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Climate-driven changes in diet composition and physiological stress in an arboreal folivore at the semi-arid edge of its distribution

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ABSTRACT

Species, particularly foliovores, at the trailing edge of their geographical range are likely to be most vulnerable to climate change as they respond to physiological stress and the decline in the nutrient richness of their food source. We investigate the effect of environmental conditions on diet composition, resource use, and physiological stress of koalas (*Phascolarctos cinereus*) in the semi-arid landscapes of southwest Queensland, Australia, across three different biogeographic regions. Fresh faecal pellets were collected to measure cortisol metabolites and assess diet. Regression analyses were used to relate the diet composition and physiological stress of wild koalas to environmental variables. The impact of drought was apparent, with higher faecal cortisol metabolites (FCM) levels recorded during drought conditions compared with post-flood conditions. Diet composition also changed between drought and post-flood conditions, with diets during drought being mainly composed of species with high leaf-moisture content. Low minimum temperatures increased FCM concentrations, and these effects were greater during drought conditions. The results demonstrate the importance of integrating physiological assessments into ecological studies to identify stressors that have the potential to compromise the long-term survival of threatened species, as well as the need to identify the resources required for their continued survival.

1. Introduction

In the future, climate change will be one of the major threats to biodiversity worldwide causing many species and their habitats to experience shifts in their distribution or cause extinctions (Parmesan and Yohe, 2003; Williams et al., 2008). It is predicted that global temperatures will increase and climate extremes, such as drought, floods and heatwaves, will increase in frequency (Allison et al., 2009). Terrestrial vegetation, and thus habitat quality and resource availability for many species, will also be affected by climate change (Hughes, 2003). It is predicted that changes in foliar chemistry due to elevated CO_2 levels will significantly affect arboreal folivores (Kanowski, 2001; Lunney et al., 2012; Moore et al., 2004). Climate change predictions for Australia indicate that droughts and heatwaves will become more frequent and intense, and moisture availability will decrease (CSIRO, 2007).

Habitat is often defined as the suite of resources (food and shelter) and environmental conditions (abiotic and biotic) that determine the presence, survival and reproduction of a population (Block and Brennan, 1993; Hall et al., 1997). Habitat selection by animals becomes more specific when the quantity and quality of resources differ in space and time (Orians and Wittenberger, 1991), especially when affected by extreme weather (Godvik et al., 2009), such as droughts.

Wildlife species have a physiological response to changes in habitat resources and environmental conditions, reflected by variations in stress hormone levels (Foley et al., 2001; Harper and Austad, 2001; Megahed et al., 2008; Strier et al., 1999). Sources of stress include biotic factors (predation, competition, social dynamics), extremes in physical factors (temperature, salinity) and climatic factors (drought, storms) (Creel et al., 2013; Hoffmann and Hercus, 2000; Wingfield et al., 1998). Stressors can impact on both physical and biotic components of an organism's environment and, depending on their pervasiveness, magnitude and frequency, can

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profoundly influence the fitness of individuals via costs to health, reproduction and survival (Bonier et al., 2009; Jessop et al., 2013). Ultimately, stressors can affect population viability, distribution and extinction risk (Bijlsma and Loeschcke, 2005; Hoffmann and Parsons, 1997). Unfavourable conditions trigger physiological responses that result in hypothalamic–pituitary–adrenal (HPA) axis activation and increased glucocorticoid secretion (cortisol in marsupials) by the adrenal cortex (Axelrod and Reisine, 1984; Mostl and Palme, 2002). Glucocorticoid receptors are distributed widely in the body, thus glucocorticoid hormones can initiate a wide range of responses affecting behaviour, reproduction, growth, the immune system, metabolism and energy allocation (Romero, 2004; Sapolsky, 2002). Glucocorticoid secretion resulting from acute stress (e.g. predator attack) improves the fitness of an organism by mobilising energy during the stressful situation (Sapolsky, 2002). However, a stress response involving excessive and prolonged glucocorticoid secretion, often termed allostatic overload or chronic stress, arises when an individual's HPA axis is challenged by excessive and prolonged stressor exposure or pervasiveness resulting in fitness loss (McEwen and Wingfield, 2003, 2010). Physiological studies of wild animals are vital to identify specific conservation concerns and threat status, and they potentially offer a metric for evaluating species risk to global change (Jessop et al., 2013; Wikelski and Cooke, 2006).

Species, particularly folivores, at the trailing edge of their geographical range are likely to be most vulnerable to climate change, through physiological stress and the decline in the nutrient richness of their food sources (DeGabriel et al., 2010; Ellis et al., 2010). Individuals within such environments probably survive at the limit of their physiological capacity to endure drought and heat. The frequency, intensity and duration of extreme temperatures, drought and humidity may determine survivorship of a species directly, or change habitat quality and resource availability (Adams, 2010; Albright et al., 2010). Monitoring diet composition at the limit of a species range during favourable conditions and comparing this to unfavourable conditions that mimic those predicted under climate change scenarios will help identify and manage the effects of climate change. Combining such data with information on physiological stress for the same conditions will further our understanding of how climatic variables are impacting on populations.

