Defining and mapping rare vegetation communities: improving techniques to assist land-use planning and conservation

Stephen A. J. Bell BSc. (Hons)

A thesis submitted for the degree of
Doctor of Philosophy
School of Environmental and Life Sciences
The University of Newcastle

February 2013
Declaration

Statement of Originality
This thesis contains no material which has been accepted for the award of any other degree or diploma 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. 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.

Statement of Collaboration
I hereby certify that the concepts embodied in Chapter 2 of this thesis have been done in collaboration with a fellow researcher at this university. I have included as part of the thesis in Chapter 2 a statement clearly outlining the extent of collaboration with whom and under what auspices.

Stephen A. J. Bell
“The vegetated landscape .... on first appearance presents a bewildering display of living matter, a higgledy-piggledy mass of trunks, leaves, branches, shrubs and grasses seemingly without form. The more observant may notice that the higgledy-piggledy mass varies from one place to another, that in some places there are trees as tall as large buildings while in other places there are no trees at all .... By the application of a systematic approach to viewing vegetation the bewildering display of plant life can take on new meaning thus altering one’s perception of what is being seen .... Suddenly the jumble of plant life reveals structures and beauties probably hitherto unseen”.


In the early 1990’s, Nic Gellie introduced me to the perils and challenges of vegetation classification when we worked together on the production of a classification and map of Yengo National Park for the New South Wales National Parks and Wildlife Service. At the time, it seemed to be such a daunting task to encapsulate all the variation I could see in the forests, woodlands, heaths and rainforests (the ‘higgledy-piggledy mass’) and transform them into a single classification of 15 communities, particularly as at the same time I was also mastering my plant identification skills. But we succeeded. Fifteen years later, when revising that classification with Daniel Connolly, it was remarkable how much community diversity there was that Nic and I had overlooked. Unraveling the intricacies of numerical classification in those early days with Nic was, however, when the classification ‘bug’ struck me, and I have not looked back ever since.

I remember that, in the mid 1990’s when I ventured into the consultancy field following the Yengo project, the thought struck me that I should start to collect systematic sample data for all projects I worked on, irrespective of it being a requirement of a project brief or not. The idea of collecting and storing data for use ‘sometime in the future’ was of little consequence at the time, but in hindsight it was one of the best professional decisions I have made. When the opportunity arose to produce the first ever classification and map of Wollemi National Park in the late 1990’s, I grabbed it with some trepidation but also with considerable gusto. At nearly half a million hectares, and the second largest national park in New South Wales, the challenge of sampling and mapping such a vast area was both a challenge and, it must be said, a bit frightening. But again, I managed to complete that project to some level of satisfaction, knowing however that a dataset of ~340 samples was not nearly enough to highlight the diversity of such an amazing wilderness. Once again, fifteen years hence it is with Daniel Connolly and his crew that the original Wollemi classification is being revised, and again we are uncovering further community diversity. What has changed in the intervening period? Apart from considerably larger
budgets and more resources, with experience comes a better understanding of how to structure a sampling regime to capture more community diversity.

It was during these early years in my classification forays that I began to develop some of the pangs of uncertainty that have now morphed into the central themes of this thesis. When I began, the mouthful that was environmental stratified random sampling was standard practice in project design, and in the years that followed I never attempted to classify an area without implementing some form of environmental stratification from which to select my samples. But it eventually dawned on me that the stratification process was not detecting the full range of community diversity (the ‘structures and beauties hitherto unseen...’), and that there must be a more thorough way of sampling and classifying a patch of land. Plant species were not distributed randomly across a landscape, so why were we assuming that randomly locating sample plots within the landscape, albeit within broad environmental strata, would capture all variation? I started to target my sampling to those areas that were clearly different from their surrounds, a process I now know as preferential sampling. In my reading of the literature, I discovered that such a sampling method was actually at the core of the Zurich-Montpellier approach to classification, founded in Europe in the early 20th Century, and that knowing your study area intimately was the basis behind a good classification. Why, then, were we in many parts of Australia so intent on selecting our samples remotely within a computer generated environmental stratification, and actually spending less time in the field? I endeavored to find out.

