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Predicting drought using remotely sensed vegetation cover

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Abstract

In Australia, land degradation caused by wind erosion and dust storms often occur during drought when vegetation cover is low. Destocking early is a critical management action that can reduce soil erosion; however, predicting drought to inform producer decisions regarding destocking is a complicated task. In Australia, drought is determined by several indicators, such as rainfall deficiencies, soil water, pasture growth, water availability, agricultural production, and community impact. Many of these indicators influence total vegetation cover (denoted as cover), which includes photosynthetic and non-photosynthetic cover.

This study uses a 22-year record (2001-2022) to investigate if a "trigger point", i.e., the month and cover level, can be identified that would potentially inform destocking four to six months before a drought cover (<20th percentile minimum monthly cover in summer) is reached. Twenty-four properties in western NSW rangelands were evaluated to determine the trigger month and trigger cover. The trigger month was August for 83% of properties. The drought cover ranged from 60% to 25%. The trigger cover ranged from 70% to 35%. Over the 22 years, 22% of years recorded drought cover. The method correctly predicted 80% of years with drought cover, i.e. those years below the trigger cover that had drought cover the following summer. The method failed to predict drought in six percent of years. In six percent of years, it predicted drought, but no drought occurred. The study demonstrates the practical application of a new tool to help land managers prepare for drought.

Introduction

Degradation of soils and vegetation is highly undesirable (Duniway *et al.* 2019). According to the United Nations Convention to Combat Desertification definition, land degradation can be caused by both human and climate factors (UNCCD 1994). Drought alone does not cause land degradation; the major cause is carrying too many animals for too long (McKeon *et al.* 2004). Maintaining cover is key to avoiding land degradation. Pasture production is low in drought, and ground cover declines, especially when stock numbers exceed the forage available and soil erosion increases. It has long been recognised that preventative early warning before the onset of drought would help land managers reduce livestock and unmanaged herbivore numbers before total vegetation cover (denoted as cover), which includes photosynthetic and non-photosynthetic cover, is reduced to levels that enable soil erosion (Childs 1973; McKeon *et al.* 2004; O'Reagain 2011). McKeon et al. (2004, p.22) state, "it is hard to imagine that any manager, if forewarned of a potential degradation event, would take the risk of animal losses, financial cost, and environmental damage by not reducing stock numbers early". However, knowing when to destock, referred to as a decision trigger, is a significant challenge that many authors have identified (Ratcliffe 1938; Condon 1992; McKeon *et al.* 2004; Hacker *et al.* 2010).

Accurately predicting the onset and termination of droughts is a major deficiency in drought prediction (Mishra and Singh 2011) because drought is a continuum (Van Loon *et al.* 2024). Several drought monitoring services exist in Australia, each providing information to assist decision-making. The Bureau of Meteorology (BoM) website has an interactive Australian Water Outlook tool (https://awo.bom.gov.au) with information on soil moisture, runoff, evapotranspiration, deep drainage, and precipitation. It also has a dedicated Drought page (http://www.bom.gov.au/climate/drought/) with information on rainfall deficiencies, soil moisture, water, and rainfall forecasts.

In New South Wales (NSW), the Department of Primary Industries and Regional Development (DPIRD) publishes an interactive tool called the Combined Drought Indicator (https://edis.dpi.nsw.gov.au/). It utilises the Rainfall Index (RI), Soil Water Index (SWI), Pasture Growth Index (PGI), and Drought Direction Index (DDI) with a multi-index approach. It tracks the onset (e.g. drought affected (intensifying)), duration and retreat of large drought events.

In the United States, the U.S. Drought Monitor (USDM) (https://droughtmonitor.unl.edu/) provides weekly maps of normal conditions, abnormally dry (D0), showing areas that may be going into or are coming out of drought, and four levels of drought: moderate (D1), severe (D2), extreme (D3) and exceptional (D4). It uses multiple data sources of streamflow, reservoir levels, temperature and evaporative demand, soil moisture, and vegetation health and blends this with drought impacts, field observations and local insight from a network of more than 450 experts.

This study aims to reduce soil erosion and land degradation by using satellite fractional vegetation cover data as a metric to set a decision trigger month and estimate the trigger cover (TC) level below which destocking should be considered for grazing properties in western NSW. Decision triggers (trigger) are designed to link cover data in this paper to a management action, i.e., consider destocking (Cook *et al.* 2016). Two triggers are presented: 1) the time of the trigger so management can be adapted, and 2) the cover threshold, i.e. a visual cue for the trigger, four to six months ahead of the drought.

Methods

Cover changes every month, and the ranges in cover change from property to property. As a result, each property is assessed for 1) which winter month is the best trigger, i.e. correlates with the following summer cover, 2) how many times the drought cover, that is, the cover measured in previous droughts since 2001 and defined as the 20th percentile of the 22-year monthly time series (DC) and how many times TC was recorded for the property over the 22 years, and 3) how many years were both TC and DC observed.

For 24 properties in the semi-arid rangelands of western New South Wales, Australia, a 22-year time series of monthly green (photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV) and total vegetation cover (cover) for each property at 500m resolution was extracted from GEOGLAMM RaPP (hereafter called RaPP) (CSIRO 2024).

