The impact of extreme drought and climate change on the demography of plains grass populations in central New South Wales

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Abstract: *Over the coming century, climate change is expected to increase the frequency and severity of extreme meteorological events both in Australia and around the world. This presents a major threat to biodiversity and sustainable agriculture, as plant populations will increasingly face abiotic stresses that lie beyond their physiological tolerances. However, it has recently been suggested that biodiversity losses under climate change could be mitigated by the inclusion of spatially heterogeneous habitats within the reserve system. In this paper we test this hypothesis using the results of a study conducted in central New South Wales between 2006 and 2008, in which we quantified the resilience and resistance of populations of plains grass (Austrostipa aristiglumis) to unprecedented drought conditions. We show that small-scale topographic variability generated significant habitat-level differences in drought survival and post-drought recovery of A.aristiglumis, and that populations growing in mesic, low-lying habitats are likely to be persistent even under future climate change scenarios. We conclude that native grass species would likely benefit from the inclusion of spatially heterogeneous landscapes within conservation reserves.*

Introduction

Climatic warming during the next century (IPCC 2007) is considered to be one of the primary threats currently facing global terrestrial biodiversity (Thomas *et al.* 2004). One of the key drivers of population and ecosystem change under global warming is likely to be an increase in the frequency and severity of droughts, heatwaves and floods (Meehl *et al.* 2000), since extreme climatic events are known to drive rapid demographic and distributional changes in plant populations and ecosystems (e.g., Breshears *et al.* 2005). Changes in ecosystem structure and function driven by such events are therefore likely to pose a major challenge for ecologists and land managers in coming decades, and new adaptive management strategies will be required to ensure adequate conservation of biodiversity and the maintenance of productive grassland systems.

Spatial heterogeneity and ecosystem resilience

Recently, it has been suggested that an ecoregional approach (Saxon 2003) to biodiversity conservation may be the most effective means of producing climate change-resilient ("climate-ready") ecosystems. This strategy involves the protection of spatially heterogeneous habitats within local and landscape-level conservation reserves or farming systems, which in turn allows plant populations to move to habitat refugia when faced with a changing climate. Capturing variation in micrometeorological and soil conditions via local topography in this way is thought to enhance both the resilience of plant species and populations to disturbance and stress (van de Koppel & Rietkerk 2004).

Currently, however, the effectiveness of this strategy for generating systems that are sufficiently resilient to withstand climate change is unknown for most plant species and plant functional groups. Few studies have determined how local variation in habitat quality enhances the resilience of plant populations to extreme climatic events, and we remain unable to predict the response of most plant species to global warming. In this paper we report on the impact of extreme drought on populations of the keystone native Australian perennial grass

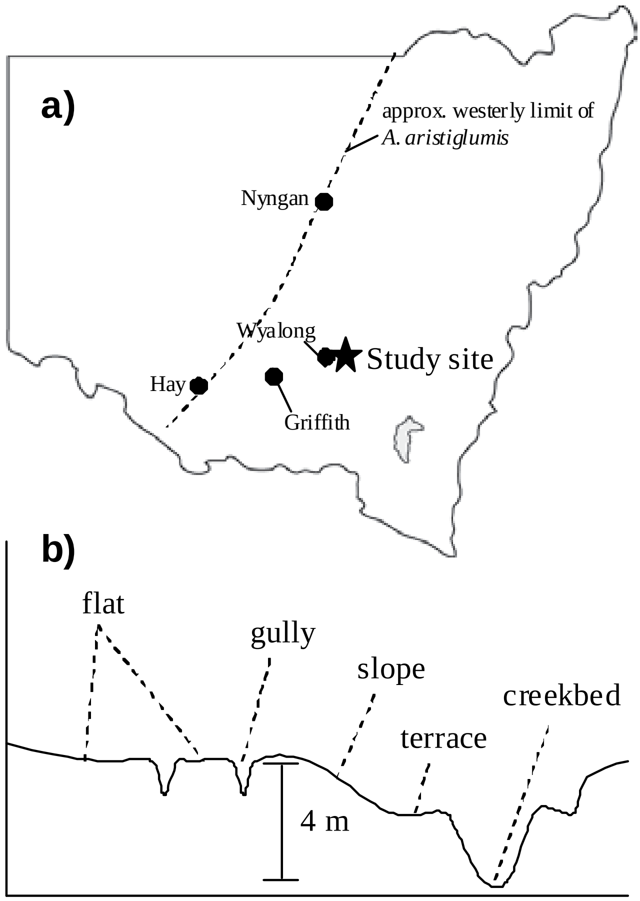

Figure 1. Location and topography of the study site. a) location of study site 30 km east of Wyalong, NSW. The approximate westerly limit of *A. aristiglumis* in NSW is indicated by the dashed line. b) basic topography of the study site.