When the Threatened Species Conservation Act was proclaimed in New South Wales in 1995, the concept of endangered communities came into the thinking of consultant ecologists and others charged with natural resource management. For a community to be endangered, it had to be definable and, often, rare or restricted in its geographical distribution. By the early 2000’s it became clear to me that vegetation communities defined through an environmentally stratified random sampling approach were often incapable of detecting many communities that may qualify as endangered; if they were, such communities were included in much broader units and their true significance was potentially lost. Some listed endangered communities were also difficult to rationalize with on-ground observations (bread & butter tasks for a working ecologist in the development industry), which in some cases could be traced back to the methods in which they were initially defined. A change was needed. Hopefully, the information presented in this thesis may facilitate a re-focusing of the way that classification is undertaken in Australia, so that truly rare and restricted communities can be protected accordingly. Or, in the prose of Ian Read, it is hoped that through this work ‘hitherto unseen structures and beauties can be extracted systematically from the higgledy-piggledy mass’.

“Since we cannot change reality, let us change the eyes which see reality”

Nikos Kazantzakis (1883-1957)
Undertaking an investigation of the scale at which this thesis has been done could not have occurred without data, and lots of it. I have been fortunate enough to earn a living collecting systematic vegetation data, and have done so for nearly 20 years. Those who know me will attest to the fact that I am, indeed, a data-junkie. But with data comes possibilities, and as I have found over the years those possibilities are endless. Working as a consultant botanist has allowed me access to numerous locations within (mainly) the Sydney Basin of New South Wales, where collecting systematic sample data has become second nature to me. However, I am indebted to all those landowners and government authorities (too numerous to mention all by name) that have allowed me access to their properties for data collection purposes, which may or may not have been used directly in this thesis. In particular, I wish to thank the NSW Office of Environment & Heritage (and all of its constituent parts and former incarnations), the Commonwealth Department of Defence, and the local government Councils of Lake Macquarie, Cessnock, Gosford and Wyong. For allowing access to private lands, I wish to thank Eve and Alan Lowson, Helen and Peter Horn, Rixs Creek Coal, Mt Owen Coal, Wallarah Coal, Bloomfield Coal, Wyong Shire Council, Lake Macquarie City Council, and the Roche Group. Lake Macquarie City Council and the Roche Group are particularly thanked for permission to use data from a previous study in northern Lake Macquarie as a case study for Chapter 2.

Within the NSW Office of Environment & Heritage, I am grateful to Daniel Connolly, Liz Magarey, Renee Woodford, Brian Flannery, Tricia Hogbin, Phil Craven, Sean Thompson, Karen Thumm and Lucas Grenadier for field assistance, logistics and/or general discussions about classification and its implications. Several of these people project managed or assisted with surveys over the years, making the job of data collection and analysis so much easier. NSW OEH also allocated funding towards a revision of Lower Hunter Spotted Gum-Ironbark Forest, detailed in Chapter 4, and this is greatly appreciated. To those staff involved, and particularly Andrew McIntyre, many thanks for your patience, particularly during those times when, for various reasons, the revision work was progressing slowly.

At the University of Newcastle, I extend particular thanks to Mike Cole, Tina Offler and John Patrick. Completing a research thesis on a part-time basis was always going to be difficult, but these three were exceedingly flexible in their supervision, allowing me the freedom and time to explore exactly what and where I wanted to go with this thesis, even when at times I was unsure myself. But, when it was time to bite the bullet they reined me in sufficiently enough to progress. I am also thankful to a number of colleagues and fellow ecologists for their often unspoken encouragement during the years I have been undertaking this research. Some I know very well, others I have only ever communicated via email. These include, in no particular order, Dee Murdoch, Martin Fallding, Max Elliott, Robbie Economos, Karen Thumm, Alison Hunt, Doug Beckers, Rachel Lonie, Travis Peake, Renee Woodward, Tricia Hogbin, Tim Curran,
Lachlan Copeland, and Miquel de Cáceres. For the review of specific chapters, I also thank Tim Curran and Martin Fallding; both provided new angles and helped to clarify my thinking on certain issues.

