

**Remote sensing and modelling the distribution of
Lantana camara L. in relation to land-use, soil drainage
and climate change**

Subhashni Taylor

BSc. University of the South Pacific

MSc. London South Bank University

A thesis submitted for the Degree

of

DOCTOR OF PHILOSOPHY

of

UNIVERSITY OF NEW ENGLAND

December 2011

Certification

I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree or qualification.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.



Subhashni Taylor

2nd December 2011

Abstract

Lantana camara L. (lantana) is a major problem globally and has been declared a weed of national significance (WoNS) in Australia due to its significant negative impacts on Australian biodiversity and agriculture. Development of remote sensing techniques and modelling approaches that can map lantana accurately and project its likely future distribution should be useful for formulation of more effective, long-term management plans. The research reported here comprises seven studies based on remote sensing and modelling techniques that should contribute to better mapping and projected modelling of lantana in an era of climate change.

Four image fusion techniques, namely Brovey, Hue–Saturation–Value (HSV), Principal Components (PC) and Gram–Schmidt (GS) Spectral Sharpening, were investigated using Quickbird imagery to identify the most effective fusion algorithm for mapping lantana. The results identified GS and PC spectral sharpening techniques as the most effective for this purpose. Brovey transformation and HSV, on the other hand, performed poorly with much lower overall accuracies. Three commonly available satellite images of varying spectral, spatial and radiometric resolutions from Landsat TM, SPOT 5 and Quickbird were assessed for accuracy and cost effectiveness in lantana mapping. The most cost-effective option was provided by Landsat TM with no significant difference in overall accuracies between the three types of imagery.

A further study involved the identification of optimal hyperspectral bands for lantana discrimination from co-occurring vegetation. The results identified 86 bands from the reflectance data and 18 bands from the first derivative of reflectance (FDR), respectively, where lantana significantly differed from co-occurring species. The effectiveness of these optimal bands was evaluated using Hyperion imagery. There was no significant difference in overall accuracy with the full set of Hyperion bands compared to the 86 and 18 bands spectral subsets. The FDR analysis combined with the statistical analysis proved to be a useful procedure for data reduction by refining the discrimination to fewer optimal bands for lantana detection with no adverse impacts on classification accuracy. These first three remote sensing studies were conducted in Toonumbar and Richmond Range National Parks near Kyogle in New South Wales, Australia.

The modelling studies involved CLIMEX, a widely used software program for modelling species distributions. It allows the incorporation of climate change scenarios, thereby

providing an estimate of how lantana distribution may change under the impacts of projected climate change. Knowledge of the potential distribution of this invasive species, under current and future climate, will assist the development of more precise and targeted strategies to manage lantana.

The potential global distribution of lantana was assessed under current and future climate scenarios. Climatic suitability for lantana decreased substantially in South and Central America as well as Africa by the 2070s. However, new areas of climatic suitability were identified in North Africa, Europe, Australia and New Zealand. The model was also run for continental Australia but with the incorporation of land-use data to further refine the distributions. These results showed that the range of lantana could expand into new areas in Victoria, South Australia and Tasmania while the northern parts of the continent become climatically unsuitable. However, the inclusion of land-use data restricted projected distribution.

Potential distribution of lantana for Queensland was estimated based on climate, land-use and soil drainage data. Climate change scenarios identified the northern parts of the state as becoming climatically unsuitable in the 2070s while southern coastal regions remain highly suitable. A more restricted distribution was projected with the inclusion of land-use and soil drainage data.

In the final study, a sensitivity analysis was conducted to identify the CLIMEX model parameters that had the most influence on lantana distribution. Projected lantana distribution was highly sensitive to changes in the upper and lower limits of temperature tolerance. The distribution was also highly sensitive to limiting low soil moisture. Highly sensitive parameters require extensive research and data collection to be fitted accurately in species distribution models while relatively insensitive parameters can be fitted with a wider margin of error.

These studies demonstrated the potential of remote sensing and modelling techniques in more effective management of lantana. The findings provide useful information on the actual and potential distribution of this weed which can lead to better informed management strategies. Furthermore, the techniques identified here are also relevant to the management of other invasive species. Additionally, this research makes a valuable contribution to the ongoing debate on impacts of climate change on invasive species.

