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Multi-scaled calibration of high-resolution burnt area and fire severity mapping - workshop report

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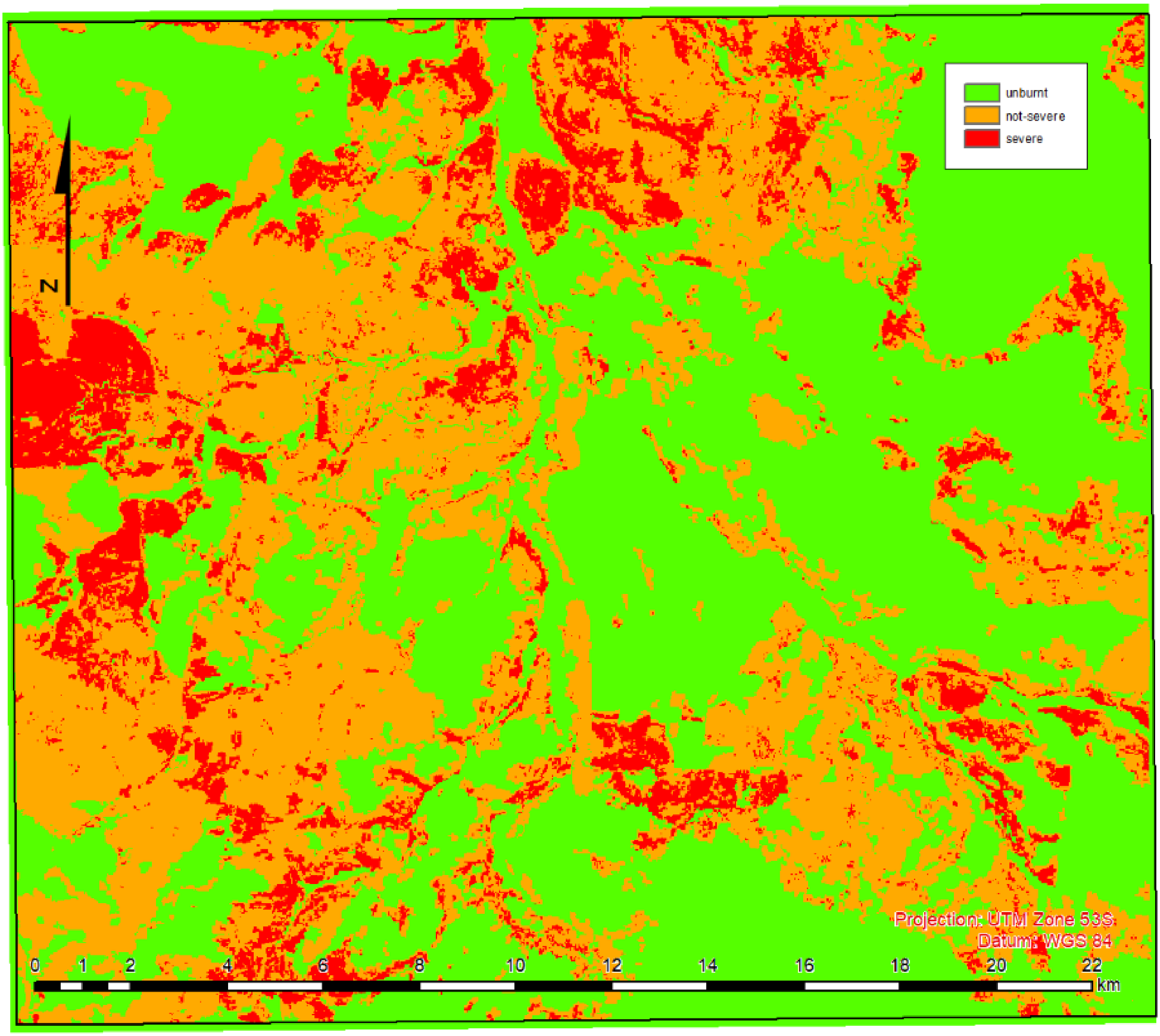

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We would like to thank the participation of key individuals, whose exceptional operational experience in the development and supply of useful fire mapping products made this workshop worthwhile. The attendees at the workshop included our long standing collaborators from NASA:
Professors Luigi Boschetti from the University of Idaho and;
Professor David Roy from the University of South Dakota;
colleagues from the European Space Agency:
Professor Jose M.C. Pereira from the Instituto do Agronomia, Lisbon and;
Professor João Neves Silva from the Instituto do Agronomia, Lisbon;
colleagues from the Queensland Department of Science and the Environment:
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colleagues from the Darwin Centre for Bushfire Research:
Dr Rohan Fisher, Mr Cameron Yates, Mr Patrice Weber, and Professor Jeremy Russell-Smith;
and our long time colleague:
Dr Stefan Maier from Maitec.

Also in attendance to help guide the appropriateness of the science were colleagues from the National Greenhouse Gas Inventory Team, including leading remote sensing scientist Dr Shanti Reddy.

ABSTRACT

Many remote Indigenous communities in the tropical savannas of northern Australia reply upon "Savanna Burning" methods, as payment for ecosystem services, providing employment and supporting their livelihoods. The methods rely upon accurate science to calculate greenhouse gas emissions. The current methods use fire seasonality to discriminate emissions estimates, whereas fire severity, if mapped with adequate accuracy, will provide a greenhouse gas emissions method more appropriate to customary burning, by advantaging low severity fires, that has the added advantage of being of overall benefit to biodiversity.

In November 2018, we brought an international group of remote sensing scientists together to develop a collaborative program to increase the spatial resolution of current burnt area mapping programs and incorporate fire severity within them. This report firstly outlines the requirements for the products and summarises the findings of the workshop.