Over the years, there have been innumerable conversations discussing the problems and intricacies of vegetation classification, often shared around the campfire or while travelling to and from a study area, with Daniel Connolly and Colin Driscoll. These discussions have inevitably shaped the way in which I now approach classification, and I thank both chaps equally. Daniel and Colin have never met, but with me as the ‘meat in the sandwich’, my ideas and problems have been suitably massaged by these two, as each approach an issue from different angles. Colin, too, was the culprit who initially convinced me to enroll for a PhD, so it is he who I can blame for the stress (!), challenges and fun of the last few years.

To my parents and siblings, and nieces and nephews, I also extend thanks. Although none of you really understand what it is I actually do when I “go bush”, your support and lack of questioning and interrogation is, strangely, much appreciated. By all means, read this thesis and if you are still perplexed, feel free to ask questions.

Most of all, though, I wish to thank my family: Cathy, Emily, Andrew and Daniel. Having a husband and father who worked and studied at home, and who rarely seemed to go out to work (“like other Dads”) must have been difficult to comprehend over the last few years, so I thank them immensely for their understanding and support. They knew I had something worthwhile to say (even though they didn’t understand it), and encouraged me constantly and (on occasion) noisily. Once we domesticated the ‘stampeding wildebeest’ upstairs, all was well in the world...

Stephen Bell

February 2013

Cover image: Scribbly Gum-dominated dune forest at Cockle Creek (see Chapter 3).

A note on the use of grey literature: In addition to the published literature, work presented in this thesis draws upon a considerable amount of unpublished (grey) classification and mapping studies. While this is not ideal, it is important to acknowledge that many land-use planning and conservation decisions are actually based on such grey literature (from local to national scales), and discussion and use of these is critical in advancing our understanding of vegetation science. Use of this material in this thesis, from numerous sources, is gratefully acknowledged.
Table of Contents

Preface ........................................................................................................................................... i
Acknowledgements ....................................................................................................................... iii
Table of Contents .......................................................................................................................... v
List of Figures ................................................................................................................................. ix
List of Tables .................................................................................................................................. xiii
Abbreviations ................................................................................................................................. xv
Abstract .......................................................................................................................................... xvi

Chapter 1: Introduction & Research Plan ....................................................................................... 1
Overview .......................................................................................................................................... 2

1.1 Classification of Vegetation ....................................................................................................... 3
  1.1.1 The Zurich-Montpellier School ......................................................................................... 4
    1.1.1.1 The quadrat .................................................................................................................. 5
    1.1.1.2 The association ............................................................................................................. 5
    1.1.1.3 Species fidelity ............................................................................................................. 7
    1.1.1.4 Hierarchical classification ............................................................................................ 8
    1.1.1.5 Summary of the Zurich-Montpellier school ................................................................. 9
  1.1.2 Criticisms of the Zurich-Montpellier School ..................................................................... 10
  1.1.3 Static and Dynamic Classification ...................................................................................... 12
  1.1.4 Defining rare communities ................................................................................................. 15
    1.1.4.1 What is a rare community? .......................................................................................... 15
    1.1.4.2 Why are rare communities important? ....................................................................... 17
    1.1.4.3 Rarity & legislation ..................................................................................................... 18

1.2 Mapping Vegetation Communities .......................................................................................... 22
  1.2.1 Predictive Modelling vs Traditional Mapping .................................................................... 22
  1.2.2 Summary of Classification & Mapping in SE Australia .................................................... 25
    1.2.2.1 Brief history in Australia & NSW ............................................................................ 25
    1.2.2.2 Lower Hunter & Central Coast REMS ..................................................................... 27
    1.2.2.3 Sampling design in Australia ....................................................................................... 28
    1.2.2.4 Assessing map and classification accuracy ................................................................. 30
  1.2.3 Recent NSW Government Initiatives .................................................................................. 32
    1.2.3.1 The NSW Native Vegetation Interim Type Standard .................................................. 32
    1.2.3.2 BioBanking ................................................................................................................ 35
    1.2.3.3 The NSW Vegetation Information System ................................................................. 36
Chapter 2: Improving Sampling Design: Data-informed Sampling and Mapping