Acknowledgements

I am grateful to my principal supervisor Lalit Kumar, and my co-supervisor, Nick Reid, for their encouragement, support and generous contribution of time and knowledge. I would like to thank Steven King from the Department of Environment and Climate Change for providing access to the study site and support in field work.

A very special thank you to Cate MacGregor, not only for your technical support but also for being a wonderful source of support and friendship. Thanks to all the postgrads who provided help and encouragement during my time here and in particular Rhiannon Smith, for numerous cups of coffee and brain storming sessions, Carlos Muñoz and Priyakant Sinha for patiently answering all my GIS and remote sensing questions.

Thank you to my husband, Neil, for his unstinting support throughout the PhD and my son Marc, who was always forgiving if mum seemed a bit preoccupied at times!

Finally, I'd like to dedicate this thesis to the memory of my mother, Rukhmani. Thank you for everything ma.

Note to Examiners

This thesis has been written in journal-article- format. I have attempted to minimize the duplication of material between chapters. However, some repetition remains, particularly in the methodology sections of certain of the articles. Please excuse this repetition.

Although efforts have been made to ensure consistency in the format for the purposes of this thesis, I acknowledge that some inconsistencies remain because of the requirements of each of the journals to which the separate papers were submitted.

CONTENTS

Abstract	iii
Acknowledgements	v
Note to Examiners.....	vi
List of Tables	xii
List of Figures	xiii
CHAPTER 1 GENERAL INTRODUCTION	2
1.1 Invasive species and their impacts.....	2
1.2 Lantana	3
1.2.1 Lantana biology	3
1.2.2 Lantana distribution	5
1.2.3 Impacts of lantana	5
1.3 Information requirements for management of lantana.....	6
1.3.1 Remote sensing	6
1.3.2 Remote sensing techniques: image fusion	7
1.3.3 Types of imagery	9
1.3.4 Species distribution models (SDMs)	10
1.4 General aims	14
1.5 Format of thesis	15
CHAPTER 2 MAPPING <i>LANTANA CAMARA</i>: ACCURACY COMPARISON OF VARIOUS FUSION TECHNIQUES.....	17
Abstract	17
2.1 Introduction	17
2.2 Methodology.....	19
2.2.1 Study Site	19
2.2.2 Image Analysis	20
2.2.3 Image Fusion	23
2.2.3.1 Brovey Transformation	24
2.2.3.2 Hue-saturation-value (HSV).....	24
2.2.3.3 Principal Components Spectral Sharpening (PC)	24
2.2.3.4 Gram–Schmidt Spectral Sharpening (GS)	25
2.3 Results	25

2.3.1 Visual Comparison.....	25
2.3.2 Statistical Analysis.....	28
2.3.3 Classification Accuracies	30
2.4 Discussion	32
2.5 Conclusions	34
CHAPTER 3 ACCURACY COMPARISON OF QUICKBIRD, LANDSAT TM AND SPOT 5 IMAGERY FOR <i>LANTANA CAMARA</i> MAPPING.....	39
Abstract	39
3.1 Introduction	39
3.2 Materials and Methods.....	42
3.2.1 Study Area.....	42
3.2.2 Image and Image Processing	42
3.2.3 Supervised Classification	44
3.2.4 Statistical Analysis of Image Accuracies	46
3.3 Results and Discussion.....	47
CHAPTER 4 OPTIMAL BAND SELECTION FROM HYPERSPECTRAL DATA FOR <i>LANTANA CAMARA</i> DISCRIMINATION.	55
Abstract	55
4.1 Introduction	55
4.2 Materials and methods	58
4.2.1 Study site and data collection.....	58
4.2.2 First derivative reflectance	60
4.2.3 Statistical analysis.....	61
4.2.4 Image processing and classification.....	62
4.3 Results	64
4.3.1 Visual difference.....	64
4.3.2 Statistical difference.....	65
4.3.3 Image classification	71
4.4 Discussion	72
4.5 Conclusions	74
CHAPTER 5 CLIMATE CHANGE AND THE POTENTIAL DISTRIBUTION OF AN INVASIVE SHRUB, <i>LANTANA CAMARA</i> L.	79
Abstract	79
5.1 Introduction	79
5.2 Materials and Methods.....	81