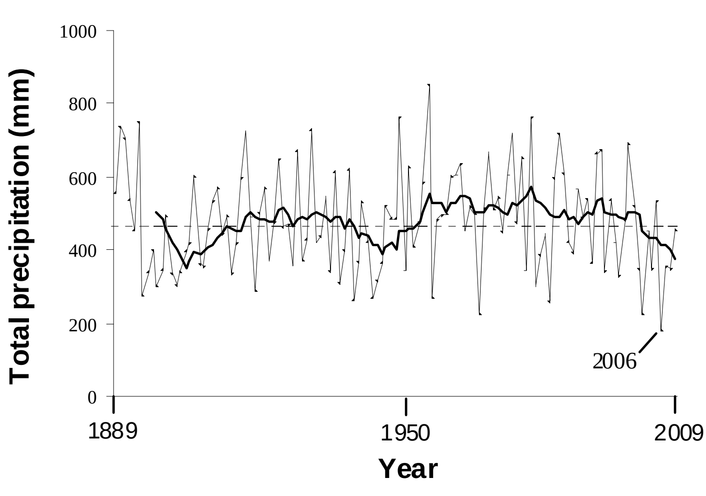

Figure 2. Annual rainfall recorded at Wyalong Post Office 1889–2009. The dashed line indicates the long-term average while the solid line indicates the 10-year running mean.

species *Austrostipa aristiglumis* (plains grass) in central NSW, and discuss the likely role that spatial variability will play in maintaining resilient grassland populations over the longer term.

The study system

Our work was conducted in a 34 hectare study site located approximately 30 km east of West Wyalong, NSW (S 33° 50.9′, E 147° 33.6′; Fig. 1a). The study site contains a range of habitat types dominated by *A. aristiglumis* (Fig. 1b), including steeper north-and south-facing slopes, terraces, small gullies and flats, the latter of which are most extensive. The site has low relief, with larger creekbeds lying 3–4 m below the surrounding flats. Grazing pressure at the site is minimal.

Between 2006 and 2008 the study site experienced extreme drought, with 2006, 2007 and 2008 all ranking among the driest 10% of years on record (records since 1889; Fig. 2). Overall, 2006 was the driest year in the instrumental record (180 mm, 65% below normal; Fig. 2), with considerably less rainfall than the next driest year (225 mm in 2002). Annual mean temperatures were also at or near record highs in 2006–2008, resulting in record low monthly and annual atmospheric water balances at the study site during this period.

Impact on demography of *A. aristiglumis*

The unprecedented drought conditions experienced between 2006 and 2008 resulted in dramatic changes in the size and structure of *A. aristiglumis* populations in all of the primary habitats investigated at the study site. Repeated surveys of *A. aristiglumis* populations over the study period showed that the most acute period of drought (July 2006 to December 2007) caused the death of 40% to 98% of all adult tussocks, with the highest mortality rates occurring on steeper sloping terrain (98%) and on the spatially extensive *A. aristiglumis* flats habitat (96%), despite the fact that prior to drought the density of *A. aristiglumis* tussocks was highest on flats (Table 1). In contrast, tussock mortality in low-lying gully and terrace habitats was lower (40–75%), most likely due to a higher overall soil moisture content. These data clearly show that the resistance (i.e., the ability to resist change) of *A. aristiglumis* populations to extreme drought is strongly influenced by local variation in topography, with low-lying mesic habitats providing drought refugia for adult tussock plants.

Table 1. Demography of *A. aristiglumis* populations in four key topo-edaphic habitat types based on data collected during the extreme drought period of July 2006 – July 2008.

	Habitat type			
	Flat	**Terrace**	**Slope**	**Gully**
Slope (degrees)	1.0	2.3	11.2	1.5
Area (% of total)	48	12	6	5
Density (m^{-2})[2]				
July 2006	3.7	3.2	0.3	2.8
Dec 2007	0.2	1.9	0.0	0.7
July 2008	1.4	3.9	0.1	5.2
Drought mortality (%)[3]	96	40	98	75
Persistence time (yr)[4]	3	13.5	2.5	6

[1]Several minor habitats contributing 29% of the total area are not shown. Slopes refer to north-facing slopes.