Overview

2.1 Introduction

2.2 Methods

2.2.1 Study Areas

2.2.1.1 Edgeworth LEP

2.2.1.2 Columbey National Park

2.2.1.3 Cessnock-Kurri

2.2.2 Mapping Pathway

2.2.3 Comparisons to Previous Mapping

2.2.3.1 Previous Mapping Products

2.2.3.2 Accuracy Assessment

2.2.4 Time Resources

2.3 Results

2.3.1 Edgeworth LEP

2.3.1.1 Mapping process

2.3.1.2 Comparison to existing mapping

2.3.1.3 Time resources

2.3.2 Columbey National Park

2.3.2.1 Mapping process

2.3.2.2 Comparison to existing mapping

2.3.2.3 Time resources

2.3.3 Cessnock-Kurri Region

2.3.3.1 Mapping process

2.3.3.2 Comparison to existing mapping

2.3.3.3 Time resources

2.4 Discussion

2.4.1 The D-iSM Process

2.4.2 Sample Selection

2.4.3 Map Accuracy
Chapter 3: Defining new communities: Scribbly Gum Forest on the Central Coast .......... 109

Overview .................................................................................................................. 110

3.1 Introduction .......................................................................................................... 111

3.2 Methods ................................................................................................................ 115

3.2.1 Study Region .................................................................................................. 115

3.2.2 Study Design .................................................................................................. 119

3.3 Results .................................................................................................................. 122

3.3.1 Analysis 1: Scribbly Gum Analysis .................................................................. 122

3.3.2 Analysis 2: Regional Central Coast Analysis ................................................. 127

3.3.3 Environmental Relationships ......................................................................... 130

3.4 Discussion ............................................................................................................ 131

3.4.1 Survey Design ................................................................................................ 132

3.4.2 The Importance of Resolution ....................................................................... 134

3.4.3 Conservation Implications ............................................................................. 136

3.5 Conclusions: Key Principle in Community Definition ........................................ 139

Chapter 4: Refining existing communities: Lower Hunter Spotted Gum-Ironbark Forest .... 141

Overview .................................................................................................................. 142

4.1 Introduction .......................................................................................................... 143

4.2 Methods ................................................................................................................ 149

4.2.1 Study Region .................................................................................................. 149

4.2.2 Study Design .................................................................................................. 151

4.3 Results .................................................................................................................. 157

4.3.1 Classification .................................................................................................. 157

Analysis 1: Regional Spotted Gum-Ironbark Vegetation ............................................. 157

Analysis 2: Eucalyptus fibrosa – Corymbia maculata ................................................. 161

Analysis 3: Eucalyptus fibrosa .................................................................................. 165

Analysis 4: Hunter Valley Floor ............................................................................... 169

4.3.2 Profiling Candidate-Lower Hunter Spotted Gum-Ironbark Forest ................. 173

4.3.3 Mapping .......................................................................................................... 180

4.4 Discussion ............................................................................................................ 180

4.4.1 Refining Existing Communities ...................................................................... 181

4.4.2 Current Understanding of Lower Hunter Spotted Gum-Ironbark Forest ......... 184
4.4.3 Lower Hunter Spotted Gum-Ironbark Forest as a TEC ............................................ 193
4.4.4 Distribution & Reservation: Lower Hunter Spotted Gum-Ironbark Forest .... 199
4.4.5 A Revised Lower Hunter Spotted Gum-Ironbark Forest Determination? ...... 200
4.5 Conclusions: Key Principles in Community Refinement ..................................... 201

Chapter 5: General Discussion .................................................................................. 204
Overview ................................................................................................................. 205
  5.1 Identifying and Describing Rare Communities ................................................... 206
  5.2 Survey Design for Vegetation Classification ...................................................... 208
  5.3 Data-informed Sampling and Mapping ............................................................... 211
  5.4 Standards for Sampling Design ....................................................................... 217
    5.4.1 International Standards ............................................................................. 217
    5.4.2 Australian Standards ............................................................................... 218
  5.5 Re-setting the Focus of Classification in Australia ............................................. 222
  5.6 Conclusion ....................................................................................................... 230

Chapter 6: References ............................................................................................... 233

