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Aboriginal burning promotes fine-scale pyrodiversity and native predators in Australia's Western Desert

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ABSTRACT

Both invasive mesopredators and altered fire regimes impact populations of vulnerable native species. Understanding how these forces interact is critical for designing better conservation measures for endangered species. This study draws on Indigenous ecological knowledge and practice to explore heterogeneity in faunal responses to Indigenously managed landscapes in the Western Desert of Australia. Using track plot surveys and satellite image analysis of fire histories, we find evidence that pyrodiversity increases activity measures of dingoes and monitor lizards. Dingoes were more active in recently burnt patches, while foxes were more active in slightly older burnt patches. These results add to previous work showing significant effects of pyrodiversity on kangaroo populations in the region. Together, the findings suggest that Aboriginal burning not only creates diverse niches for native animals, it helps to facilitate the ecological role of species that are themselves functionally vital. This work adds to a growing body of research suggesting that the loss of Aboriginal burning can cascade through ecosystems by transforming and simplifying ecological networks, thus contributing to the decline and extinction of vulnerable species.

1. Introduction

Fire is a disturbance that shapes ecosystems around the world (Bowman et al., 2009), but its role in promoting biodiversity remains poorly understood (Driscoll et al., 2010). This lack of understanding is concerning given over 1000 animal species are threatened by altered fire regimes (IUCN, 2015), which cover ~60% of the world's terrestrial ecosystems (Shlisky et al., 2009). Drivers of altered fire regimes are manifold, but the displacement of Indigenous people—often in conjunction with subsequent fire suppression and climate change (Enright et al., 2015; Westerling, 2016)—is paramount.

There is increasing evidence that Indigenous burning promotes (or promoted) fire regimes that maintained high levels of 'pyrodiversity' (Bowman et al., 2004; Bliege Bird et al., 2008; Trauernicht et al., 2015). Pyrodiversity refers to the "temporal and spatial heterogeneity of fire" (Martin and Sapsis, 1992)—landscapes with fine-scale patterning of diverse fire histories have high pyrodiversity, while landscapes with broad-scale patterning and more uniform fire histories have low pyrodiversity (Parr and Andersen, 2006). For instance, in grassland ecosystems in Brazil and Australia, Indigenous burning creates a patchier distribution of fires, preventing fires from burning too frequently and limiting vegetation loss (Vigilante et al., 2004; Welch et al., 2013). It is hypothesized that the loss of pyrodiversity following Indigenous displacement impacts animals by rearranging the distribution of food and shelter resources due to the rescaling of fire mosaics (Keith et al., 2002; Bliege Bird et al., 2008), and in doing so exposes many species to enhanced predation (Doherty et al., 2015; Woinarski et al., 2015).

The impact of shifts in fire regimes on species is further compounded by invasive predators, as fire regime shifts may act synergistically with predator invasion to increase the vulnerability of native animal species (McGregor et al., 2014; Leahy et al., 2016). In Australia, loss of traditional fire regimes has been hypothesized to be an important factor shaping the ability of invasive mesopredators (i.e. feral cats, *Felis catus* and red foxes, *Vulpes vulpes*) to decimate mammal populations (Burbidge et al., 1988; Ziembicki et al., 2015). Invasive predators may be favored by large, intense fires indicative of modern fire regimes due to increased hunting efficiency in open habitats (McGregor

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et al., 2015; Leahy et al., 2016), resulting in heightened mortality as prey must travel further to access unburnt refugia (Leahy et al., 2016).

Studies of links between indigenous burning, pyrodiversity and biodiversity are challenging because of the enormous scale of indigenous dispossession by European colonialism. One region where traditional fire regimes remain are the spinifex grasslands of Australia's Western Desert, where Indigenous traditional owners (Martu) continue to burn for subsistence purposes in ways that recall historic landscape-scale patterning of fire regimes in some locations (Bliege Bird et al., 2008). In landscapes where Martu hunt more, hunting fires rescale pyrodiversity and buffer against climate-driven shifts in mean fire size (Bliege Bird et al., 2008; Bliege Bird et al., 2012; Bliege Bird et al., 2016). Landscapes that are not utilized by Martu exhibit a shift in fire regime toward much larger fires, with a pronounced seasonal dominance in ignition toward summer fires (Burrows et al., 2006; Bliege Bird et al., 2012). The latter fire regime may favor invasive predators, which prefer to hunt in recently burned areas (McGregor et al., 2014; McGregor et al., 2016; McGregor et al., 2017), driving down native mammal populations. This synergy between altered fire regimes and invasive predators has been offered as an explanation for the local extinction of 21 mammal species and the decline of a further 43 that coincided with a brief (~15 year) Martu exodus from their homelands (Burbidge et al., 1988; Burrows et al., 2006).

In this paper, we examine the response of native and invasive predators and prey to fire history and successional stage diversity in the Martu homelands of the Western Desert (Fig. 1a). Our approach draws on Martu ethnoecological knowledge to classify patches recovering from fire into functionally important stages linked to food and shelter. Martu are uniquely placed to provide such knowledge through their shared history with the region's climates and environments and their attachments to country. Martu recognize at least five distinct successional classes following fire (Fig. 1b), categorized by the food and shelter each stage provides, to people and other animals. We focus on the responses of common invasive and native predators and prey to these stages—the dingo (*Canis dingo*), cat, fox, monitor lizards (sand goanna, *Varanus gouldii*), mulgara (*Dasycercus blythi*) and native mice (including *Notomys alexis* and *Pseudomys hermannsburgensis*). Using track surveys conducted by Martu and researchers they've trained (Fig. 1c), we examine how predator and prey activity varies with the cover, presence and diversity of ethnoecologically-defined successional stages.

