



Satellite remote sensing to monitor land condition and dynamics in arid Australia

Letting the landscape speak for itself



Thesis submitted for the degree of

Doctor of Philosophy

by

Evertje Frederika Lawley

Bachelor of Natural Resource Management
Bachelor of Science (Honours)

School of Earth and Environmental Sciences
The University of Adelaide, Australia

July 2014

Title page image: Landscape in the northwestern Alinytjara Wilurara Natural Resources Management region near Pipalytjara. Photo by E F Lawley, February 15, 2012.

ABSTRACT

The natural arid regions of Australia hold special value because their ecosystems are relatively intact. They play an important role in carbon cycling, provide ecosystem services, deliver benchmark information about ecosystem structure and function in unmodified landscapes, and are often the last stronghold of threatened species. Many of these regions are also homelands for Aboriginal traditional owners. These regions are under increasing external pressures from mining, tourism, localised grazing and invasive species. Careful management is needed to maintain their ecological values.

Monitoring land condition is vital for management, but in extensive remote regions collecting field data to adequately represent land systems and processes is time consuming and costly. The high spatio-temporal variability of the arid landscape further confounds data interpretation. Long-term patterns of variability in vegetation response need to be understood to interpret management effects as distinct from natural variability. These long-term patterns cannot be understood from field data alone. In contrast, satellite-based monitoring offers potential monitoring solutions, with spatially comprehensive and consistent coverage over wide regions at relatively low cost.

This overall aim of the research was to improve arid land condition monitoring through use of satellite remote sensing. Vegetation cover and soil exposure were used as indicators of land condition throughout the study.

The study focused on the Alinytjara Wilurara (AW) Natural Resources Management (NRM) region in the far west of South Australia. This region is 261,180 km² in extent, much of it in near-pristine or wilderness condition, and is co-managed by the South Australian Government and the Aboriginal traditional owners. The landscape is extremely varied, incorporating calcarenite cliffs and dunes along the southern coast, the flat limestone Nullarbor Plain, red dune fields of the Great Victoria Desert, and the granitic Central Ranges and associated alluvial fans and plains in the north.

The research comprised three components to address the overall aim. Specific objectives were to characterize and better understand the patterns of long term spatio-temporal variability in vegetation growth over the Australian arid zone; to interpret these patterns, their significance and implications for monitoring and management across the AW study region; and to evaluate the potential of high-temporal frequency

low-spatial resolution fractional cover imagery for rapid land condition monitoring in the region. To address the difficulties of field validation, a further objective was to develop the use of high-spatial resolution satellite data as a tool for evaluation of low-spatial resolution fractional cover products.

To detect long-term patterns of variability in vegetation growth, 25 years of twice-monthly AVHRR NDVI data were analysed with principal components analysis. The main components that underlie Australia-wide arid zone variability were revealed as total vegetation growth, seasonal response, and erratic east-west response driven by cyclonic activity. These factors were used as the basis to classify the Australian arid region into 24 classes. The new spatio-temporal classes, which represent long-term vegetation function, were compared to the existing Interim Biogeographic Regionalisation for Australia (IBRA), which describes vegetation in terms of structure and composition. Some classes showed close correspondence with IBRA regions, but in other areas the classes revealed variation in functional response within and between IBRA regions.

Subsequently, focusing on the AW region, the four dominant classes in this region showed distinct characteristics in relation to average amount and temporal variability of vegetation growth, timing of growth cycles, and vegetation type. These distinctions can improve interpretation of on-ground data and have important implications for site selection and monitoring protocols such as timing and frequency of monitoring.