END-USER STATEMENT

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Program Coordinator
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As Program Coordinator at the Darwin Centre for Bushfre Research I manage the savanna burning methodology development projects for future adoption into the multi-million dollar Carbon Industry.

The burnt area and fire severity mapping workshop provided the opportunity for International collaboration, and the development of a spatial fire severity product for northern Australia. Historically, satellite based fire products were purely burnt/unburnt mapping with severity inferred from seasonality. With advancement in satellite sensors and computing, fire severity mapping is now more than ever possible, as was evident through the number of great presentations at the workshop. The international collaborators provided fantastic incites and advice, as all their groups have operationalized large automated mapping programs previously. The development of this fire severity product will build into the current living tree biomass savanna burning methodology which will further develop opportunities for better fire management in northern Australia.

EXECUTIVE SUMMARY

The mapping of the level of effect of fire on vegetation, referred to as fire severity, has the potential to increase the accuracy of greenhouse gas emissions and carbon sequestration calculations. However, unlike burnt area mapping, it is not readily discernible from a satellite image, meaning that it can not be manual mapped by a human operator. Automated burnt area mapping has yet to demonstrate the accuracy of semi-automated methods, improved by the complex interpretive capabilities of a human mind, with its abilities to discern context, colouration and texture, unlike any automated algorithm available today. Unfortunately, the intervention of a trained human mind is not possible with fire severity mapping as there are few direct optical links available through the bands available in an image derived from a satellite-borne sensor. The challenge for fire severity mapping then is to develop an automated mapping system that can be improved by ground observation in a pure machine learning environment, accounting for seasonal changes such as curing, soil moisture and deciduousness.

The Bushfire and Natural Hazards CRC has funded research into the development of a fire severity mapping system for a number of years. In this workshop, this body of research was examined and expanded through a collaboration from international scientists working in this field from NASA, the European Space Agency and leading Australian agencies.

The outcome of the workshop is further collaboration, and the opportunity to develop meaningful spatiall explicit fire severity outputs to improve carbon farming opportunites.

BACKGROUND

Many remote Indigenous people in north Australia are shifting to payment for ecosystem services (PES) economies, thus moving away from capricious government programs, and reducing risk to communities, empowering people economically, socially and culturally.

Many ecosystem services revolve around active land management, such as in joint management arrangements with national, state and territory conservation agencies; Indigenous Protected Area management through Working on Country funding; pastoral activities of one sort or another through the Indigenous Land Corporation. However, each of these arrangements still leaves people vulnerable to the vagaries of short-term government programs and funding directions. The natural answer to this problem is for them to move into non-government industries, such as "Savanna Burning".

The Savanna Burning program not only grew out of the need to provide better economic opportunities for remote Indigenous people in north Australia, but was initially a response by scientists to the obvious and accelerating demise of biodiversity, seen at the time to be strongly influenced by poor fire management. The advent of satellite based sensors in the 70's, and its free access from NASA in the 90's, provided scientists with real and regular images, deriving data regarding the distribution, occurrence, seasonality and severity of fires. Fires were noticeably far more wide spread and deleterious than in previous national assessments (State of the Environment 1996).

Savanna Burning uses robust scientific methods to describe greenhouse gas emissions abatement and carbon sequestration, but with a strong ecological focus. Management is forced to focus on reducing total area burnt, by implementing strategic EDS burning to mitigate wildfire in the LDS. Habitats that require a fire management regime not compatible with the methods are purposely excluded. For instance, floodplain areas do not dry out until very late in the dry season, when burning is disadvantageous to a carbon project, but, in many places they are burnt for traditional hunting and management, having been burnt in this manner customarily, therefore floodplain habitats are not included to allay any perverse outcome. Similarly, grassland habitats in many northern areas can be readily permeated by Melaleuca *spp*. (generally *M. Viridiflora*), converting them into woodlands. There are many species that inhabit these grasslands exclusively (Garnett and Crowley 1995, Russell-Smith *et al.* 2014). This suggests that customary fire management has maintained these habitats, without it, the reduction in these habitats will move some species to extinction. The grasslands need regular hot fires to eliminate the Melaleuca, again, the Savanna Burning program would be disadvantaged by this regime, and to reduce the possibility of losing this habitat, it is not included in the methodology.

To date, Savanna Burning methodologies have relied on the seasonal occurrence of fires. Emissions are related to the amount of biomass consumed, a high severity fire consumes more biomass, and therefore emits more gas. It is well understood that a certain small proportion of high severity fires occur in the early dry season (EDS), but that the majority of EDS fires are low to moderate (~95% in one study, (Russell-Smith and Edwards 2006)). However, in the late dry season (LDS) the distribution is more even, more like 30/40/30 for low/moderate/high, and sometimes even extreme, with documented evidence of extreme fires covering many hundreds of km^2 (Edwards *et al.* 2018). Therefore, to improve emissions estimates, fire seasonality needs to be replaced by fire severity mapping, forcing fire management programs to restrain fire severity as much as possible in the appropriate habitats, and to assist those regions that feel they need, and can successfully, burn appropriately outside of the EDS constraint, such is a common complaint in north Queensland, although research would suggest otherwise (Crowley and Garnett 2000).

EDS fires are highly patchy and affect less of the vegetation, making them far more difficult to discern from satellite-based imagery (Edwards *et al*. 2018). The most useful means of reducing these inhibiting factors is through increased spatial resolution, however, it is the case with all available satellite sensors, that an increase in spatial resolution equates to a decrease in image swath width and temporal resolution. Thus, rapid detection is obviously reduced, but most importantly algorithms that rely on a specific window of change detection do not work as efficiently as they do for coarser resolution images with high temporal resolution.