The koala (*Phascolarctos cinereus*) is an arboreal marsupial folivore which feeds almost exclusively on a limited variety of *Eucalyptus*, *Corymbia* and *Angophora* species. Koalas are an ideal subject to study the effects of temporal variability in resources (such as variability between drought and post-flood conditions) having a specialised diet and a need to balance nutrient and water intake against plant secondary metabolites (PSMs) (Marsh et al., 2007; Moore and Foley, 2005).

Previous research within arid and semi-arid landscapes in western Queensland has determined that the distribution, density, habitat preferences, home range sizes and physiological stress of koalas are affected either by water availability (including leaf moisture) and/or rainfall (Davies et al., 2013b,c; Sullivan et al., 2003a). Therefore, western Queensland koalas may cope poorly with changes in these factors resulting from climate change. In southwestern Queensland, riparian habitats have been identified as the primary resource used by koalas (Davies et al., 2013c; Seabrook et al., 2011; Smith et al., 2012), with evidence of populations declining and contracting to riparian habitats during droughts and heatwaves (Gordon, 1988; Seabrook et al., 2011). The loss of food resources, resulting from defoliation of fodder trees during drought, contributed to these declines (Gordon, 1988; Gordon et al., 1990). Drought has also been found to impact on the diet of other species, including Townsend's ground squirrels (van Horne et al., 1998) and sun bears (Fredriksson et al., 2007) with differences in food nutrient levels resulting in low reproduction and survival during and immediately following drought. The effect of drought on Townsend's ground squirrel diet also varied with habitat type (van Horne et al., 1998).

Trailing-edge populations can be critical to the long-term survival of species because they may contain individuals that can adapt to changing climatic conditions (Hampe and Petit, 2005; Thomas et al., 2006). This enhances the need for detailed investigation of trailing-edge populations, including detailed information on the feeding ecology of threatened species to monitoring change over seasonal, annual and extreme climatic periods. Combining this information with measurements of physiological stress will enable us to better understand how environmental challenges (such as drought) impact on individuals and populations.

This study investigated the ecology and physiology of koalas at the trailing edge of their range during drought and post-flood conditions to answer the question: Do climatic conditions affect the diet composition and physiological stress of koalas at the range edge? We hypothesised that during drought conditions the diet of koalas would consist mainly of tree species that are known to have high leaf moisture, such as river red gum (*Eucalyptus camaldulensis*) and cortisol levels would be higher, while post-flood diets would be more varied and cortisol levels lower. We hypothesised that season and temperature would also influence cortisol concentrations. We also hypothesised that cortisol concentrations would decrease as the availability of tree species known to have high leaf moisture increases. To test these hypotheses, we used faecal cuticle and FCM analysis from pellets collected during both drought and post-flood conditions from sites in three different bioregions at the semi-arid edge of the koala's range in southwestern Queensland, Australia, to assess diet and cortisol concentrations.

2. Materials and methods

2.1. Study area

This study was conducted at the western edge of the koala's distribution in semi-arid, southwestern Queensland. It incorporated portions of the Mulga Lands, the Mitchell Grass Downs and the Brigalow Belt South bioregions (Fig. 1) (Sattler and Williams, 1999). Annual average rainfall ranges from 750 mm in the east declining to 250 mm in the west. Rain falls mainly in summer and is highly variable. Winter rainfall is low in this region. Mean summer temperatures throughout the study area range from 19 °C to 35 °C, with mean winter temperatures of 3.5–19 °C (Bureau of Meteorology, 2013). A drought occurred during 2009 with below average rainfall and higher than average maximum and minimum temperatures (Fig. 2). This drought broke in early 2010 with major flooding across the region in March and above average annual rainfall (Fig. 2).

The Mulga Lands bioregion is dominated by flat to undulating plains and low ranges supporting mulga (*Acacia aneura*) shrubland and low woodlands (Sattler and Williams, 1999). The woodlands that dominate waterways and associated floodplains are predominantly *Acacia* spp., poplar box (*Eucalyptus populnea*), river red gum, coolabah (*Eucalyptus coolabah*) and yapunyah (*Eucalyptus ochrophloia*) (Sattler and Williams, 1999).

The western portion of the Brigalow Belt South bioregion is predominantly comprised of brigalow (*Acacia harpophylla*), belah (*Casuarina cristata*) and Poplar box open-forest woodland (Sattler and Williams, 1999). Riparian vegetation is dominated by river red gum, coolabah and black box (*Eucalyptus largiflorens*) (Thackway and Cresswell, 1995).

The Mitchell Grass Downs bioregion is dominated by treeless plains of Mitchell grass (*Astrebla* spp.) with some occasional ridges,