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It's not the plants you can see but those you can't see: managing Australia's rangelands means managing pest rabbits

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Abstract

European rabbits are thought to have colonised most of Australia's vast rangelands by about 1910, leaving destitute pastoralists, decreased livestock production and a degraded environment in their wake, resulting in an-going need to manage and rehabilitate these critical environments. At a broadscale, rabbit control has been implemented, with varying degrees of success, using a variety of biocontrol agents most notably myxomatosis in the 1950's and more recently rabbit haemorrhagic disease virus. Native perennial vegetation still shows these recruitment pulses due to a modern awareness that seedling survival tolerances of palatable species can be as little as one rabbit/km^2. Such low rabbit density was achieved with initial impacts of the viral biocontrols, and where land managers have undertaken landscape scale warren destruction. Utilising GPS mapping of rabbit warrens we mapped the native vegetation recruitment following destruction of approximately 28,000 warrens by a bulldozer with long ripping tines at Thackaringa Station in western NSW. Using the remotely sensed Normalised Difference Moisture Index on the 22,545 ripped and GPS-mapped warrens at Thackaringa has detected a differential recovery trend in areas where rabbits have been eradicated. Based on this initial analysis, it suggests that the potential benefits for landscape-scale restoration of native vegetation, ecological recovery, pastoralism and potential carbon storage may be appreciable. However, satellite sensors are optimised for vegetation that is not the dominant signal for the Australian geographies, necessitating the exploration of tailored analysis methods to address the unique complexities of Australia's diverse ecosystems.

Introduction

Australia's rangelands, spanning six million square kilometres and comprising 81% of the continent. Notwithstanding those in the tropical north, the remainder is inhabited and severely impacted by the pest European rabbits (*Oryctolagus cuniculus*), which became established in Australia in the mid-19th century and had colonised these rangelands by 1980 (Stodart and Parer 1988). By the late 19th century, the rangelands faced devastating rabbit plagues. By the early 20th century, the extent of rangeland degradation was seen in state legislation such as South Australia's Sand Drift Act of 1923 (Ratcliffe 1938). The battle to manage the overgrazing of the pest rabbits had its first significant success in the 1950's due to the introduction of the myxoma virus as a biocontrol agent (Fenner and Fantini 1999). The most recent significant reduction in rabbits coming with the 1995 establishment of rabbit haemorrhagic disease virus (RHDV1/GI.1) (Mutze *et al.* 1998) and then the 2014 emergence and rapid establishment of RHDV2/GI.2 (Hall *et al.* 2015) with associated rabbit reductions (Mutze *et al.* 2018).

Primary environmental benefits have been the associated recovery of some native rangeland vegetation (Burrell *et al.* 2017) and threatened fauna species (Pedler *et al.* 2016). However, though the iconic rabbit plagues have ended, rabbit impacts on rangeland vegetation remain. Recent research documents the extreme sensitivity of many species of palatable native vegetation to rabbit grazing at densities as little as one per square kilometre, where 40% of mulga (*Acacia aneura*) seedlings were eaten (Henzell 2002). At the very minimal $\geq$ 0.005 rabbits km^2 palatable rangeland species such as *Acacia carneorum*, *Eremophila alternifolia*, *Allocasuarina luehmannii* and *A. verticillata* cannot successfully reproduce and establish new plants (Mutze *et al.* 2016). In the management of the rangelands, the impacts of rabbit grazing have been shown to generally be much more significant in impact on native vegetation recruitment and hence availability than pastoral factors such as water points and stock grazing (Mutze 2016).

To achieve effective landscape-scale rabbit control and the associated recovery of native rangeland vegetation, biodiversity, and pastoral benefits, landholders have undertaken major rabbit warren mapping and destruction works. The objective of this study was to examine the impact of the large-scale destruction of rabbit warrens on the presumptive increase in native vegetation based on remotely-sensed estimates of Normalised Difference vegetation Index (NDVI) before and after ripping.

Methods

This study was undertaken on Thackaringa Station which is located in arid rangelands of western NSW. Of approximately 28,000 rabbit warrens that were ripped, a total of 22,545 were mapped using a Garmin handheld GPS. Once mapped, rabbit warrens were destroyed using a Cat D8/9 bulldozer with c. 120 cm ripping tines spaced 75 cm apart. The primary objective of these activities was to achieve a significant reduction in rabbit numbers and promote the recovery of native vegetation. The ripping of these warrens largely occurred yearly between 2000 to 2004 (Fig. 1).