Lastly, a MODIS fractional cover product, designated for Australia-wide usage, was tested for suitability over the AW region for ongoing monitoring of land condition. In the absence of field data, remotely-sensed surrogates were created, which classified high-spatial resolution (2.5m) ALOS PRISM data into fractions of bare soil and vegetation cover. These were up-scaled to MODIS resolution. Weak correlation was found between the surrogate and the MODIS fractional cover product, implying that the MODIS product is not suitable in its current form for use in the AW region. The finding of a slightly stronger correlation with increased vegetation cover suggests that the lack of relationship may be due to the generally low NDVI response of the arid perennial vegetation in this region. The novel method employed to create the soil exposure surrogate for this evaluation warrants further development and application for validating low spatial resolution image products in arid regions worldwide.

This research shows how remote sensing can be used to define the high spatio-temporal variability of the Australian arid zone and provide new spatio-temporal information to improve regional environmental monitoring and management. We recommend that satellite remote sensing, because of its temporal capacity and comprehensive nature, be included as an essential component for monitoring remote arid environments.

TABLE OF CONTENTS

ABSTRACT	III
TABLE OF CONTENTS.....	VII
DECLARATION.....	XI
DEDICATION.....	XIII
ACKNOWLEDGEMENTS.....	XV
LIST OF FIGURES	XIX
LIST OF TABLES.....	XXI
LIST OF PUBLICATIONS	XXIII
ACRONYMS	XXV
CHAPTER 1: INTRODUCTION	1
1.1 Background.....	3
<i>1.1.1 Wilderness management.....</i>	<i>4</i>
<i>1.1.2 Threats to land condition</i>	<i>5</i>
<i>1.1.3 Land condition indicators</i>	<i>6</i>
1.2 Research motivation and approach.....	7
1.3 Study areas.....	8
<i>1.3.1 Currently available quantitative data</i>	<i>10</i>
1.4 Field-based monitoring of land condition.....	11
1.5 Remote sensing for monitoring land condition.....	11
<i>1.5.1 Long time series to investigate vegetation dynamics</i>	<i>12</i>
<i>1.5.2 Long time series to monitor fractional vegetation cover</i>	<i>14</i>
<i>1.5.3 Validating low spatial resolution satellite products.....</i>	<i>16</i>
1.6 Aims and significance of the research	17
1.7 Thesis structure	18
CHAPTER 2: ENVIRONMENTAL ZONATION ACROSS THE AUSTRALIAN ARID REGION BASED ON LONG TERM VEGETATION DYNAMICS	23
Statement of authorship.....	25
2.1 Introduction.....	27

2.2	Methods	29
2.2.1	<i>Study area</i>	29
2.2.2	<i>NDVI data</i>	31
2.2.3	<i>Principal component analysis</i>	32
2.2.4	<i>Classification</i>	33
2.3	Results	33
2.3.1	<i>Factors in vegetation temporal response</i>	33
2.3.2	<i>Classification of vegetation temporal response</i>	38
2.3.3	<i>Relationship between classification and IBRA</i>	42
2.4	Conclusions	44

CHAPTER 3: USING SPATIO-TEMPORAL VEGETATION IMAGERY FOR ARID LANDS MONITORING47

	Statement of authorship	49
3.1	Introduction	52
3.2	Materials and method	54
3.2.1	<i>Study region</i>	54
3.2.2	<i>Data</i>	56
3.2.3	<i>Analysis</i>	56
3.3	Results and interpretation.....	59
3.3.1	<i>AW regional variability in continental context</i>	59
3.3.2	<i>Classes characterised in relation to the environment</i>	64
3.3.3	<i>Comparing the classes with IBRA stratifications</i>	74
3.3.4	<i>Implications for management</i>	76
3.4	Conclusion.....	78

CHAPTER 4: EVALUATING MODIS SOIL FRACTIONAL COVER FOR ARID REGIONS, USING ALBEDO FROM HIGH-SPATIAL RESOLUTION SATELLITE IMAGERY81

	Statement of authorship	83
4.1	Introduction	86
4.2	Methods	89
4.2.1	<i>Study area</i>	89
4.2.2	<i>Estimating bare soil fraction at high spatial resolution</i>	91
4.2.3	<i>The MODIS fractional product to be evaluated</i>	96