5.2.1	CLIMEX Software.....	81
5.2.2	Taxonomy and Native and Naturalized Distribution of <i>L. camara</i>	82
5.2.3	Climate Data and Climate Change Scenarios.....	83
5.2.4	Fitting CLIMEX Parameters	83
5.2.5	Stress Indices	84
5.2.5.1	Cold Stress.....	84
5.2.5.2	Heat Stress	84
5.2.5.3	Dry Stress	85
5.2.5.4	Wet Stress.....	85
5.2.6	Growth Index.....	85
5.2.6.1	Temperature Index	85
5.2.6.2	Moisture Index.....	85
5.2.6.3	Annual Heat Sum.....	86
5.3	Results	87
5.3.1	Current Climate	87
5.3.2	Future Climate	89
5.4	Discussion	92
CHAPTER 6 IMPACTS OF CLIMATE CHANGE AND LAND-USE ON THE POTENTIAL DISTRIBUTION OF A WEED: A CASE STUDY OF <i>LANTANA CAMARA</i> L. IN AUSTRALIA.....		98
6.1	Introduction	98
6.2	Ecology of <i>Lantana camara</i>	99
6.2.1	The current global distribution of <i>Lantana camara</i>	99
6.2.2	Species distribution modelling	100
6.3	Materials and Methods.....	101
6.3.1	CLIMEX Software.....	101
6.3.2	Meteorological Database and Climate Change	101
6.3.3	Fitting CLIMEX Parameters	102
6.3.4	Stress Indices	102
6.3.4.1	Cold Stress.....	102
6.3.4.2	Heat Stress	103
6.3.4.3	Dry Stress	103
6.3.4.4	Wet Stress.....	103

6.3.5Growth Index.....	103
6.3.5.1 Temperature Index.....	103
6.3.5.2 Moisture Index.....	104
6.3.5.3 Annual Heat Sum.....	104
6.3.6Land-Use Data.....	104
6.4 Results.....	107
6.4.1Historical Climate.....	107
6.4.2Future Climate.....	109
6.4.3Incorporating Land-Use.....	110
6.5 Discussion.....	113
6.5.1Limitations of models.....	115
CHAPTER 7 POTENTIAL DISTRIBUTION OF AN INVASIVE SPECIES AND RISK ASSESSMENT UNDER CLIMATE CHANGE SCENARIOS USING CLIMEX, SOILS AND LAND- USE: A CASE STUDY OF <i>LANTANA CAMARA</i> L. IN QUEENSLAND, AUSTRALIA.....	120
Abstract.....	120
7.1 Introduction.....	121
7.2 Materials and Methods.....	125
7.2.1CLIMEX Software.....	125
7.2.2Meteorological Database and Climate Change.....	125
7.2.3Fitting CLIMEX Parameters.....	126
7.2.4Stress Indices.....	127
7.2.4.1 Cold Stress.....	127
7.2.4.2 Dry Stress.....	127
7.2.4.3 Wet Stress.....	127
7.2.5Growth Index.....	128
7.2.5.1 Temperature Index.....	128
7.2.5.2 Moisture Index.....	128
7.2.6Land-Use Data.....	129
7.2.7Soil Drainage.....	130
7.3 Results.....	131
7.3.1Historical Climate.....	131
7.3.2Future Climate.....	132
7.3.3Incorporating Land-Use and Soil Drainage.....	134

7.4	Discussion	136
Appendix 7.1.....		143
CHAPTER 8 SENSITIVITY ANALYSIS OF CLIMEX PARAMETERS IN MODELLING POTENTIAL DISTRIBUTION OF <i>LANTANA CAMARA</i> L.....		149
Abstract		149
8.1	Introduction	149
8.2	Materials and methods	153
8.3	Results	156
8.4	Discussion and Conclusions	160
CHAPTER 9 GENERAL CONCLUSIONS.....		169
9.1	Introduction	169
9.2	Summary of Main Findings.....	169
9.2.1	Remote Sensing	169
9.2.2	Modelling	170
9.3	Implications of the Study	172
9.4	Recommendations.....	173
Bibliography.....		174