[2]Density of adult tussock plants >1 year old.

[3]Percentage mortality over the period July 2006 – Dec 2007

[4]Time until <1% of the population remains under recurring extreme drought (based on July 2006–July 2007 drought conditions).

Follow-up surveys conducted in July 2008 show that significant recovery of adult *A. aristiglumis* populations had occurred in all habitats, following widespread recruitment from the seedbank in autumn and winter 2007. Indeed, by July 2008 the density of adult *A. aristiglumis* tussocks exceeded the pre-drought density in both terrace and gully habitats (Table 1), mainly due to very high seedling recruitment rates in these environments. In contrast, populations declined overall on slopes and flats between 2006 and 2008, with virtual extirpation occurring on sloping terrain (Table 1). Consequently, the resilience of *A. aristiglumis* populations (the ability to return to a prior state following disturbance) was also higher in terrace and gully habitats.

Matrix-based population models constructed using life history data collected over the course of the study provide further indication that *A. aristiglumis* populations growing in mesic habitats at the study site are more likely to persist under chronic drought than populations in dry habitats. Population projections based on life history data collected between July 2006 and June 2007 indicate that *A. aristiglumis* populations in mesic habitats would persist for 6–14 years even under recurring, extreme drought, before declining to <1% of their pre-drought size (Table 1). This compares with 2–3 years in drier slope and flat habitats, where persistence is mainly a function of the longevity of the seedbank.

Prospects for *A. aristiglumis* under climate change

Over the coming century much of south-eastern Australia is expected to become significantly warmer and drier, particularly in winter and spring (Hennessy *et al.* 2004); by 2070 the study region could see a 2–5% decline in annual rainfall, a 2–4% increase in potential evapotranspiration, and a 1–2°C increase in annual temperature (see www.climatechangeinaustralia.gov.au). These changes would result in the climate of the study area approximating that currently experienced by Nyngan, NSW, which lies 260 km to the north. Interestingly, at Nyngan, and at comparable locations to the west of Wyalong with similar atmospheric water balances (e.g., Hay and Griffith, NSW; Fig 1a), *A. aristiglumis* has only a scattered distribution in mesic habitats along rivers. This distributional range, along with the demographic data discussed above, suggests that drying and warming of the climate over the next century would increasingly restrict *A. aristiglumis* to local topoedaphic riverine refugia, where resilience of populations to drought is highest. This appears to be true even in regions near Wyalong that lie near the centre of the species distribution.

The contraction of *A. aristiglumis* towards small-scale refugia under a warming and drying climate would pose significant challenges for land managers. From a conservation perspective, *A. aristiglumis* is a keystone species in a range of endangered native grasslands in south-eastern Australia (DEWHA 2010) and its decline would significantly alter the composition and structure of these communities. While our data indicate that, even under climate change, viable populations would continue to exist in mesic habitats, these comprise only a small fraction of the landscape (<20% at our study site) and so the continued existence of widespread *A. aristiglumis*-dominated grassland ecosystems in south-eastern Australia appears uncertain.

Finally, *A. aristiglumis* is also an important forage pasture species over much the western slopes of NSW, particularly on self-mulching vertosols (McKenzie *et al.* 2004). Our data suggest that in drier parts of its range, adaptation to future climate change may necessitate the establishment of more drought-tolerant ecotypes, or even the replacement of *A. aristiglumis* with more drought tolerant species. Future work will focus on the ability of *A. aristiglumis* and other native grassland species to adapt to climate change through expression of phenotypic plasticity or micro-evolution for stress tolerance.

Conclusions

The results of our work support the hypothesis that local topographic variation generates variation in the resilience and resistance of native grass populations to extreme drought. Indeed, even topographic relief of only 3 to 4 m can produce significant variation in drought survival, seedling recruitment rates and the overall drought persistence of *A. aristiglumis* populations. We are therefore confident that *A. aristiglumis*, and probably other native grass species as well, would benefit from an ecoregionally-based conservation and management strategy for climate adaptation based on the inclusion of spatially heterogeneous landscapes within conservation reserves.

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