Google Earth Engine was used to facilitate the extraction of NDVI, enabling precise temporal and spatial analysis of changes in vegetation and soil moisture. The satellite sources used included the Landsat series 5, 7, and 8 and Sentinel-2, which provided multispectral signals. Cloud anomaly removal was conducted using a combination of cloud masking algorithms, including the Sentinel-2 Quality Assessment Band and Landsat Collection 1 Level-1 QA tools. Additionally, shadow detection was applied to minimise anomalies, and a median compositing approach was used to mitigate the influence of sporadic cloud cover. Further data cleaning included radiometric correction to standardise reflectance values across different time points, enhancing the reliability of the derived vegetation indices. Control data were derived from non-ripped comparable areas, which were identified based on similar soil types, vegetation profiles, and climatic conditions as the ripped areas. These control regions were selected to ensure a valid comparison, accounting for any external variables and providing a baseline to determine the direct impacts of rabbit management interventions.

To evaluate changes in vegetation and moisture, data derived from the satellite sources described in the previous paragraph was used. The Normalised Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), and Normalised Difference Moisture Index (NDMI) were extracted for each warren site and the comparative control areas. These indices were analysed over a temporal span from before warren destruction through to most recently available satellite imagery. Monthly composite values for NDVI, SAVI, and NDMI were calculated by taking the median value of all valid observations within each calendar month for each polygon. This approach minimises the impact of remaining atmospheric contamination or bidirectional reflectance distribution function effects. The resulting monthly time series data for each index (NDVI, SAVI, NDMI) were analysed to identify patterns and trends. The presence and period of seasonality were assessed by examining the autocorrelation function for each index's time series. To distinguish long-term trends from seasonal variations, a seasonal decomposition using LOESS (Locally Estimated Scatterplot Smoothing) was applied to each time series. Further analysis specifically compared trends before and after 2004, as this year marked the completion of the main phase of systematic warren destruction across the study sites.

Results

Remote sensing analysis across the 22,545 mapped and ripped rabbit warrens at Thackaringa station revealed significant, sustained changes in vegetation cover and near-surface moisture dynamics over the 1988-2022 period. Vegetation indices showed clear recovery trends following the period of intensive warren destruction. The Soil-Adjusted Vegetation Index (SAVI) trend, which corrects the Normalised Difference Vegetation Index (NDVI) for soil brightness influences, closely tracked the NDVI trend throughout the period, confirming that the observed greening was not primarily a soil-reflectance artefact. Both indices exhibited peaks around 2000 and again in the mid-2010s (reaching approximately 0.30 for SAVI and 0.20 for NDVI), punctuated by a major dip around 2010-2011 corresponding to drought conditions (SAVI < 0.15, NDVI < 0.10).

In stark contrast, the Normalised Difference Moisture Index (NDMI), representing surface moisture, displayed a markedly different trajectory, particularly after 2004 and the major wet event of 2010-2011. While NDMI values fluctuated around a moderately positive baseline (e.g., averaging near +0.08 to +0.10) in the earlier part of the record, the trend shifted dramatically downwards following the 2010-2011 peak (around 0.15), declining to negative values (averaging near or below -0.02) after 2012 and remaining persistently low despite subsequent periods of vegetation recovery. This pronounced decoupling between the recovering vegetation greenness indices (NDVI, SAVI) and the declining moisture index (NDMI) emerged most strongly post-2010/11, coinciding with a very wet year in the period after intensive warren destruction efforts. This divergence was reportedly absent from matched, unripped control polygons. Seasonal decomposition using LOESS and autocorrelation analysis confirmed strong annual cycles in all indices, but the sustained post-2010 NDMI decline represents a significant trend shift beyond typical seasonal or inter-annual variability. These patterns suggest that increased water uptake by recovering perennial vegetation drew down upper soil profile moisture more rapidly than replenishment occurred, establishing a new, lower NDMI baseline in the treated areas.

