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# Rangeland plants in a warming world

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Australia's rangeland vegetation is a vital asset to this country, supporting a multi-billion dollar grazing industry (Bastin 2008) and responsible for significant carbon drawdown (Cleverly *et al.*, 2013; Eamus *et al.*, 2016). Australian rangeland plants often grow in extremely nutrient-poor soils, cope with highly variable rainfall and are predominantly evergreen (although less so in the northern regions) (Morton *et al.*, 2011). Because of its fundamental effect on biological processes, temperature is a critical determinant of species survival and distribution (Tattersall *et al.* 2012; Körner *et al.* 2016). Recent years have seen Australia's climate records being broken almost annually, with high temperature extremes becoming more frequent and intense (Hennessy *et al.* 2007; IPCC 2014). To be maintained on a plant and to remain healthy for several seasons, the leaves of rangeland species must be able to withstand critically high temperatures. Heat stress tolerance of Australian arid and semi-arid land plants has only recently been investigated (Curtis *et al.*, 2014; Curtis *et al.*, 2016; O'Sullivan *et al.*, 2017).

Our research explores how different rangeland plant species respond to heat stress and what factors influence variation in their tolerance to high temperature. In a series of linked experiments, we have measured thermal tolerance thresholds for 47 species growing under comparable conditions at the Australian Arid Lands Botanic Garden, Port Augusta, South Australia. Thermal thresholds are measured using chlorophyll fluorometry to determine the point at which the leaf photosynthetic tissue begins to sustain irreversible damage:  $T_{50}$  (Knight & Ackerly 2003; Curtis *et al.* 2014). Using a series of temperature controlled water baths, we subject leaves to different stress treatments (ranging from 36 °C to 56 °C, plus a control treatment of 28 °C).  $T_{50}$  is determined as the temperature at which photosystem health declines to 50% of pre-stress levels; this index can be used to compare relative thermal tolerance among species.

As plant thermal tolerance is known to vary with environmental conditions (Knight & Ackerly 2003), we have measured  $T_{50}$  in winter, spring and summer. Not only environmental temperature, but also water availability can influence how plants experience temperature. One reason for this is that many plants close their stomata when water stressed, which impairs their ability for evaporative cooling (Macinnis-Ng & Eamus 2009; Teskey *et al.* 2015). We therefore have grouped species according to their natural preferences for particular micro-habitat conditions with respect to water availability. For example, xeric-adapted species are defined as those growing on well-drained slopes and ridgetops; whereas more mesic-adapted species include those growing along dry riverbeds and floodplains.

Our research has found that plant high temperature tolerance varies widely, not only among species, but also through time and space. In a given season,  $T_{50}$  can vary by up to 10 °C among species (Curtis *et al.* 2014; Curtis *et al.*, *in review*). We also have found clear seasonal differences, with average thresholds increasing by 5 °C from winter to summer (Curtis *et al.*, *in review*). In spite of this clear shift, the trajectory for increasing thresholds across seasons also varies, with different groups of species shifting early vs late in the season or not at all. Regardless of seasonal effects, plants inherently adapted to more readily accessible water have significantly lower thermal tolerance thresholds than species naturally occurring in local micro-habitats where water availability is more restricted or short-lived (Curtis *et al.* 2016; Curtis *et al.*, *in review*). By contrast,  $T_{50}$  does not appear to correspond with species' broad-scale, regional distribution. These results suggest that the ability of species to adjust their heat tolerance is somewhat genetically constrained and relates to the conditions of their native habitat.

Our findings have implications for predicting how different rangeland species will respond to altered timing, frequency and intensity of heat waves. In particular, if high temperature extremes are coupled with drought, species in previously wetter, productive habitats potentially are most vulnerable to heat stress among rangeland plants. Given the importance of these areas in supporting a multi-billion dollar grazing industry (Bastin, 2008), along with their critical role as refugia for biodiversity (Morton, 1990; Morton *et al.*, 1995), this is an unsettling proposition. We suggest that management and modelling efforts a) account for temporal variation of thermal

tolerance and b) incorporate species distribution information at the finer scale of habitat type, rather than the predominant focus on broader, regional scales.

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