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Biodiversity responds to increasing climatic extremes in a biome-specific manner

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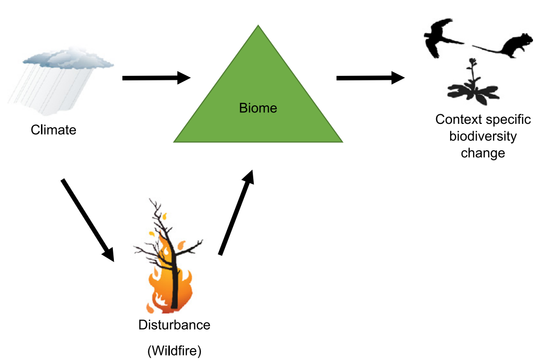
HIGHLIGHTS

- An increase in the frequency of extreme weather events in all biomes studied.
- Biodiversity changes driven by climate, wildfire or both, varied among biomes.
- Biodiversity responded to recent climate change either directly or indirectly.
- There was no evidence of non-linear change in biodiversity to disturbance.
- Long-term data are essential for detecting biotic responses to environmental change.

GRAPHICAL ABSTRACT



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ABSTRACT

An unprecedented rate of global environmental change is predicted for the next century. The response to this change by ecosystems around the world is highly uncertain. To address this uncertainty, it is critical to understand the potential drivers and mechanisms of change in order to develop more reliable predictions. Australia's Long Term Ecological Research Network (LTERN) has brought together some of the longest running (10–60 years) continuous environmental monitoring programs in the southern hemisphere. Here, we compare climatic variables recorded at five LTERN plot network sites during their period of operation and place them into the context of long-term climatic trends. Then, using our unique Australian long-term datasets (total 117 survey years across four biomes), we synthesize results from a series of case studies to test two hypotheses: 1) extreme weather events for each plot network have increased over the last decade, and; 2) trends in biodiversity

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will be associated with recent climate change, either directly or indirectly through climate-mediated disturbance (wildfire) responses. We examined the biodiversity responses to environmental change for evidence of non-linear behavior. In line with hypothesis 1), an increase in extreme climate events occurred within the last decade for each plot network. For hypothesis 2), climate, wildfire, or both were correlated with biodiversity responses at each plot network, but there was no evidence of non-linear change. However, the influence of climate or fire was context-specific. Biodiversity responded to recent climate change either directly or indirectly as a consequence of changes in fire regimes or climate-mediated fire responses. A national long-term monitoring framework allowed us to find contrasting species abundance or community responses to climate and disturbance across four of the major biomes of Australia, highlighting the need to establish and resource long-term monitoring programs across representative ecosystem types, which are likely to show context-specific responses.

1. Introduction

Environmental changes during the 21st century are projected to be comparable in magnitude to those of the largest recorded global change that occurred 65 million years ago, and to increase at rates 10–100 fold faster (Diffenbaugh and Field, 2013). The unprecedented rate of global environmental change predicted for the next century is coupled with increases in the unpredictability of climatic events and increases in extreme weather (Urban, 2015). Ecosystem responses to these changes are highly uncertain and challenging to predict (Walther et al., 2002). A range of linear and non-linear ecosystem responses to environmental change potentially exist (Scheffer and Carpenter, 2003). Non-linear responses are characterised by large changes in ecosystem properties in response to a small range of environmental change, in contrast to relative insensitivity outside that critical range of environmental conditions. This threshold behavior is sometimes linked to hysteresis, allowing alternative stable states to persist under the same environmental conditions. 'Regime shifts' between such states may be triggered either by gradual environmental change until a threshold is reached, or by disturbance events (Scheffer and Carpenter, 2003). Ecosystems that display these kinds of responses are challenging to manage because points of change are difficult to predict and reversal of state changes could necessitate major manipulations that may not be feasible (Suding and Hobbs, 2009).