List of Tables

Table 2.1: Overall accuracies and Kappa coefficients of the four classifications.	27
Table 2.2: Producer (P) and user (U) accuracy of the maximum likelihood classification of the original MS and four fused images for each category of land-cover.	27
Table 2.3: Confusion matrices for the classification of the MS and various fused images. The main diagonals indicating correct allocations have been highlighted.	32
Table 3.1: The main characteristics of the imagery used in this study.	43
Table 3.2: Overall accuracies and Kappa coefficients for the three classifications.	47
Table 3.3: Producer and user accuracy that resulted from the Maximum Likelihood classification for each category.	47
Table 3.4: Kappa analysis results for the pairwise comparison of error matrices.	47
Table 4.1: Tree species and sample size.	60
Table 4.2: 155 Stable Hyperion Bands	62
Table 4.3: Overall accuracies, Kappa coefficients and producer and user accuracies of the three classifications of the Hyperion image.	71
Table 5.1: The CLIMEX parameter values that were used for lantana.	86
Table 6.1: The CLIMEX parameter values that were used for <i>Lantana camara</i>	105
Table 7.1: The CLIMEX parameter values that were used for <i>Lantana camara</i> L.	129
Table 7.2: Number of herbarium point records within each suitability category.	132
Table 7.3: Estimated area for each suitability category for the climate only and climate, land-use and soil drainage models in Queensland.	133
Table 8.1: The CLIMEX parameter values that were used for <i>Lantana camara</i> L. in the baseline model.	155
Table 8.2: Number of herbarium point records within each suitability category.	157
Table 8.3: Impact of sensitivity analysis of the temperature, soil moisture and cold stress parameters on suitable and highly suitable areas.	161

List of Figures

Figure 2.1: Map showing location of study area and surrounding national parks and state forests. The study area is bounded by the extent of the Quickbird image.	20
Figure 2.2: (a): Dense lantana growth in areas with open canopy, and (b) Lantana can grow up the trunks of trees to heights of 5 to 6 m. Dense shrubbery at the forefront of both pictures is lantana.....	20
Figure 2.3: The rectified and relative atmospherically corrected QuickBird image of the study area. The white areas represent open pastures and other exposed surfaces such as roads. Image size is 8 km × 8 km. (© QuickBird image, Copyright 2004, DigitalGlobe). .	21
Figure 2.4: Results of the four image fusion approaches. A subset of the image is displayed with band combination 4 (near-infrared), 3 (visible red), and 2 (visible green) (RGB): (a) Brovey fused image, (b) HSV fused image, (c) PC fused image, and (d) GS fused image. For comparison with the original MS image see (e). Image width is approximately 1 km.	26
Figure 2.5: Results of the classification showing the four fused and classified images and the classified MS image of the whole study area: (a) Brovey fused image, (b) HSV fused image, (c) PC fused image, (d) GS fused image, and (e) Multispectral image. Image size is 8 km × 8 km.....	29
Figure 2.6: Correlations and statistical analyses of the original MS and the four fused images: (a) Correlation between each MS band and the respective fused bands, (b) Correlation of band 1 of MS image with other MS bands before and after fusion, (c) Maximum value of all bands of the original MS and the four fused images, (d) Mean value of all bands of the original MS and the four fused images, and (e) Standard deviation of all bands on the original MS and the four fused images.....	31
Figure 3.1: Map showing location of study area and surrounding National Parks and State Forests.	42
Figure 3.2: Spectra of the land-cover classes extracted from the three images. (a) Forest, (b) Lantana and (c) Pasture	45
Figure 3.3: The classified images: (a) Quickbird, (b) Landsat TM and (c) SPOT 5. Pasture (red), Forest (green), Lantana (blue). Image size is approximately 8 km × 8 km. The black area to the right of the image was masked out during classification because it was in shadow due to an escarpment.	49