4.2.4	<i>Evaluation of MODIS Fract-G</i>	97
4.3	Results.....	98
4.4	Discussion.....	104
4.5	Conclusion.....	106
CHAPTER 5:	DISCUSSION AND CONCLUSIONS	109
5.1	Overview of the research contributions	111
5.1.1	<i>Spatio-temporal vegetation dynamics Australia-wide</i>	<i>112</i>
5.1.2	<i>Spatio-temporal dynamics for regional management</i>	<i>113</i>
5.1.3	<i>Fractional cover imagery for rapid monitoring</i>	<i>116</i>
5.1.4	<i>Summary</i>	<i>119</i>
5.2	Recommendations for future research	119
REFERENCES	123
APPENDICES	137
Appendix A.	Average annual rainfall and pan evaporation.	137
Appendix B.	Average daily annual maximum and minimum temperature....	139
Appendix C.	Satellite imagery used in the study	141
Appendix D.	Minor classes average 25 year NDVI.....	143
Appendix E.	Tropical cyclone paths onto the Nullarbor.....	145

DECLARATION

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

The author acknowledges that copyright of published works contained within this thesis resides with the copyright holder(s) of those works.

I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

Signed:.....

Date:.....

DEDICATION

FOR STEVEN

29-12-1975 – 29-03-1995

ACKNOWLEDGEMENTS

Well here we are, and what a journey it has been. There seems to be a certain madness in going to university after 30 years of filling in “occupation – home duties” on the census forms. When asked why I am studying, with the “at your age?” implied, my reply has been: curiosity drove me! But truth-be-told, the wish to write a scientific report on our findings as environmental volunteers, and my inability to do so, was the driver.

This adventure would however never have happened without the encouragement of many people along the way. From Ben Pavy, who infected me with the joy of recognising plants, to Sue Kenny and Lee Heard who showed how to preserve and record the information, and most of all to Brad Page and Annelise Wiebkin, who on distant islands, under starry skies while waiting silently for Little penguins to come home, swayed my mind into believing that studying for a university degree was a realistic option; I may have surprised them as much as myself, when it became a PhD. Thanks goes to Dr. Scoresby Shepherd, whose example I admire, not spending time on obstacles, but navigating around them and keeping on course. He showed me, in his role as editor, how to “omit needless words”, though I confess that has remained a struggle. To these and many others I owe gratitude for their belief in me that set me on this journey.

Most importantly I would like to acknowledge my supervisor extraordinaire, Professor Megan Lewis, who inspired, guided, read, made suggestion for edits, and made time when she really did not have any... who never failed to make me feel that I was capable when I felt the least I was. Thank you; this thesis would have never happened without you. I’d like to thank co-supervisor Assoc. Prof. Bertram Ostendorf for his contribution to discussions and for his reading and encouragement to publish results.

I’m ever grateful to all the fellow students of the Spatial Information Group at the Waite campus for the many coffee room discussions. With special appreciation to Ramesh Raja Segaran, for the numerous times he showed me better ways to use Arc-GIS and R and for encouraging me to delve into the “why” before tackling the “how”, and to Ken Clarke, Greg Lyle and Valerie Lawley, for the many instances of help and data. Special thanks to Victoria Marshall for opportunity to see the landscape and for the wonderful times in the field.

Thanks to Adam Woods of the Alinytjara Wilurara office for the invaluable shape files and information.

And lastly, and most important of all, I would like to acknowledge and thank my family for their support. Thanks to my husband and best friend John, who ever encouraged the study. To all the kids...proud of you...and love you all.

.

ACKNOWLEDGEMENTS

The study was supported by a University of Adelaide PhD divisional scholarship.

Additional funding from the Alinytjara Wilurara Natural Resource Management Board is gratefully acknowledged.

Thanks goes to the South Australian Government Department of Environment (then DEH, now DEWNR) for use of the ALOS satellite imagery.

