nov
Shallow soil (depth = 40 cm)						
Darwin	5.3	0.1	-0.1	-0.4	-0.8	-1.4
Katherine	4.7	0.0	-0.1	-0.2	-0.3	-0.8
Deep soil (depth = 120 cm)						
Darwin	38.8	-0.4	-0.3	-1.9	-4.7	-10.0
Katherine	34.6	-0.8	-0.1	-0.4	-1.6	-5.4

The changes in carbon stock reported are primarily the result of a decrease in live above ground tree biomass, which in turn results in a decline in coarse woody debris (CWD).

Under the most severe drying scenario (120 cm soil with a 9 month drought from March to November) the modelled declines in the average potential above ground carbon stocks were 10.0 and 5.4 t ha^{-1} for Darwin and Katherine respectively. This equates to significant decreases in the stored landscape carbon stock.

3.4 Management options.

If climate change leads to reduced rainfall during the dry season, then the predicted declines in the carbon stored in tree stands are highly likely to follow. This means that the potential carbon stock storage capacity for the region would decline. The Top End of the Northern Territory NRM currently supports substantial tree stands for Australian savanna woodlands. Therefore any decline in these stands will result in significant reductions in C stocks.

Such a decline in carbon stock would not be the result of any land management practice, but would need to be taken into account in carbon farming methodologies. These would need to reflect altered baselines and potential greenhouse gas benefits from management actions. It would be necessary to demonstrate a sustained change in dry season rainfall to start to take the impacts into account.

Regardless of predicted negative trends in tree populations under climate change, managers will still aim to manage landscapes for the lowest reasonable emissions and highest reasonable carbon storage to maximise abatement. While a decrease in tree stands and associated carbon stocks would appear to reduce the economic return from abatement, shifts in the tree/grass balance and decomposition versus combustion pathways of coarse woody debris add complexity to predicting the outcome.

While the carbon stock graphs suggest both live and dead biomass pools will decline under an increase in dry season length, the simulations do not account for management options to change fire frequency. Fire frequency may have a greater impact on the stores of fuel loads, particularly coarse woody debris, than some of the changes in rainfall have on the overall tree stand. For this reason managing fire for fuel loads as well and tree populations is still very important. It may also be found that reducing the current fire frequency from that used in the model simulations may actually mitigate the predicted losses due to changes in rainfall. There is also a period where the management of coarse woody debris from trees as they die from water stress or other causes may be beneficial.

Management options to improve tree stands in this region, such as reforesting degraded areas, may also counteract any decline due to rainfall patterns. Managing invasive grasses such as Gamba grass that leads to increased fire intensities and resulting tree declines may also improve regional tree stocks.

4 Kimberley region of Western Australia

4.1 Study Sites

Two towns were selected to represent the Kimberley region of Western Australia NRM area. These were Kununurra, representing a high rainfall location (812 mm yr^{-1}) and Fitzroy Crossing (532 mm yr^{-1}) representing a low rainfall location. Both locations show strongly seasonal rainfall with the majority of rain falling in the wet season (summer, Figure 13) as a result of monsoon driven events with <2% and <8% of the annual rainfall occurring between May and August inclusive in Kununurra and Fitzroy Crossing respectively.