FIGURE 1. EXCERPT FROM THE PRESENTATION BY DR STEFAN MAIER, ILLUSTRATING THE VARIOUS EFFECTS OF FIRE IN NORTH AUSTRALIAN TROPICAL SAVANNA EUCALYPT DOMINATED WOODLANDS

RESEARCH APPROACH

STUDY AREA

The mapping required must cover the extent of the tropical savannas region experiencing > 600 mm mean seasonal rainfall and the main vegetation fuel types included in the "Savanna Burning" methodology, Figure 2. These habitats make up the vast majority of landscape types, including 15% Eucalypt Open Forest, 52% Eucalypt Woodland (both Lowland and Sandstone Woodland), 22% Eucalypt Open Woodland, < 1% Closed Forest (i.e. monsoon jungles), and 11% non-wooded areas (i.e. 0.8% Shrubland, 4.8% Tussock Grassland, 4.5% Hummock Grassland, 0.7% Sedgeland/Samphire etc)

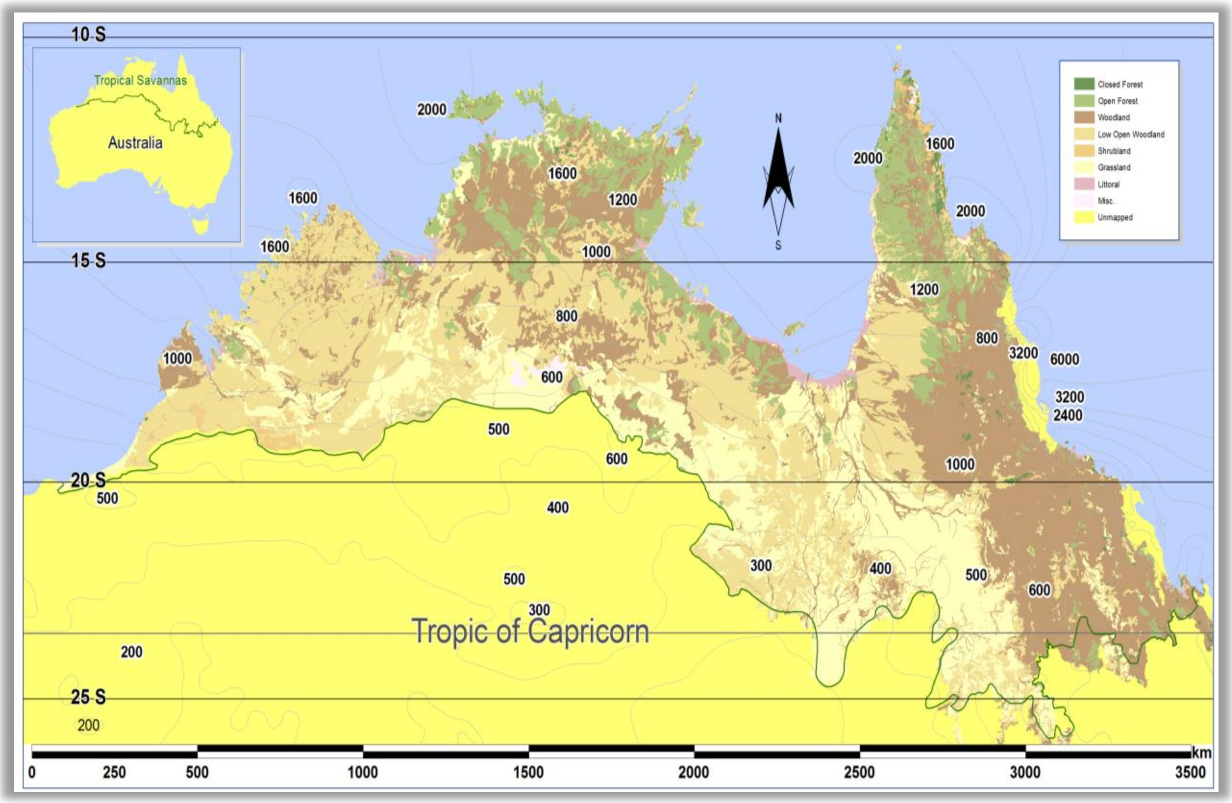

FIGURE 2. THE MAIN VEGETATION STRUCTURE CLASSES AND ISOHYETS OF RAINFALL ACROSS THE TROPICAL SAVANNAS OF NORTHERN AUSTRALIA (AFTER FOX ET AL., 2001).

CLASSIFICATION

FIELD GUIDES HAVE BEEN DEVELOPED FOR BOREAL SYSTEMS (KEY AND BENSON 2006) PARTICULARLY SUITED FOR NORTH AMERICAN AND NORTHERN EUROPEAN SYSTEMS, ALSO FOR MEDITERRANEAN SYSTEMS (DE SANTIS AND CHUVIECO 2009) AND, MOST RELEVANT, LOCAL HABITATS (EDWARDS 2009). THE FIELD GUIDE PROMOTES FIVE CLASSES OF SEVERITY FOR TROPICAL SAVANNAS FROM A FIELD OBSERVATION PERSPECTIVE, HOWEVER, WITH RESPECT TO REMOTE SENSING, IT IS CLEARER TO DELINEATE A SEVERE AND A NOT-SEVERE (BINARY) FIRE SEVERITY CLASSIFICATION,

Figure 3.

The proposal for the binary classification system was discussed at length. The trade-off is between the classification accuracy and the accuracy of the classification, that is, having more classes provides for more detailed analyses of fire effects, but fewer classes improves the overall accuracy.