Long time-series of ecological data offer an opportunity to investigate drivers of change and to provide a meaningful context for interpreting trends. Time series data are also appropriate to explore beyond considerations of central tendencies (Pearson and Dawson, 2003) and are paramount for understanding how the extreme highs and lows of temperature or precipitation may drive biodiversity responses (Greenville et al., 2013; Wardle et al., 2013). Such understanding of ecosystem drivers and mechanisms of change is critical for developing more-reliable predictions about ecosystem structure and function in future (Keith et al., 2008, 2013). This, in turn, will better inform decisions on climate adaptation which, to be effective, must be cognisant of the likelihood of synergistic effects among existing processes and legacies from past events (Sala et al., 2012; Monger et al., 2015). It is therefore essential that investment in environmental monitoring programs be sophisticated enough to improve mechanistic knowledge, not simply detect change.

The world's climate has changed. Global mean temperatures have increased by 0.85 °C from 1880 to 2012 due to anthropogenic activities (IPCC, 2014), and these increases, combined with changes in global rainfall patterns, have changed disturbance regimes (Bowman et al., 2014). There has also been an increase in the frequency and magnitude of extreme climate events such as floods and heat waves (IPCC, 2014; CSIRO and Bureau of Meteorology, 2015). Understanding the effects of changes in climate and disturbance regimes on biota can only be provided by long time-series of ecological observations or experiments (Lindenmayer and Likens, 2010; Lindenmayer et al., 2012). Such insight will be vital for identifying species and ecosystems at risk of collapse and for informing mitigation measures.

Here, we use case studies drawn from the Australian Long Term Ecological Research Network (LTERN) to examine ecosystem responses to changes in climate and disturbance regimes. We first compare climatic variables recorded annually at each plot network during its period of operation, and place these in the context of long-term climatic trends. Then, we raise and test the following hypotheses:

1. The number of extreme weather events recorded by each plot network has increased over the last decade;
2. Trends in biodiversity will be associated with recent climate change, either directly or indirectly through climate-mediated disturbance (e.g., wildfire) responses. We examined biodiversity responses to environmental change for evidence of non-linear behavior.

Using insights gained from long-term datasets, we consider management implications for long-term monitoring in conservation organisations that seek to maintain species populations that are likely to face increases in extreme weather events and an increasingly unpredictable climate.

2. Methods

Long-term data (10–35 years) were obtained from five of the 12 Australian LTERN plot networks (Lindenmayer et al., 2014). These five plot networks monitor biodiversity in tropical savannas and heathlands, deserts, alpine systems, temperate heathlands and temperate woodlands, representing half of the major Australian biomes defined by Olson et al. (2001) (Fig. 1).

2.1. Climate

To compare the climate at each plot network during their survey years in relation to longer-term climate trends, annual climate data from 1970 to 2014 were extracted for each of the five plot networks using ANUCLIM 6.1 (Xu and Hutchinson, 2013). ANUCLIM data were used instead of data from the nearest Bureau of Meteorology weather station (distance to plot range 5–217 km), as it provided a standardised dataset with equal length for each plot network. For each plot network, we constructed density histograms for a suite of climate variables (annual rainfall, mean annual temperature, mean minimum temperature, and mean maximum temperature). For the Alpine Plot Network, snow depth data from the Falls Creek (1954–2011; http://gergs.net/wp-content/uploads/2014/04/Rocky_Valley_peak_trend.png) and Mt. Hotham (2012–2016; http://www.mthotham.com.au/all-about-hotham/snow-weather/snow-charts/) weather stations were combined to make a complete time-series from 1954 to 2016, and this was used instead of rainfall at that site. Depth of snow cover determines over-wintering habitat suitability for alpine biota such as small mammals (Shi et al., 2015), so we used this instead of rainfall as a key measure of environmental change. These two snow weather stations were chosen because they are close to each other (~10 km) and their annual precipitation records are highly correlated ($r = 0.92$).