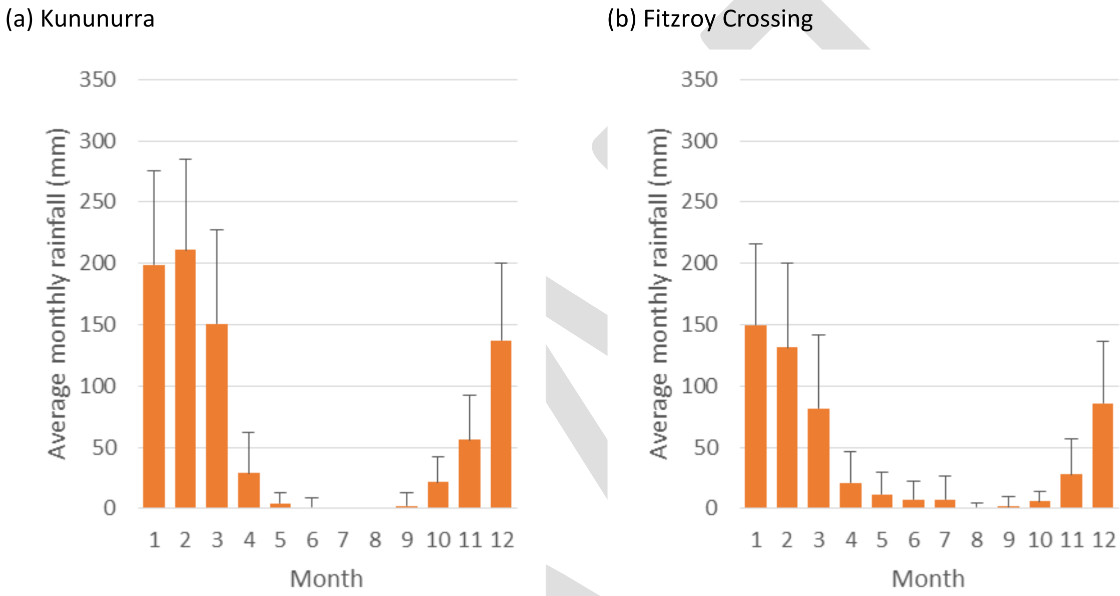


Figure 13 Simulated average monthly rainfall (mm) for (a) Kununurra and (b) Fitzroy Crossing based on historic daily rainfall records

4.2 Contemporary situation

An example of the variation in tree stands for the two locations is shown in Figure 14. Here the data lines represent the 20 simulations showing changes in total basal areas of trees over a 100 year periods for Kununurra and Fitzroy Crossing with a either a deep (120 cm) or shallow (40 cm) soil. Tree stands on soils of with depths between 40 cm and 120 cm should be of intermediate total basal area. The range of total basal area for deep soils at Kununurra at about 5 to 10 m^2 ha^{-1} was greater than that at Fitzroy Crossing at about 3 to 9 m^2 ha^{-1}.

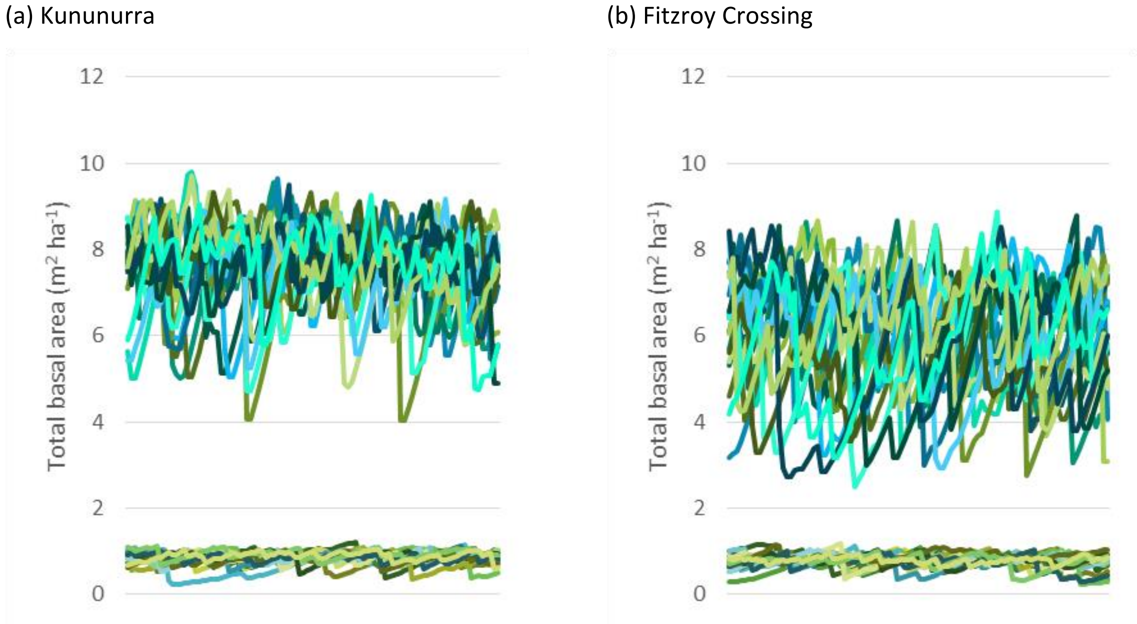


Figure 14 Simulated total basal area for 100 years and 20 initial populations for 120 cm (top) and 40 cm (bottom) soil depth for (a) Kununurra and (b) Fitzroy Crossing

4.3 Future scenarios

The climate projections for rainfall in this region are highly uncertain, but the increasing temperatures and range of rainfall projections suggest that the dry season rainfall may decrease. The daily rainfall projections from climate change scenarios were not available for the tree modelling. Therefore, we simulated the effects of less rain during the dry season by removing rainfall for an increasing period of time from 1 month (July), to 9 months (March to November) and used these as modified rainfall records in our tree stand modelling. This is akin to either an increase in the length of the dry season, and/or a decrease in the amount of rain falling during the dry season (see Figure 5). We assume that the range of scenarios included will represent the outcomes from no change (baseline) to 9 months dry or the worst case of drying. The impact of removing rainfall for various dry season lengths can be seen in average annual rainfall (mm) for each location in Table 5.