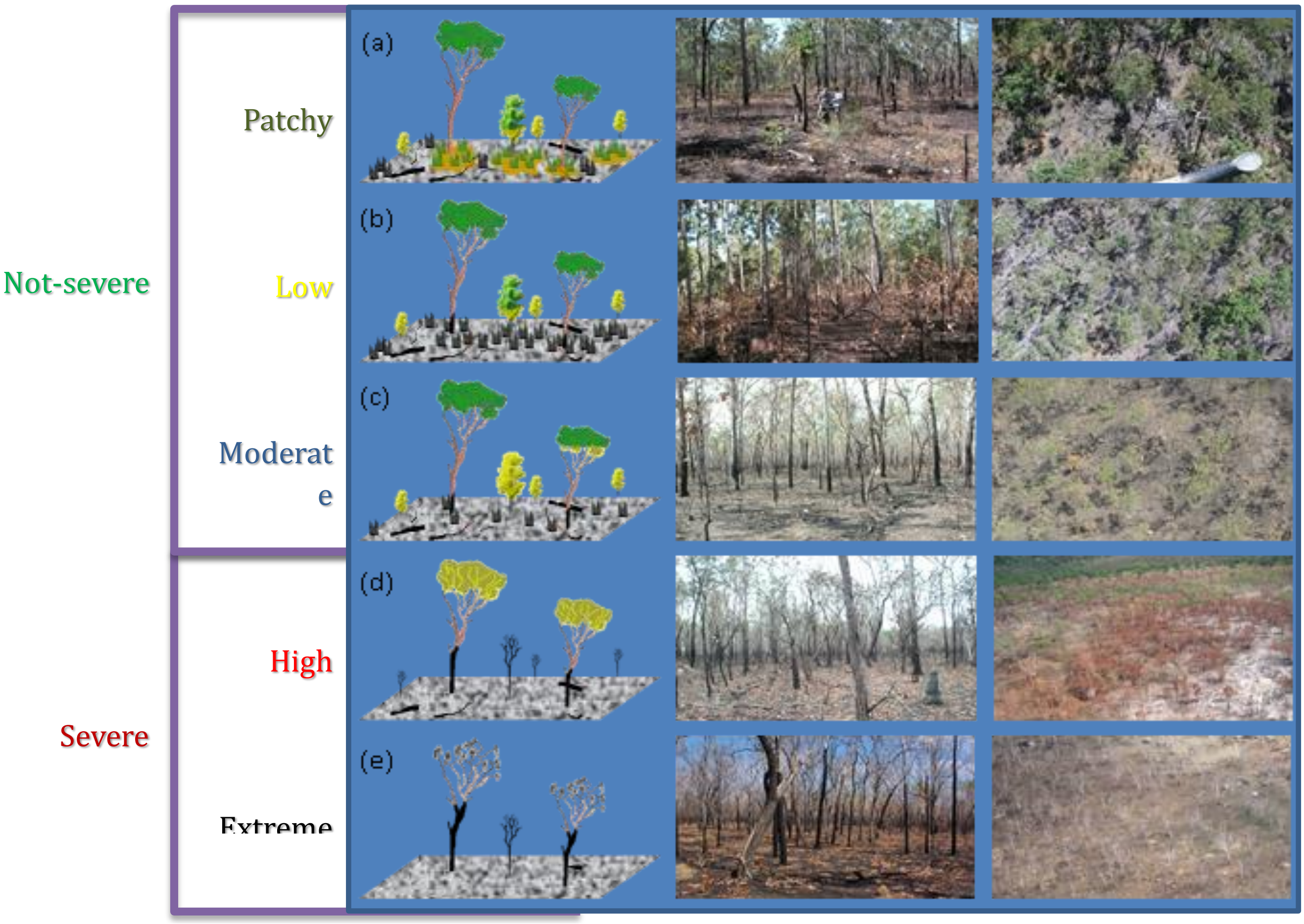

FIGURE 3. THE FIVE GROUND CLASSES OF FIRE SEVERITY, FROM LEFT TO RIGHT, A SCHEMATIC ILLUSTRATING SCORCHED (YELLOW) AND GREEN LEAVES AND BURNT UNDERSTOREY WITH VARIOUS PROPORTIONS OF UNBURNT, BURNT AND SCORCHED PATCHES, NEXT IS A HORIZONTAL IMAGE OF THE VARIOUS FIRE SEVERITY CLASSES, AND LASTLY ON THE RIGHT ARE AERIAL PHOTOS.

BINARY CLASSIFICATION APPLICABILITY

The tropical savanna woodlands and open forest, are generally fairly simply constructed, Figure 4, containing very low proportions of biomass in the lower and mid-storeys. The study in the PhD thesis by Dr Andrew Edwards, detailed the measurements at over 30 eucalypt woodland and open forest sites (Edwards 2011). In unburned sites, the upper canopy contained an average of 45% of the biomass of the total upper canopy area, and 94% of the ground layer biomass area, using a point based method.

The Tropical Savanna Fire Severity field guide referred to earlier, was undertaken with a number of land managers, mostly working in conservation land management, and provided the notion, and support for the notion, of the binary classification.