Chapter 7: Appendices .............................................................................................. 267
  Appendix 1 – Edgeworth LES Confusion Matrix Examples .................................... 268
  Appendix 2 – Columbey NP Confusion Matrix Examples ...................................... 269
  Appendix 3 – Cessnock-Kurri Confusion Matrix Examples .................................... 272
  Appendix 4 – Werakata NP Confusion Matrix Examples ....................................... 274
  Appendix 5 – Lower Hunter Spotted Gum-Ironbark Forest EEC Final Determination .... 275
  Appendix 6 – Chronological history of LHSGIF Revision .................................... 281
  Appendix 7 – Spotted Gum-Ironbark Vegetation (NSWNPWS 2000b) ..................... 283
  Appendix 8 – Vegetation superficially similar to LHSGIF ...................................... 285
  Appendix 9 – LHSGIF 3-d nMDS ordination diagrams ......................................... 288
List of Figures

Fig. 1.1. Conceptual representation of a dynamic vegetation classification, showing the process of initial and subsequent vegetation survey results (de Cáceres 2011)........................................................................................................................................13

Fig. 1.2 Types of community rarity. R1 – R7 refer to the seven forms of rarity (from Izco 1998)................................................................................................................................................15

Fig. 1.3. Cumulative number of Threatened Ecological Communities (TECs) listed for the Hunter-Central Rivers Catchment Management Area since inception of the NSW Threatened Species Conservation Act in 1995..................................................................................21

Fig. 1.4. The Lower Hunter and Central Coast of New South Wales, showing member councils........................................................................................................................................28

Fig. 2.1 Location of the three study areas within the lower Hunter Valley, shown over Landsat TM imagery to illustrate differences in context and fragmentation.................................................................52

Fig. 2.2 Flowchart showing the D-ISM mapping pathway. .........................................................55

Fig. 2.3. Potential relationships between floristic strata units, floristic communities and final vegetation map, after sampling and classification of full floristic sample quadrats.. .............................................................................61

Fig. 2.4 Schematic representation of Steps 1-8 used to create a vegetation map of the Edgeworth LEP. ........................................................................................................................................67

Fig. 2.5 Vegetation maps of the Edgeworth LES study area thematically portrayed using the same regional (NSWPWS 2000b) community nomenclature.....................69

Fig. 2.6 Mean user accuracy (+/− SE) of vegetation communities defined by NSWPWS (2000b) for Edgeworth LEP, determined from a confusion matrix of 180 Rapid Data Points (10 random batches of 18 Rapid Data Points). .............70

Fig. 2.7 Allocation of 180 Rapid Data Points across vegetation communities defined by NSWPWS (2000b) for Edgeworth LEP.................................................................70

Fig. 2.8 Percentage task allocation for creating a vegetation map for Edgeworth LES using the D-ISM method. ......................................................................................................................71

Fig. 2.9 Schematic representation of Steps 1-8 used to create a vegetation map of Columbey National Park ....................................................................................................................72

Fig. 2.10 Vegetation maps of the Columbey National Park study area thematically portrayed using the same RN17 regional community nomenclature (FCNSW 1989)........................................................................................................................................74

Fig. 2.11 Vegetation maps of the Columbey National Park study area thematically portrayed using the same CRA regional community nomenclature (NSWPWS 1999a). ........................................................................................................................................75
Fig. 2.12  Mean user accuracy (+/- SE) of forest types defined by FCNSW (1989) for Columbey National Park, determined from a confusion matrix of 540 Rapid Data Points (10 random batches of 54 Rapid Data Points) ........................................76

Fig. 2.13  Allocation of 540 Rapid Data Points across forest types defined by FCNSW (1989) for Columbey National Park ..........................................................76

Fig. 2.14  Mean user accuracy (+/- SE) of forest ecosystem units defined by NSWNPWS (1999a) for Columbey National Park, determined from a confusion matrix of 540 Rapid Data Points (10 random batches of 54 Rapid Data Points) ................77

Fig. 2.15  Allocation of 540 Rapid Data Points across forest ecosystems defined by NSWNPWS (1999a) for Columbey National Park .............................................78

Fig. 2.16  Percentage task allocation for creating a vegetation map for Columbey National Park using the D-iSM method ..................................................79

Fig. 2.17  Schematic representation of Steps 1-8 used to create a vegetation map of the Cessnock-Kurri region .................................................................80

Fig. 2.18  Pre-1750 vegetation map of the Cessnock-Kurri study area produced by NSWNPWS (2000b) thematically portrayed using the regional community nomenclature (NSWPWS 2000b) ..................................................82