Table 5 The average simulated annual rainfall (mm) for the Kimberley region of Western Australia NRM locations given current historic rainfall patterns and increasing dry season length with no rainfall from 1 to 9 months.

DRY SEASON LENGTH	KUNUNURRA	FITZROY CROSSING
Current rainfall	813	533
Dry July	813	527
Dry June-August	807	519
Dry May-September	808	500
Dry April-October	777	480
Dry March-November	601	394

Both locations displayed similar impacts of increasing dry season length and severity (Figure 15 and

Table 6).

The changes in carbon stock reported are primarily the result of a decrease in live above ground tree biomass, which in turn results in a decline in coarse woody debris (CWD).

The worst case scenario (120 cm soil with a 9 months drought from March to November) revealed that we could expect declines in the average potential above ground carbon stocks of 3.8 and 4.3 t ha^{-1} for Kununurra and Fitzroy Crossing respectively. This equates to significant decreases in the stored landscape carbon stock of between 15 and 22 percent.

4.4 Management options.

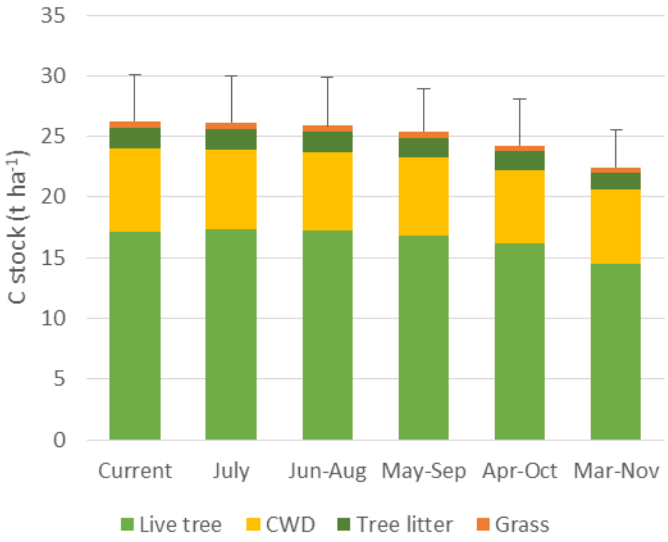
If climate change leads to reduced rainfall during the dry season, then the predicted declines in the carbon stored in tree stands are highly likely to follow. This means that the upper carbon stock storage capacity for the region would decline. Any decline in these stands will result in significant reductions in C stocks. Such a decline in carbon stock would not be the result of any land management practice, but would need to be taken into account in carbon farming methodologies. These would need to reflect altered baselines and potential greenhouse gas benefits from management actions. It would be necessary to demonstrate a sustained change in dry season rainfall to start to take the impacts into account.

Regardless of predicted negative trends in tree populations under climate change, managers will still aim to manage landscapes for the lowest reasonable emissions and highest reasonable carbon storage to maximise abatement. While a decrease in tree stands and associated carbon stocks would appear to reduce the economic return from abatement, shifts in the tree/grass balance and decomposition versus combustion pathways of coarse woody debris add complexity to predicting the outcome.

While the carbon stock graphs suggest both live and dead biomass pools will decline under an increase in dry season length, the simulations do not account for management options to change fire frequency. Fire frequency may have a greater impact on the stores of fuel loads, particularly coarse woody debris, than some of the changes in rainfall have on the overall tree stand. For this reason managing fire for fuel loads as well and tree populations is still very important. It may also be found that reducing the current fire frequency from that used in the model simulations may actually mitigate the predicted losses due to changes in rainfall. There is also a period where the management of coarse woody debris from trees as they die from water stress or other causes may be beneficial.

Management options to improve tree stands in this region, such as reforesting degraded areas, may also counteract any decline due to rainfall patterns.