LIST OF FIGURES

Fig. 1.1	The Australian arid zone and Alinytjara Wilurara study areas.....	9
Fig. 2.1	The study area comprising the Australian arid zone excluding cultivated areas. Biogeographic regions defined by IBRA vs 6.1 are shown.	31
Fig. 2.2	Principal components 1 to 5.....	35
Fig. 2.3	Plot of eigenvector band loadings of the first 5 principal components.....	35
Fig. 2.4	Colour composite of PC1 (red) and PC2 (green) with IBRA regions overlaid to indicate approximate locations.....	37
Fig. 2.5	a. Geographic distribution of 24 classes resulting from unsupervised classification of the first 14 PCs of 25-year NDVI, with overlay of IBRA vs 6.1 regions. b. 3-D plot of class scores for PC 1, 2 and 3.....	39
Fig. 2.6	The variation in NDVI response over 25 years for each class.....	41
Fig. 3.1	The AW study region showing pastoral paddocks and conservation reserves. CP=Conservation Park, RR=Regional Reserve, WA=Wilderness Area, NP=National Park. Rain recording stations highlighted in blue are used in the analysis, as they have near complete records for the entire 1982 - 2006 study period.....	55
Fig. 3.2	The distribution of IBRA (vs 6.1) regions across non-cultivated arid Australia.	59
Fig. 3.3	Colour composite of the three main factors that define vegetation variability across the Australian arid zone, and as expressed in the AW region. The area within the oval shape on the legend cube shows the AW response: the vegetation 25-year aggregate is moderate to low (red), vegetation response is aseasonal to winter active (green), and not strongly affected by extreme east-west erratic events (blue).	61
Fig. 3.4	The study site showing the classes represented within the AW region, with main classes named. Biogeographic regions mapped are, a. IBRA regions, b. IBRA sub-regions, c. South Australian IBRA associations.	65
Fig. 3.5	NVDI for each class averaged over 25 years at twice monthly intervals. Variability for each date is shown by the coefficient of variation (CV, dashed lines). For minor classes see Appendix D.	66
Fig. 3.6	Trend analysis for each of the major classes. STL plot showing for each class the raw twice monthly NDVI values over 25 years in the top panel; below this are the seasonality after Loess smoothing, the trend panel and the residual panel. The grey scale bars shown to the right of each panel indicate the same data range within each individual plot. These values correspond to the relative contribution of the components.	67
Fig. 3.7	Desert class (17) and Yellabinna class (13) NDVI time series showing vegetation growth over 25 years. Rainfall shown was recorded at Maralinga, the most relevant station with comprehensive records for the 1982 - 2006 period.	69
Fig. 4.1	Alinytjara Wilurara Natural Resources Management region forming the study area in South Australia. The ALOS PRISM satellite path used in the study and the 22 25 × 34 km sampling regions north to south within this path are shown. Relevant rain-recording stations are indicated.	89
Fig. 4.2	Bare soil colour of the minor roads is similar to that in the surrounding landscape (image: E Lawley- 7/12/2011, 3:30pm, West of Umuwa).	94
Fig. 4.3	Illustration of the procedure followed to determine the bare soil albedo threshold and percentage of bare soil. (a) ALOS scene selected, here 4165 in the Great Victoria Desert region of the AWNRM. (b) ALOS sampling area 4165 shown in natural colour with overlay of known road. (c) Same area in ALOS panchromatic 2.5 m, indicating subset in	

magenta. (d) Enlarged subset, showing parallel east-west dune crests crossed by minor roads that were used to determine the reflectance threshold for sampling region 4165. (e) Same enlargement classified using the threshold; bare soil - yellow, cover - green. (f) The image with 500 m grid and percentage bare soil per cell calculated. 95

Fig. 4.4 (a) ALOS PRISM sampling area 4230 at the southern edge of the Nullarbor Plain; subset outlined. (b) Enlarged subset showing east-west road and clearly visible tree crowns. (c) The subset classified, bare soil - yellow, cover – green, 500 m sampling grid and percentage bare soil per cell indicated. (d) Same subset in MODIS Fract-G 041 and (e) in MODIS Fract-G 049. 100