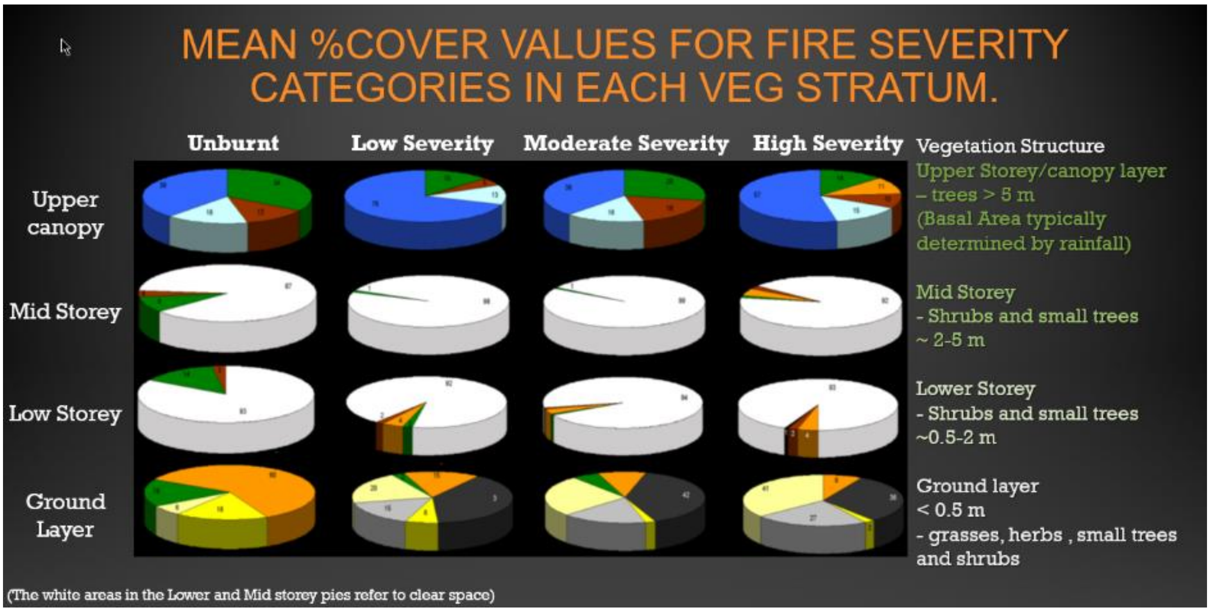

FIGURE 4. ILLUSTRATION OF MEASUREMENTS MADE AT 30 SITES IN TROPICAL SAVANNA WOODLAND AND OPEN FOREST IN THE TOP END OF THE NORTHERN TERRITORY. EACH PIE REPRESENTS A PORTION OF THE CANOPY (NOTED ON THE LEFT) AND THE FIRE EFFECT (NOTED ACROSS THE TOP). EACH PORTION OF EACH PIE REPRESENTS THE PROPORTION OF THAT PHENOMENON: MID-BLUE = OPEN SKY BETWEEN CANOPIES, LIGHT BLUE = OPEN SKY WITHIN CANOPY, BROWN= NON-PHOTOSYNTHETIC VEGETATION (E.G. TWIGS, STEMS, BRANCHES), GREEN = PHOTOSYNTHETIC VEGETATION (I.E. FOLIAGE), WHITE = OPEN AIR IN THE MID AND LOWER STOREYS, ORANGE = SCORCHED/DEAD LEAVES, YELLOW = CURED GRASS, LIGHT YELLOW = BARE GROUND, LIGHT GREY = WHITE MINERAL ASH, DARK GREY = CHARCOAL OR CHARRED LEAVES/STEMS.

EFFICACY OF FIRE SEVERITY MAPPING

The group workshopped an assessment of the various parameters of the greenhouse gas emissions calculations of abatement methodology that would be improved by replacing fire seasonality with fire severity, Figure 5 .

MEASUREMENT ERROR MARKEDLY REDUCED BY TRANSFERRING FROM A SEASONAL TO A SEVERITY BASED MODEL

Factor/Variable	Season	Vegetation Fuel type	Fuel Age+	Fuel type	Gas type
Fuel load*	x	x	x	x	
Patchiness	x				
Burning Efficiency Factor	x			x	
Emissions Factor		x		x	x
N:C				x	
Molecular to elemental mass conversion factor					x
Global Warming Potential					x

* Only Fine fuels accumulate (grass, leaves, stems ≤ 5 mm diam.)
Coarse wood (5mm – 5 cm diam.), Heavy wood (> 5 cm diam.) and Shrubs remain constant

+ Fuel age is dependent upon the time (years) since last fire affected.

FIGURE 5. ASSESSMENT OF THE PARAMETERS INVOLVED IN GREENHOUSE GAS EMISSIONS CALCULATIONS.

The latest method, however, attempts to model the accumulation of coarse woody debris and includes this in the summary calculations for greenhouse gas emissions, unlike the former methodologies that could not find significant relationships between coarse woody debris and the time since last burnt in the higher rainfall region and therefore used only a mean value measured at all sites, and although significant relationships were found for coarse woody debris in the lower rainfall region, again averages were used to be consistent with the high rainfall region.

A proportion of the study sites were burnt and biomass re-measured post-fire. Fire severity was scored according to the field guide, (Edwards 2009), but also scorch height (the strongest relative indicator of fire severity according to the findings of the field guide) and the height of all stems (thus providing mean tree height). Therefore, it is possible to determine the relative proportion of the canopy affected by fire, and a quantitative measure of the fire severity. This than can be applied to develop a relationship between fire severity and biomass burnt (fuel load), for different vegetation fuel types, in different seasons under the various climatic conditions. Similarly for patchiness and, consequently, burning efficiency.

INDICES IN CURRENT USAGE

Work in northern Australia has focused on the development of a single fire severity algorithm that applies a threshold value of the relativisation of the normalised burn ratio derived from the near and short wave infrared bands of the electromagnetic spectrum (Edwards *et al.* 2018):

1. Normalized Burn Ratio

NBR = ((Near Infrared) – (Short-wave Infrared)) / ((Near Infrared) + (Short-wave Infrared))

2. Change in NBR

dNBR = $(NBR_{pre\text{-}fire}) – (NBR_{post\text{-}fire})$

3. Relativized dNBR =

RdNBR = dNBR / $(|NBR_{pre\text{-}fire}|)^{0.5}$

The indices have been applied in two major studies in the region as presented by Dr Edwards, Figure 6, indicating the variation that can be affected by two sensors of very different scale.