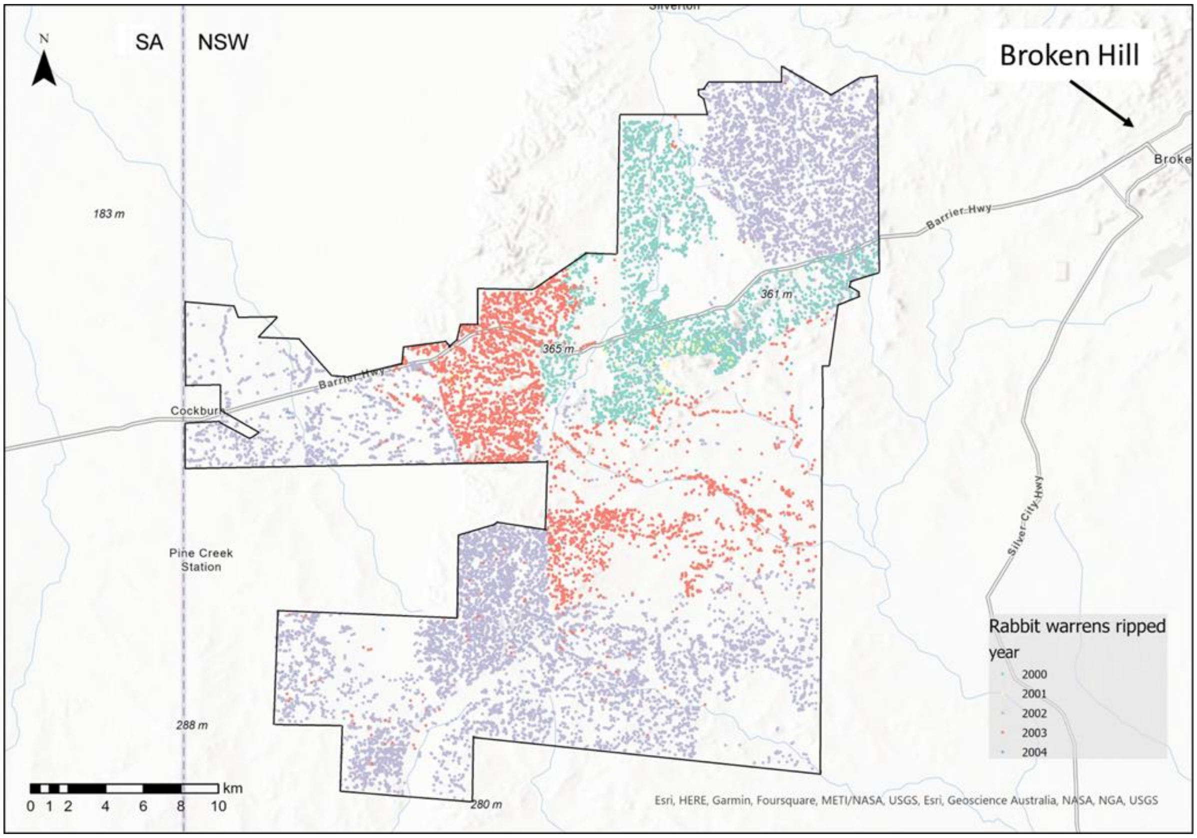

Figure 1: 22,545 mapped rabbit warrens, subsequently destroyed, on Thackaringa station (NSW).

Discussion

These findings demonstrate that landscape-scale rabbit warren destruction at Thackaringa station induced significant shifts not only in vegetation cover but also in local water balance dynamics. By facilitating the recovery of groundcover, primarily perennial vegetation, the intervention led to increased NDVI and SAVI values, indicative of greater photosynthetic biomass. Concurrently, the marked and sustained decrease in NDMI suggests increased evapotranspiration rates associated with this recovering vegetation kept near-surface soil layers significantly drier compared to the pre-treatment or early treatment period. This outcome aligns with observations from semi-arid exclusion studies, where the establishment of shrubs and perennial grasses modifies soil moisture regimes compared to denuded or annual-dominated systems.

The observed decoupling between the vegetation indices and NDMI post-intervention is critical. Because SAVI is specifically designed to minimise soil background influences on the greenness signal, its continued recovery alongside a declining NDMI strongly supports the interpretation that increased plant water uptake, rather than a spectral measurement artefact or simple lack of rainfall, drove the reduction in surface moisture detected by NDMI. This fundamentally alters the site from a quasi-fallow state around former warrens to one characterised by active hydrological cycling through established perennial vegetation.

Future research should aim to quantify these component changes more explicitly. Utilising products like Digital Earth Australia's Fractional Cover, which partitions satellite pixels into green vegetation, non-photosynthetic vegetation (dry/dormant), and bare soil components, could provide a more detailed understanding of how vegetation structure changes relate to water use. Furthermore, the advanced hyperspectral sensors aboard the Kanyini mission offer potential to refine these analyses by resolving specific spectral features related to plant pigments, water content, and dry matter, potentially improving discrimination even in complex semi-arid vegetation communities. Integrating these advanced remote sensing capabilities with ongoing adaptive management strategies, including follow-up warren control, can provide land managers with near-real-time feedback on both vegetation recovery status and associated water dynamics, strengthening the ecological and economic rationale for sustained rabbit management in Australia's rangelands.

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