Figure 3.4: Cost-effectiveness of three satellite images for mapping lantana (the maximum price km ⁻² is shown on the graph).	51
Figure 4.1: Map showing location of study area and surrounding national parks. The extent of the Hyperion imagery is shown by the large rectangle and the black dots within it represent data collection sites.	59
Figure 4.2: Extracted reflectance spectrum from atmospherically corrected Hyperion sample pixel.....	63
Figure 4.3: Mean reflectance spectra for all species (resampled to match the wavelengths and bandpass of the Hyperion data). The 95% confidence level for the mean spectra was within 3%.	65
Figure 4.4: Pairwise test results for the reflectance spectra. The grey shaded regions indicate the wavelengths where reflectance differed significantly between species at p=0.001 (Bonferroni adjusted).	67
Figure 4.5: Frequency plot of statistically significant differences (using the Mann-Whitney U-Test), between the reflectance for all possible pairs at every channel, overlaid with the mean reflectance curve of lantana. Grey shaded areas and the right plot axis indicate wavelength regions where lantana is significantly different from the other species.	68
Figure 4.6: First derivative curves of the mean reflectance spectra for all species (species codes as shown in Table 4.1). Vertical lines indicate wavelengths at which differences between the eight species can be seen.	68
Figure 4.7: Pairwise test results for the first derivative of the reflectance spectra. The grey shaded regions indicate the wavelengths where species differed significantly at p=0.001 (Bonferroni adjusted).	70
Figure 4.8: Frequency plot of statistically significant differences (using the Mann-Whitney U-Test), between the first derivative of reflectance spectra for all possible pairs at every channel, overlaid with the mean reflectance curve of lantana. Grey shaded areas and the right plot axis indicate wavelength regions where lantana is significantly different from the other species.	71
Figure 5.1: The current global distribution of lantana taken from the Global Biodiversity Information Facility 2007.....	87
Figure 5.2: The potential distribution based on CLIMEX:	88

Figure 5.3: Current and modelled potential distribution for reference climate (averaging period 1950-2000). Data for current Australian distribution is taken from Australia's Virtual Herbarium.	89
Figure 5.4: Potential distribution of <i>lantana</i> under CSIRO-Mk3.0 GCM for 2030.....	91
Figure 5.5: Potential distribution of <i>lantana</i> under CSIRO-Mk3.0 GCM for 2070.....	91
Figure 5.6: Potential distribution of <i>lantana</i> under MIROC-H GCM for 2030.....	91
Figure 5.7: Potential distribution of <i>lantana</i> under MIROC-H GCM for 2070.....	92
Figure 6.1: Flowchart describing the data processing methodology	107
Figure 6.2: The current global distribution of <i>lantana</i> taken from the Global Biodiversity Information Facility 2007.....	108
Figure 6.3: The potential distribution of <i>lantana</i> based on CLIMEX.....	108
Figure 6.4: (a) The current Australian and (b) potential distributions of <i>lantana</i> based on reference climate only (1961-1990) and (c) climate and land-use.	109
Figure 6.5: The ECHAM3 GCM showing the potential distributions of <i>lantana</i> based on climate only and climate and land-use.	112
Figure 6.6: The HadCM2 GCM showing the potential distributions of <i>lantana</i> based on climate only and climate and land-use.	113
Figure 7.1: The current Queensland (a) and potential distributions of <i>lantana</i> for reference climate (1961-1990) based on climate only (b) and climate, land-use and soil drainage (c). Data for current Queensland distribution is taken from Australia's Virtual Herbarium. CYP: Cape York Peninsula; WT: Wet Tropics; BBN: Brigalow Belt North; CMC: Central Mackay Coast; SEQ: South East Queensland.	132
Figure 7.2: The ECHAM3 GCM showing the potential distributions of <i>lantana</i> based on climate only and climate, land-use and soil drainage.	135
Figure 7.3: The HadCM2 GCM showing the potential distributions of <i>lantana</i> based on climate only and climate, land-use and soil drainage.	137
Figure 8.1: Current and modelled potential distribution of <i>lantana</i> . Data for current global distribution was taken from Global Biodiversity Information Facility 2007.....	156

Figure 8.2: Current and modelled potential distribution for reference climate (averaging period 1961-1990). Data for current Australian distribution is taken from Australia's Virtual Herbarium.....	157
Figure 8.3: Sensitivity analysis of the temperature parameters in CLIMEX for <i>L. camara</i> as change in area of the suitable and highly suitable categories.....	159
Figure 8.4: Sensitivity analysis of the soil moisture parameters in CLIMEX for <i>L. camara</i> as change in area of the suitable and highly suitable categories.	159
Figure 8.5: Changes in suitability; A. DV0 = 8°C; B. DV0 = 9°C; C. DV0 = 11°C; D. DV0 = 12°C; E. DV3 = 31 °C; F. DV3 = 32°C; G. DV3 = 34°C and H. DV3 = 35°C.....	162
Figure 8.6: Changes in suitability; A. SM0 = 0.08; B. SM0 = 0.12	163