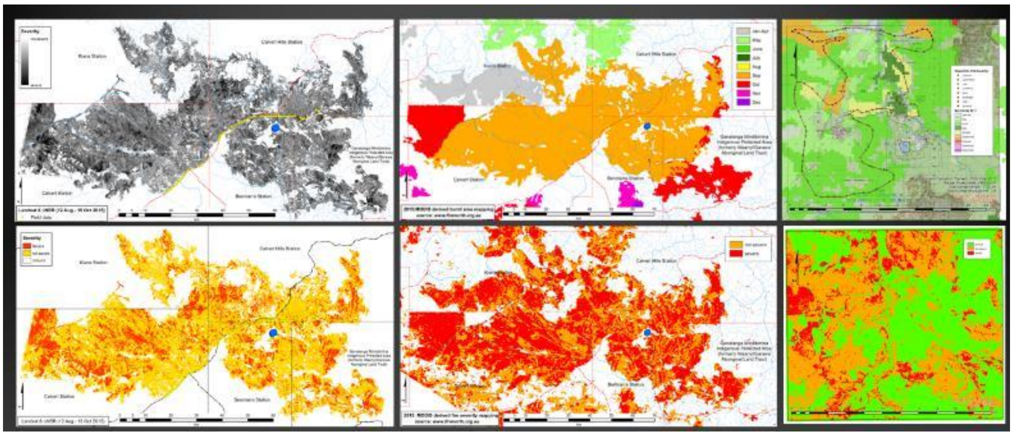

FIGURE 6. FIRE SEVERITY MAPPING RESULTS UNDERTAKEN BY DR ANDREW EDWARDS AND COLLEAGUES AT THE DARWIN CENTRE FOR BUSHFIRE RESEARCH. (A) LANDSAT DNBR SHOWING FULL SPECTRUM OF RESULTS WITH NO CLASSIFICATION, (B)MODIS DERIVED BURNT AREA MAPPING, (C) VALIDATION POINTS COLLECTED AT THE JABIRU STUDY SITE, (D) THE BINARY CLASSIFICATION OF THE DNBR LANDSAT 8-DERIVED MAPPING, (E) FIRE SEVERITY ALGORITHM APPLIED TO MODIS DIFFERENCE IMAGERY AND, (F) LANDSAT 8 DERIVED RDNBR MAPPING IN THE JABIRU AREA.

A DIFFERENT APPROACH

Dr Stefan Maier and Dr David Roy, are separately researching the possibilities of a spectral un-mixing approach, in north Australia and Africa, respectively, an example is given in **Error! Reference source not found.** and illustrated in **Error! Reference source not found.**. It is neither scale dependent nor sensor specific, instead relying solely on the physical nature of fire severity, not an index, so no field calibration is necessary (nor readily possible, which is the counter argument for its application). To date, the field comparison looks reasonable, but very little validation data have been applied.

The Fractional Pixel Burnt approach allows us to directly measure the patchiness factor and therefore, the combustion completeness of the biomass and therefore negates the use of surrogates including seasonality. The assessment found that the shift of some fire regimes from EDS to LDS dominated patterns has reduced the severity of the LDS fires, possibly because the fires are smaller in size and less likely to progress into periods of adverse climate (e.g. high winds and temperatures).

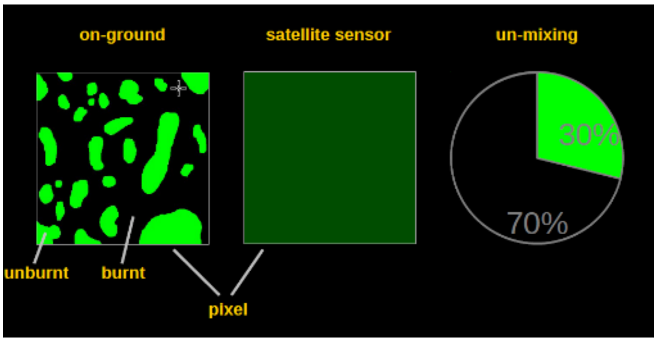

FIGURE 7.SPECTRAL UNMIXING OF MODIS PIXELS (FRACTIONAL PIXEL BURNT).

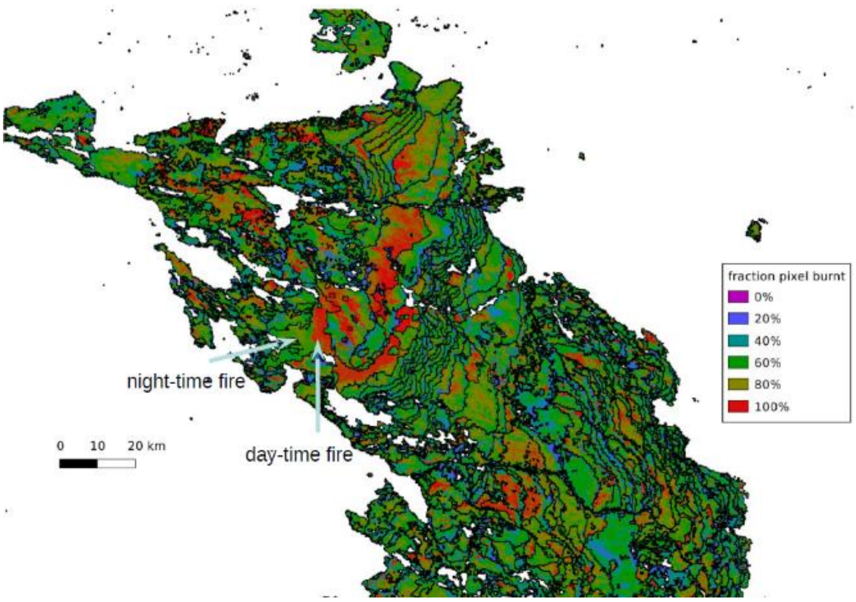

FIGURE 8. EXAMPLE OF FRACTIONAL PIXEL BURNT ALGORITHM APPLIED TO AUTOMATED BURNT AREA MAPPING.