Drought cover, rounded to the nearest 5%. This coincided with the Millennium Drought (2002-2009) and the Tinder-box drought (2017-2020). The DC level was determined for each of the 24 properties. The trigger month, i.e., the month in winter that can predict DC the following summer, was determined using linear regression (E 1) for each winter month (June/July/August) cover (WC) against the month with the minimum summer cover (December/January/February) (MSC).

MSC= a WC – b
(1)

Where a is the slope and b intercept of El 1.

The TC, i.e., the level of cover in the trigger month below, which predicts DC the following summer, was determined using a regression equation for August for each property to calculate the DC (Eq 2).

TC= DC -b) / a
(2)

Using the exact rounded TC, e.g., 65%, and DC, e.g., 50%, ignores errors in the estimates of the values. In determining if TC or DC occurred in any month, we added a tolerance of 2.5%. This value was chosen because it is half the possible rounding error. For example, if the measured WC was 67% and the TC was ≤ 65%+2.5%, the TC was said to have occurred. Similarly, if the MSC was 51%, and DC was ≤ 50%+2.5%, the TC was said to have occurred.

Years with DC and TC were counted for each property. The ‘Prediction of Drought” model (PoD) was said to work when the TC and DC conditions were met. PoD performance was calculated by counting PoD years and dividing by the DC years (Table 1). Errors in the model were assessed as follows: yearly counts of no trigger measured, but DC occurred in summer, and the trigger was measured, but no DC occurred.

Results

The results of the fractional cover time series analysis successfully identified the DC, the TC, and the TC month for each property. The values were different for each property. August had the highest coefficient of determination (R2), with 83% of properties, July 12%, and June 4%. For simplicity, August was chosen as the trigger month for all properties. TC ranged from 35 to 75%, and DC ranged from 25 to 60%. The cover declined, i.e., the difference between TC and DC, 10 to 20%. Properties with low differences were stoney or had tree cover. Properties with large differences were either treeless or sandy country with scattered trees and shrubs.

On average, across the 24 properties, 33% of years between 2002-2022 experienced DC in summer months, while the PoD model predicted DC for 27% of years (Table 1). The primary test was to evaluate if the model could predict TC and DC for a year when DC occurred. To evaluate this test, we divide the years when the PoD model worked (27%) by the DC years (33%). The method correctly predicted 82% of years that recorded DC. The method failed, i.e. no trigger was measured, but DC occurred in six per cent of years; similarly it failed in six percent of years when a trigger occurred, but DC did not.

Table 1. The results for the 22 years, 2002-2022, of the 24 properties in western New South Wales. Results expressed as a percentage of 22 years

	Years when drought cover was recorded (DC) (%)	Prediction of droughts (PoD) (%)	No trigger was measured, but DC occurred next summer (TnDCy) (%)	The trigger was measured, but no DC occurred (TyDCn) (%)
Minimum	23	14	0	0
Maximum	64	64	23	32
Average	**33**	**27**	**6**	**6**

Discussion [Conclusions/Implications]

Remote sensing and modelling are widely used to estimate drought (Mishra and Singh 2011; Vicente-Serrano *et al.* 2020; Fleming-Muñoz *et al.* 2023; Guillory *et al.* 2023). Drought forecasting plays a significant role in risk management and drought preparedness (Mishra and Singh 2011). Landholder discussions have revealed that it is difficult to know when drought is coming because it can be a slow process of change (Van Loon *et al.* 2024). This contributes to the difficulty of recognising the onset of drought and is one reason we have sought to set objective trigger months and cover levels.

This study defines a property-based decision trigger point for when to destock. The aim was to have a month for the decision and a trigger cover level that would indicate that the cover level will likely be lower than that previously measured in drought during summer. The trigger would link to destocking management action to avoid soil erosion. Land managers in western NSW rangelands utilise a range of triggers for destocking, including drought forecasts produced by various agencies, cumulative rainfall, and visually assessing pasture biomass and cover. Some managers have specific months to decide stocking rates based on past experiences and risk determination. The results of this study build on this concept to provide objective property scale metrics.

We calculated the triggers using cover as the metric because cover is closely related to soil erosion. Other drought indices, e.g., rain and soil moisture, are related to vegetation growth and cover but do not describe the cover. Using the cover metric, the analysis found that 32% of years had cover dropping to below DC levels. When PoD is expressed as a percentage of years with DC, the model worked 82% of the time. Increasing the tolerances, currently 2.5%, for TC and DC could improve the PoD model.

Averaged across the 24 properties, DC was measured in 32% of years, and PoD worked in 27% of the 22 years. Of those years when DC was measured, 82% had a predicted TC, and the cover level went to DC levels; that is, the model worked. In this study, destocking too early would have occurred 6% of the time because a trigger was measured, but the cover did not drop to DC levels the following summer. Destocking, in this case, would mean forfeiting production. When discussing the model results with producers in western NSW, one manager said, "You have to own your decision", and pointed out that this scenario would result in the country getting a rest. The opposite situation of having no trigger and DC occurring the next summer means the model failed to predict the upcoming DC levels, and no management action would be taken. This would result in an increased risk of erosion.

This project demonstrates a trigger method that improves the clarity and transparency of management decisions. The approach can also be applied to paddocks or individual landforms. Cover can be used as an early warning before the onset of drought, which helps maintain cover going into drought.

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