If Indigenous fire management buffers native species from the impacts of invasive predators in the Western Desert, we predict that: 1) pyrodiversity should be greater and unburned habitat refugia more common in areas close to Martu communities than more remote areas, due to the frequent lighting of small fires by Martu for hunting (Bliege Bird et al., 2008), which reduces the frequency of large fires, thereby protecting unburned refuges (Bliege Bird et al., 2012); 2) invasive predators should be associated with recently burned areas due to their enhanced hunting efficiency in open habitats (McGregor et al., 2015) and should be more common in areas subject to altered fire regimes (i.e. low pyrodiversity areas further from Martu communities); 3) native predators that have co-evolved alongside Martu should be favored by traditional burning regimes and thus pyrodiversity (Bliege Bird et al., 2013); and 4) potential prey species should be associated with traditional fire regimes due to pyrodiversity improving foraging returns and diminishing predation risk.

2. Methods

2.1. Study area

This study is situated within the spinifex dominated sandplains of the Little Sandy Desert bioregion of Western Australia (Fig. 1a). The region includes Martu Native Title lands and Karlamilyi National Park. Climate is hot and semi-arid, with a variable mean annual rainfall of 363 mm, ranging from 108 to 1455 mm (www.bom.gov.au); winter lows are typically well above freezing, 10–12 °C, with summer high temperatures exceeding 40 °C (www.bom.gov.au). Vegetation in the region is mostly spinifex (*Triodia schinzii* and *T. basedowii*) and Acacia (*A. pachycarpa* and *A. ligulata*, among others) on sandplain and dune substrates covering 85.6% of the land area. Current human occupation of the study region is limited to one Martu community, Parnngurr, and limited tourist visitation; a gold mine (Telfer) and two other Aboriginal communities lie to the north of the National Park.

The Western Desert was first occupied in the Late Pleistocene, between 40,000 and 50,000 years ago (Veth et al., 2009; McDonald, 2017), with the last 9000 years witnessing a population growth trend culminating in a rapid population increase during the late Holocene (Williams, 2013; Williams et al., 2013). The region thus likely has a long history of Aboriginal burning, perhaps intensifying with increased climatic variability at the onset of ENSO conditions 4.5–2000 years ago (Zeanah et al., 2017). Martu (including Manyjiljarra, Warnman, and Kartujarra linguistic groups) lived in this region until 1966, when the last nomadic bands left for missions and cattle stations on the desert fringe. Martu returned in 1984 to reoccupy the study area, establishing Parnngurr community as a base for traditional foraging activities and patch mosaic burning (see Bliege Bird et al., 2008; Bliege Bird et al., 2012; Bliege Bird et al., 2013; Bliege Bird et al., 2016). However, hunting and burning activities are heterogeneously distributed across the landscape, concentrated in certain regions along tracks within 40–50 km of the community (Fig. 1a). This heterogeneity provides a unique natural experiment to examine the effects of human-induced pyrodiversity on faunal populations.

2.2. Site selection and survey methods

A total of 76 1 ha plots were randomly chosen from a stratified sample of 5000 sample plots located across a gradient of Martu hunting activity within 75 km of Parnngurr community. Plot map shapefiles were loaded onto GPS-enabled tablets enhanced with more accurate external Bluetooth GPS units (BadElf GPS), which were used to navigate to each plot and establish boundaries. Plots chosen for survey were constrained to be within 2 km of a vehicle track (to facilitate access), to fall on soil types that retain track imprints (were limited to plots with 50% or more spinifex sandplain), and had to be at least 1 km from their nearest neighbor. Plots were sampled during winter months between July 2014 and July 2016. Due to the logistical and financial difficulty of conducting fieldwork in this remote region, and because many plots were 1–2 km away from tracks to diminish their influence on species' occurrence (which can be problematic for predator surveys: Hayward et al., 2015), sites were surveyed on one occasion each. Tracks were readily visible on the smooth sand surfaces between spinifex hummocks (Fig. 1c), and fire is commonly applied to sandplain ecosystems by Martu and therefore most tracking occurs in this ecosystem type.

Percent cover of the five Martu successional categories within each 1 ha plot was evaluated by an experienced Martu-trained observer (RBB and/or DWB) using standard comparison charts (examples at https://www.for.gov.bc.ca/hts/risc/pubs/teecolo/fmdte/veg.htm). Martu burn small patches in the winter to create *nyurnma*, recently burned areas that are ideal for locating cold season monitor lizard (sand goanna) burrows (Bliege Bird et al., 2008, 2013; Bird et al., 2009). A few weeks following a fire, shrubs, trees, and some grasses will begin to resprout, and following rain, new seedlings create a flush of vegetation, which is the signal that plant recovery (*waruwaru*) has begun (Fig. 1b). If there is no available soil moisture following a fire, a *nyurnma* can remain dormant and not progress to *waruwaru* for months, even years, until the rains return. Once plants have matured and produced flowers or fruits, the area enters the next stage, *nyukura*, characterized by its high species diversity and the presence of a number of forbs and subshrubs that possess large edible fruits (e.g. bush tomatoes, *Solanum* spp., and the fan flower *Scaevola parvifolia*) and a greater diversity of seed grasses such as