FURTHER APPLICATIONS

At the time of the latest research into the application of fire severity mapping indices, previous studies by the CSIRO in Darwin had found no significant influence of fire regime (that is high versus low severity fires) on tree stem mortality, and living tree biomass overall. Coincident with the research undertaken by Edwards *et al.* (2018) on fire severity mapping was research into the effect of extreme severity fires on tree stem mortality, Figure 9. The overall proportion of extreme fires is, as yet, unknown but it was identified as a significant effect in terms of the proposed methodologies to incorporate Living Tree Biomass calculations into Carbon Sequestration methodologies.

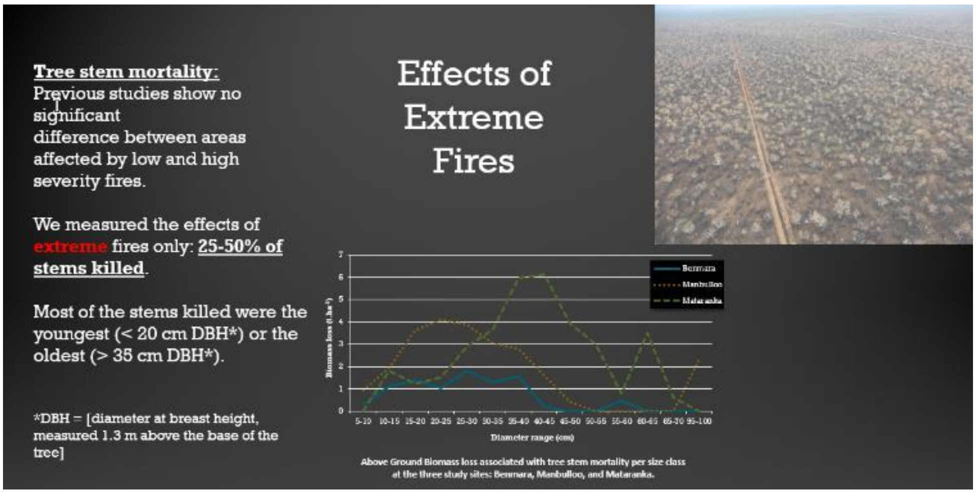

FIGURE 9. EXTRACT FROM THE PRESENTATION BY DR ANDREW EDWARDS, ILLUSTRATING THE MEASURED EFFECTS OF EXTREMELY SEVERE FIRES

OUTCOMES

The workshop was very successful in bringing together some of the latest International and Australian research, and offered many future opportunities to develop fire severity mapping programs.

Dr Roy from NASA offered to use his Fractional Pixel Burnt mapping program being applied in Africa to areas of north Australia. DCBR have an extensive field dataset describing fire severity across many hundreds of kilometres of helicopter transect that can be readily used to calibrate the classification and assess the accuracy.

Dr Leo Hardtke from the Queensland Department of Science and the Environment, has a machine learning system that will, initially, only map burnt areas, as this is the product that fire managers in Queensland are most interested in having, especially in higher density areas where the scale of MODIS derived data is too coarse to meet their needs. However, the system Leo is developing leaves it open to the possibility of readily applying the thresholds developed in the north Australian research.

The Index approach has been tested and provides reasonable results, Figure 10, however relies upon a single threshold to characterise fire severity, it does not account for geographic, topographic, climatic (i.e. seasonal) differences, to most simply calculate fire severity. The data exist to account for these differences and is possibly the most strongly identified future research program for consideration in order to develop an all of north Australia fire severity map product. This would require a machine learning approach where the temporal as well as the location attributes are used to derive the classification. Also, importantly, it needs to use the masking from the NAFI derived fire mapping as it consistently provides far greater mapping accuracy, especially in terms of omission error, Figure 11

