Improved monitoring of ecosystem resilience using high-resolution remote sensing

by

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This thesis contains no material which has been accepted for the award of any other degree or diploma in any tertiary institution, and to my knowledge and belief, this thesis contains no material previously published or written by another person except where due reference is made in the text of the thesis.

Abstract

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Background

1.1 Context

Global change phenomenon has been impacted by anthropogenic activities and disturbances with an increase of carbon dioxide (Co2) in the atmosphere, causing drastic climate change and highly affecting ecosystems health. Ecosystems productivity and cycles respond in complex dynamics to climate change and other global change drivers such as the increased atmospheric Co2, raised sea- surface temperatures, ocean acidification, water balance, precipitations, soil erosion and extreme events (Malhi, Franklin, Seddon, Solan, Turner, Field and Knowlton 2020, Dronova and Taddeo 2022). Understanding how these dynamics manifest on ecosystems are critical to assess the impacts of climate change and their resilience to it.

This study focuses on terrestrial ecosystems, where remote sensing (RS) plays an important role to monitor Earth's land cover by vegetation and assess changes. Vegetation is a main component of ecosystems that connects soil, atmosphere and water or moisture and plays an important role in land surface energy exchange, biogeochemical cycle and hydrological or water cycle (Zhang, Chen, Fu, Niu, Yang and Zhang 2019, *Chapter 12 - Fractional Vegetation Cover* 2020). Consequently, there is a need to derive magnitudes of ecosystems composition, structure, and function at a range of spatial and temporal scales to explain the drivers of change. There are existing RS measurements that includes ground-based plot and transect-based filed observations that are very detailed, spaceborne satellite observations that cover a much larger extent and a higher frequency of data acquisition (the whole globe and Australian country), and airborne unoccupied aerial systems (UAS) (i.e.'drones') that provides similar detail of information or high spatial resolution, than ground-based data with wider extent cover and data frequency acquisition.

High resolution remotely sensed data are well used to develop highly precise maps of ecosystem composition, structure, derived the characterisation of functional diversity (or biophysical products). Repeated scans across time can be used to detect and assess ecosystem changes. Abiotic (such as climatic and edaphic) factors are well understood to be primary drivers of variation in natural ecosystems across spatial and temporal dimensions. The way in which biotic factors interact at different scales is less well understood. This project will use high spatial and spectral resolution remotely sensed datasets to map and detect ecosystem change. The utility of RGB, multispectral and hyperspectral systems, as well as 3D datasets derived from both photogrammetry, and Light Detection And Ranging (LiDAR) will be investigated to identify vegetation cover, develop possible spectral libraries that contribute to essential biodiversity variables (EBV) and essential climate variables (ECV), and fil the scale gap between field-based measurement and satellite monitoring. The use UAS will facilitate the collection of ultra-high spatial resolution datasets. Machine learning techniques such as, deep learning algorithms will be used to develop models that can classify vegetation based on its' spectral and structural datasets. Model interpretation and analysis by simulation will identify primary drivers of ecosystem composition, structure, develop monitoring protocols, and provide opportunities for management interventions to improve ecosystem function.

This research will further scientifically be understanding of ecosystem composition and resilience by developing remote sensing methodologies and algorithms to assess changes terrestrial ecosystems across a variety of Australian environments. The project will utilise machine learning techniques to perform classification to assist ecologists to map and understand the drivers of ecosystem change. As part of this research, the utility of RGB, multispectral, LiDAR and hyperspectral sensors will be compared. The project will also develop monitoring protocols that will enable efficient change detection and focused management interventions.

1.2 Motivation

UAS data provide a unique opportunity to rapidly assess the response of ecosystems under environmental perturbation derived from abiotic factors (such as climate, soil type or other factors) by providing new insights into ecosystem structure and composition such as detecting vegetation stress across landscapes through these ultrahigh-resolution observations. These dronee observations can help to connect field plot surveys to coarser spatial scale satellite observation leading to improved insights and a better understanding in the satellite signal (Lucieer, Turner, King and Robinson 2014, Melville, Fisher and Lucieer 2019). UAS remote sensing has the potential to provide suitable datasets for calibration and validation of national-scale satellite vegetation products (Fisk, Clarke and Lewis 2019).

In order to recognise spatial patterns in ecosystem composition and structure, ultra-high resolution remote sensing data such as that collected by UAS is required. The rapid rate of change global climate means that there is an ever-increasing need for highly precise maps of ecosystem composition, structure, and function.

Chapter 2

Literature Review

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Part II

Deriving fractional cover from drone multispectral and lidar data

Chapter 1

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Part III

Structure properties derived from drone lidar data

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References

Chapter 12 - Fractional Vegetation Cover: 2020, *in* S. Liang and J. Wang (eds), *Advanced Remote Sensing (Second Edition)*, second edition edn, Academic Press, pp. 477–510.

Dronova, I. and Taddeo, S.: 2022, Remote sensing of phenology: Towards the comprehensive indicators of plant community dynamics from species to regional scales, *Journal of Ecology* **110**(7), 1460–1484.

Fisk, C., Clarke, K. D. and Lewis, M. M.: 2019, Comparison of Hyperspectral Versus Traditional Field Measurements of Fractional Ground Cover in the Australian Arid Zone, *Remote Sensing* **11**(23), 2825.

Lucieer, A., Turner, D., King, D. H. and Robinson, S. A.: 2014, Using an Unmanned Aerial Vehicle (UAV) to capture micro-topography of Antarctic moss beds, *International Journal of Applied Earth Observation and Geoinformation* **27**, 53–62.

Malhi, Y., Franklin, J., Seddon, N., Solan, M., Turner, M. G., Field, C. B. and Knowlton, N.: 2020, Climate change and ecosystems: Threats, opportunities and solutions, *Philosophical Transactions of the Royal Society B: Biological Sciences* **375**(1794), 20190104.

Melville, B., Fisher, A. and Lucieer, A.: 2019, Ultra-high spatial resolution fractional vegetation cover from unmanned aerial multispectral imagery, *International Journal of Applied Earth Observation and Geoinformation* **78**, 14–24.

Zhang, S., Chen, H., Fu, Y., Niu, H., Yang, Y. and Zhang, B.: 2019, Fractional Vegetation Cover Estimation of Different Vegetation Types in the Qaidam Basin, *Sustainability* **11**(3), 864.

Appendices

A Supplementary Information

A.1 Edaphic variables

Geology structure by site

Bins

Soil classification by site

Bins

B Project Scripts

The project scripts are available online at:

`https://github.com/LNSOTOM/phdGeomaticEngineering`.

The scripts are written in **Python 3.8**.