Fig. 4.5 (a) ALOS PRISM sampling area 4130 in the northern pastoral region with subset outlined. (b) Enlargement of the subset showing an east-west road used to determine bare soil threshold and a dry creek bed, with tree crowns clearly visible. (c) ALOS PRISM enlargement classified: bare soil - yellow, cover – green; showing 500 m sampling grid and percentage bare soil per cell. (d) The subset in MODIS Fract-G 041 and (e) in MODIS Fract-G 049. Note that ALOS PRISM and MODIS Fract-G show a contradictory pattern in this subset. 102

Fig. 4.6 (a) ALOS PRISM sampling area 4205 in sand dunes east of Maralinga showing a fire scar in the south-east of the image and a subset outlined at the fire scar edge. (b) Enlarged ALOS PRISM subset, with bare soil visible in the fire scar and on the crests of longitudinal dunes. (c) The ALOS PRISM subset classified, bare soil - yellow, cover – green; showing 500 m sampling grid and percentage bare soil per cell. (d) The subset in MODIS Fract-G 041 revealing no fire scar. (e) The subset in MODIS Fract-G 049 revealing a fire scar pattern corresponding to the ALOS PRISM pattern in Figure 6(b). 103

Fig. 4.7 Correlation between MODIS Fract-G and ALOS PRISM bare soil is slightly better in areas with less bare soil. 104

LIST OF TABLES

Table 2.1 Percentage of variance explained by some of the 600 principal components.....	34
Table 2.2 IBRA regions in the arid zone showing percentage of IBRA occupied by each class.	43
Table 3.1 Seasonality across arid Australia shown by the number of years in which the factor 2 eigenvector extremes occurred in this month.....	63
Table 3.2 The classes most prominent in the AW region; their extent within the Australian arid zone and within the AW region.....	64
Table 3.3 STL results summarized.....	67
Table 4.1 Satellite image acquisition dates and attributes.	91
Table 4.2 Rainfall records (mm/day) relevant to the study area. Evaluation date is in bold. (N)QC = (not) quality controlled.....	93
Table 4.3 Correlation between two sequential (smoothed) MODIS Fract-G bare soil images showing correlation coefficient (r) and RMSE, and correlation between (smoothed) MODIS Fract-G 049 and ALOS PRISM bare soil values showing (r) and RMSE. For image dates see Table 4.1.....	99

LIST OF PUBLICATIONS

Publications included in this thesis

Lawley, E.F., Lewis, M.M., & Ostendorf, B. (2011). Environmental zonation across the Australian arid region based on long-term vegetation dynamics. *Journal of Arid Environments*, 75, 576-585

Lawley, E.F., Lewis, M.M., & Ostendorf, B. (2014). Using spatio-temporal vegetation imagery for arid lands monitoring. *Ecological Indicators* (Submitted)

Lawley, E.F., Lewis, M.M., & Ostendorf, B. (2014). Evaluating MODIS soil fractional cover for arid regions, using albedo from high-spatial resolution satellite imagery. *International Journal of Remote Sensing*, 35, 2028-2046

ACRONYMS

ALOS	Advanced Land Observing Satellite
AW region	Alinytjara Wilurara region
AWNRM	Alinytjara Wilurara Natural Resources Management
AVHRR	Advanced Very High Resolution Radiometer
BRDF	Bidirectional Reflectance Distribution Function
IBRA	Interim Biogeographic Regionalisation for Australia
MODIS	MODerate resolution Imaging Spectroradiometer
MODIS Fract-G	The MODIS Fractional cover product created by Guerschman et al (2009) – abbreviation coined for this thesis.
NBAR	Nadir BRDF-Adjusted Reflectance
NOAA	National Oceanic and Atmospheric Administration
PRISM	Panchromatic Remote-sensing Instrument Stereo Mapping
GVD	Great Victoria Desert