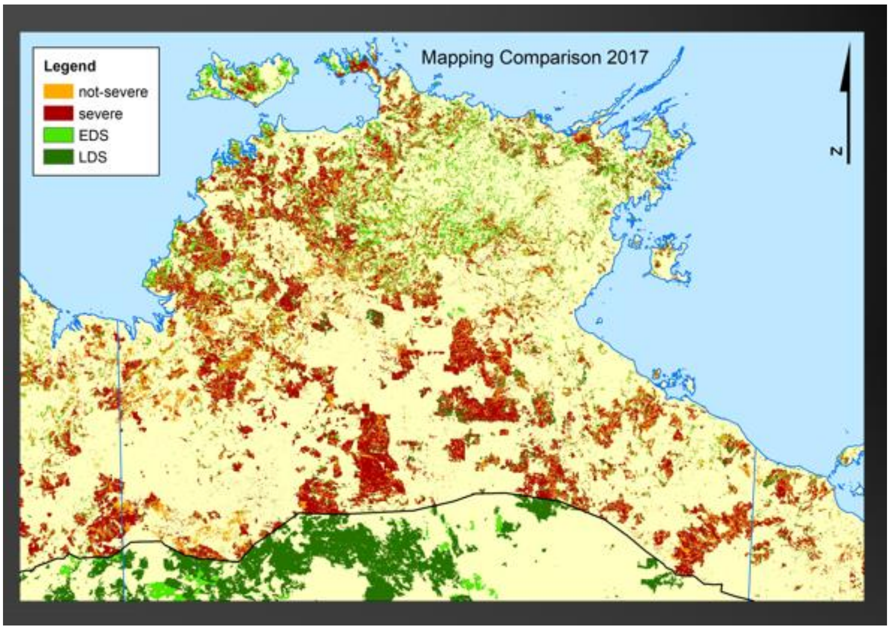

FIGURE 10. A COMPARISON OF THE NAFI BURNT AREA MAPPING CLASSIFIED FOR THE EARLY DR SEASON (EDS AND LATE DRY SEASON (LDS) IN COMPARISON TO THE OUTPUT OF THE AUTOMATED FIRE SEVERITY MAPPING, FOR THE TOP END OF THE NORTHERN TERRITORY, AUSTRALIA.

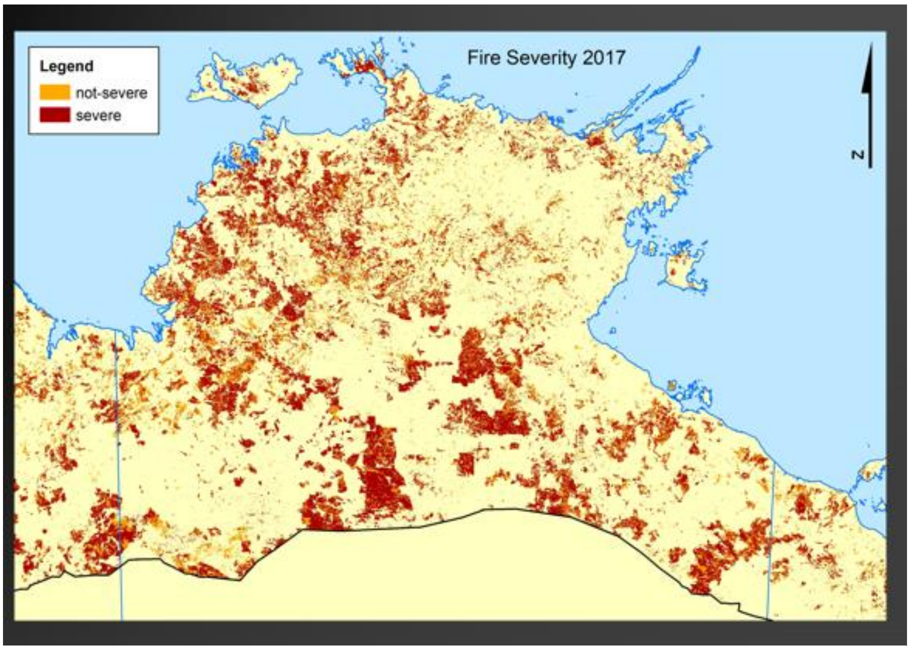

FIGURE 11. FIRE SEVERITY MAPPING DERIVED FROM THE DNIR MODIS 250 M ALGORITHM FOR THE TOP END OF THE NORTHEN TERRITORY, AUSTRLIA, 2017.

REFERENCES

Crowley, G. and S. Garnett (2000). "Changing fire management in the pastoral lands of Cape York Peninsula of northeast Australia, 1623 to 1996." Australian Geographical Studies **38**(1): 10-26.

De Santis, A. and E. Chuvieco (2009). "GeoCBI: A modified version of the Composite Burn Index for the initial assessment of the short-term burn severity from remotely sensed data." Remote Sensing of Environment **113**: 554-562.

Edwards, A. C. (2009). Fire Severity Categories for the Tropical Savanna Woodlands of northern Australia. Melbourne, Victoria, Australia, Bushfire Cooperative Research Centre.

Edwards, A. C. (2011). I spy with my little eye something beginning with...fire. Faculty of Engineering, Health, Science and the Environment. Darwin, Northern Territory, Charles Darwin University. **PhD Thesis**.

Edwards, A. C., J. Russell-Smith and S. W. Maier (2018). "A comparison and validation of satellite-derived fire severity mapping techniques in fire prone north Australian savannas: Extreme fires and tree stem mortality." Remote Sensing of Environment **206**: 287-299.

Garnett, S. T. and G. M. Crowley (1995). Ecology and Conservation of the Golden-shouldered Parrot. Cape York Peninsula Land Use Strategy. Department of Environment, Sport and Territories. Available: http://capeyorknrm.com.au

Key, C. H. and N. C. Benson (2006). Landscape Assessment: Ground measure of severity, the Composite Burn Index; and Remote sensing of severity, the Normalized Burn Ratio. FIREMON: Fire Effects Monitoring and Inventory System. USDA Forest Service, Rocky Mountain Research Station, Ogden, UT. Available:

Russell-Smith, J. and A. C. Edwards (2006). "Seasonality and fire severity in savanna landscapes of monsoonal northern Australia." International Journal of Wildland Fire **15**(4): 541-550.

Russell-Smith, J., C. Yates, J. Evans and M. Desailly (2014). "Developing a savanna burning emissions abatement methodology for tussock grasslands in high rainfall regions of northern Australia." Tropical Grasslands **2**(2): 175-187.

State of the Environment (1996). Australia: State of the Environment: Prepared under the direction of the State of the Environment Advisory Council. CSIRO, Canberra**:** 2-1 - 2-30. Available: https://soe.environment.gov.au/file/51011