(a) Kununurra



(b) Fitzroy Crossing

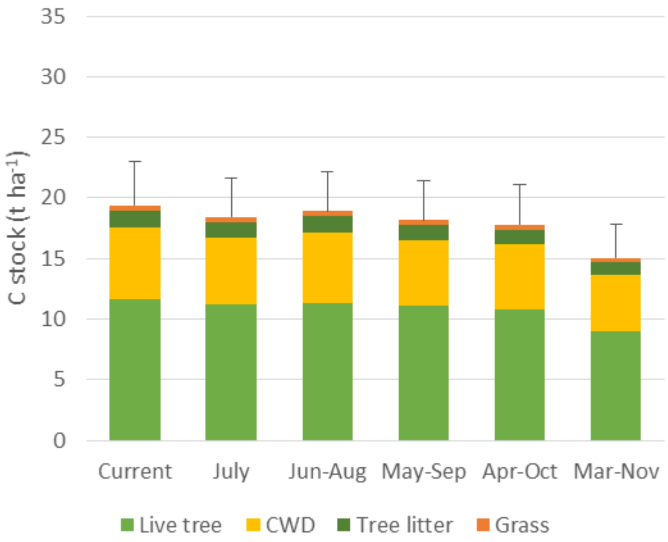


Figure 15 Average simulated carbon stock (100 years) of live above ground tree, coarse woody debris (CWD), tree litter and grass (t ha^{-1}) for 120 cm of soil at (a) Kununurra and (b) Fitzroy Crossing based on current and increasing dry season severity scenarios from 1 month to 9 months with total stock standard deviation as error bars

Table 6 The average predicted change in total above ground carbon stock (t ha^{-1}) from the current baseline with increasing length of dry season with no rainfall for the Kimberley region of Western Australia NRM locations with shallow (40 cm) and deep soils (120 cm)

Location	Current C stock (t ha^{-1})	Change in C stock with no rain (t ha^{-1})				
		July	Jun-Aug	May-Sep	Apr-Oct	Mar-Nov
Shallow soil (depth = 40 cm)						
Kununurra	3.6	0.0	0.1	-0.1	-0.2	-0.6
Fitzroy Crossing	3.3	-0.1	-0.2	-0.3	-0.4	-0.7
Deep soil (depth = 120 cm)						
Kununurra	26.2	-0.1	-0.4	-0.9	-2.0	-3.8
Fitzroy Crossing	19.4	-0.9	-0.5	-1.2	-1.6	-4.3

5 Summary

This project was designed to explore the implications of climate change in the Monsoonal North NRM region on the ability to manage fire for carbon farming and emissions abatement using the savanna fire methodology under the Carbon Farming Initiative / Emissions Reduction Fund. The savanna fire methodology presents default parameters to calculate the emissions abatement that is deemed to occur as a result of changing the fire regime in defined project areas. Although climate change may cause the value of these parameters to alter in the future, they will remain as the default values until a revised or new methodology is produced.

There is still a level of uncertainty in the climate projections both due to the current inability of climate models to provide the fine scale measures required (such as wind speed and storm activity) and because we do not know what international processes will be implemented to reduce global warming and therefore the exact conditions that will eventuate. Regardless, there will still be a window of opportunity in future in which to apply control burning and reduce the chance of large, late dry season fires which have higher emissions and are more damaging to the savannas. This means fire management to maintain or improve carbon stocks and participate in carbon trading will still be a valuable tool.

We used a process based, demographic model (Flames) to explore the impact of the predicted changes in seasonal rainfall on tree stands and resulting carbon stocks. Increasing the length of the dry season was found to have a marked impact on vegetative carbon stocks. The effect was observed in all NRM regions in the Monsoonal North, but has the potential to be greatest in the Charters Towers region of Queensland, which currently has the greatest likelihood of winter rainfall. Such changes would alter the tree-grass balance and thus the makeup and amount of the fuel for savanna fires. If it could be demonstrated that such changes were permanent, then future versions of the savanna fire methodology would need to be reparametrized.

The simulations help us to distinguish what changes are part of a naturally variable climate of northern Australia and what could be expected from a shift in baseline climate in the region whether a change in temperature, humidity or rainfall pattern, all of which will affect trees and fire dynamics.

While the model predicts some decline in tree stands and associated carbon stocks, there is potential to mitigate the loss through fire management to improved carbon pools stored in coarse woody debris, revegetate degraded areas and reduce other threats such as invasive grasses which can lead to increased fuel loads, altered fire and a further dramatic decline in tree stands.

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