Monitoring Land Degradation & Ecosystem Resilience Across Australian Water-limited Ecosystems

Leandro Daniel Giovannini

This thesis is presented as part of the requirements for the award of the degree of Doctor of Philosophy

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Leandro Daniel Giovannini, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Science at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

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ACRONYMS & ABBREVIATIONS

AI	Aridity index
ACRIS	Australian Collaborative Rangelands Information System
AMR	Aridity marginal response
ANPP	Above-ground net primary productivity
CSIRO	Commonwealth Scientific & Industrial Research Organisation
CLUM	Catchment-scale land use map
D	Drainage from the root zone
DLCD	Dynamic Land Cover Dataset
E_s	Soil evaporation
EMR	Electromagnetic radiation
eRUE	Effective rain-use efficiency
ET	Evapotranspiration
GPP	Gross primary production
I	Evaporation from the wet canopy
IGBP	International Geosphere-Biosphere Programme
iEVI	Integrated enhanced vegetation index
ISO	International Standards Organisation
IWUE	Inherent water-use efficiency
LAI	Leaf area index
MAP	Mean annual precipitation
MODIS	Moderate-resolution imaging spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalised difference vegetation index
NIR	Near-infrared
NSW	New South Wales
NVIS	National Vegetation Information System
P	Precipitation
PET	Potential evapotranspiration
Qld.	Queensland
PMR	Precipitation marginal response
R	Run-off

RESTREND	Residuals trend
RUE	Rain-use efficiency
SA	South Australia
SAVI	Soil-adjusted vegetation index
SWIR	Short-wave infrared
T	Transpiration
Tas.	Tasmania
TRMM	Tropical Rainfall Measurement Mission
TSS-RESTREND	Time-series segmented residuals trend
W_p	Vegetation water content
W_s	Soil water content
WA	Western Australia
WARMS	Western Australia Rangeland Monitoring System
WOfS	Water observations from space
WUE	Water-use efficiency
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
VI	Vegetation index
Vic.	Victoria
VPD	Vapour-pressure deficit
VSI	Vegetation sensitivity index
VT	Vegetation type

ABSTRACT

Degradation of dryland ecosystems has been of interest to ecologists for many decades, and has been reported on every populated continent. Rain-use efficiency (RUE), which describes the relationship between annual above-ground net primary productivity (ANPP) and annual precipitation (P), is a commonly used measure of ecosystem function across water-limited arid and semi-arid ecosystems. The goal of this thesis was to improve our understanding of spatial and temporal RUE relationships across Australian water-limited ecosystem in order to monitor land degradation and ecosystem resilience. A remote sensing approach was taken, as it is the only practical method that allows for spatially and temporally comprehensive assessment of RUE relationships at a continental scale.

The first step was to assess spatial RUE variability in relation to spatial variability in precipitation (P) and potential evapotranspiration (PET), as water availability is primarily determined by hydro-meteorological conditions that encompass both water supply (P) and atmospheric evaporative demand, or PET. The results showed that water-limited ecosystems did not adhere to a well-defined spatial ANPP-rainfall relationship due to strong impacts of PET on RUE. Therefore, a new index that normalised RUE by PET was developed and tested - “effective RUE” (eRUE). The eRUE relationship (i.e. the regression between ANPP and the quotient of precipitation and PET) resulted in a spatially well-defined ANPP-water model compared to RUE (which does not consider the effect of PET). Also, during extreme dry years ecosystems showed stronger convergence to a common maximum ANPP-water relationship when the effects of both P and PET were included. This driest-years spatial eRUE relationship (i.e. cross-site $eRUE_{dry}$) defines theoretical water-limitation boundary conditions. Thus, while critically low rainfall can lead to vegetation water stress and contribute to ANPP losses, increasing PET caused by future climate change is likely to exacerbate drought-induced impacts on ecosystem structure and function, including the frequency of drought-induced mortality events.

Vegetation type was also considered as a contributing factor to spatial RUE and eRUE variability. The results showed that vegetation types exhibited significant

differences in eRUE (and RUE). Furthermore, these differences were also expressed during the driest years, suggesting that each vegetation type exhibits a unique spatial eRUE relationship during periods of severe water limitation. As such, if cross-site $eRUE_{dry}$ is to be used as a theoretical drought resilience threshold, it should be defined by vegetation type-specific cross-site $eRUE_{dry}$ relationships.

Ecosystem function trends were assessed as indicators of land degradation. First, ANPP interannual variability was assessed in relation to interannual P variability, which revealed differences in sensitivity among vegetation types. Tussock grasslands, chenopod shrublands and agricultural lands were identified as the most sensitive to interannual P variability, suggesting that these vegetation types may be most sensitive to future climate change. The residuals trend (RESTREND) method was used to assess ecosystem function trends that were independent from climate trends. Sites with negative ecosystem function trends were observed across the study area, and represent potential sites of land degradation. Open woodlands, mulga shrublands, chenopod shrublands, hummock grasslands, and agricultural lands were identified as widely affected.

This thesis has contributed to our understanding of spatial and temporal RUE relationships within the context of P, PET and vegetation type variability. At the continental scale ANPP spatial variability was strongly affected by P and PET. This led to the development of the eRUE metric, which was also applied during the driest years. The cross-site $eRUE_{dry}$ represents theoretical water limitation boundary conditions that encompass water supply and atmospheric evaporative demand. Vegetation type was found to play a significant role in spatial eRUE relationships, suggesting that each vegetation type is likely to have a unique drought resilience threshold. The analysis did not reveal strong effects of PET trends on ANPP trends, perhaps indicating that negative effects of PET may be limited to drought periods. Finally, the possible presence of land degradation processes was identified across several vegetation types.