Fig. 2.19  Pre-1750 vegetation map of the Cessnock-Kurri study area using the D-iSM method thematically portrayed using the regional community nomenclature (NSWPWS 2000b) ..................................................82

Fig. 2.20  Mean user accuracy (+/- SE) of vegetation units defined by NSWNPWS (2000b) for Cessnock-Kurri, determined from a confusion matrix of 16,800 Rapid Data Points (10 random batches of 1,680 Rapid Data Points) ........................................83

Fig. 2.21  Allocation of 16,800 Rapid Data Points across vegetation units defined by NSWNPWS (2000b) for Cessnock-Kurri ..................................................84

Fig. 2.22  Vegetation mapping for Werakata National Park, from (a-c) NSWNPWS (2000b), Bell (2004a) & the current study ........................................86

Fig. 2.23  Mean user accuracy (+/- SE) of vegetation units defined by Bell (2004a) for Werakata National Park, determined from a confusion matrix of 1,400 Rapid Data Points (10 random batches of 140 Rapid Data Points) ........................................87

Fig. 2.24  Allocation of 1,400 Rapid Data Points across vegetation units defined by Bell (2004a) for Werakata National Park .............................................87

Fig. 2.25  Percentage task allocation for creating a vegetation map for Cessnock-Kurri using the D-iSM method ..................................................88

Fig. 2.26  Linear regression of person-hours and number of hectares required for Step 4 (map data acquisition) of D-iSM, 0-100 ha category (one-way ANOVA; F=115.9, p<0.0001) .................................................100

Fig. 2.27  Linear regression of person-hours and number of hectares required for Step 4 (map data acquisition) of D-iSM, 100-1000 ha category (one-way ANOVA; F=48.5, p<0.0005) .................................................100

Fig. 2.28  Linear regression of person-hours and number of hectares required for Step 4 (map data acquisition) of D-iSM, 1000-10,000 ha category (one-way ANOVA; F=20.1, p<0.005) .................................................101
Fig. 2.29 The Lower Hunter and Central Coast region, showing distribution of Rapid Data Points collected by two ecologists over the course of six years (2006-2011).................................................................105

Fig. 3.1 The NSW Central Coast region (shaded), with study locations (●). .........................116
Fig. 3.2 The NSW Central Coast region, showing annual average rainfall bands .............116
Fig. 3.3 Broad geology types of the Central Coast region, with study locations (●). .......118
Fig. 3.4 Dendrogram of sample quadrats, showing the relationship between all samples (Bray-Curtis similarity measure, 42% similarity) .........................................................123
Fig. 3.5 Non-metric Multi Dimensional Scaling ordination, showing the relationship between sample quadrats, overlain with cluster analysis groups (Bray-Curtis similarity measure, 42% similarity) .........................................................124
Fig. 3.6 Contribution of canopy, mid and ground layer species to community diversity at each study location. .................................................................127
Fig. 3.7 Partially collapsed sample dendrogram of 1771 quadrat from the regional analysis. ........................................................................................................128
Fig. 3.8 Distribution of the nine Scribbly gum communities defined in this study. ..............137

Fig. 4.1 Data extract from survey database of NSW Office of Environment & Heritage showing quadrat samples where Red Ironbark (Eucalyptus fibrosa) and Spotted Gum (Corymbia maculata, C. variegata, C. henryii) co-occur relative to New South Wales Bioregions (Thackway & Cresswell 1995). ......................147
Fig. 4.2 Distribution of Permian and Triassic Narrabeen sediments within the Sydney Basin (Source: Geological Survey of NSW) .................................................................150
Fig. 4.3 Regional dataset of full floristic quadrats available for analysis. ..........................153
Fig. 4.4 Wyong focus area for mapping of Candidate-LHSGIF within Wyong local government area. ..................................................................................158
Fig. 4.5 Non-metric Multi Dimensional Scaling (2-dimensional) ordination of Analysis 1, showing the relationship between samples (Bray-Curtis similarity measure). Candidate-LHSGIF samples are broadly defined within the larger matrix. Kruskal’s stress = 0.21 .................................................................159
Fig. 4.6 Distribution of 999 random permutations of the ANOSIM test statistic $R$ for Analysis 1, and the true value of $R$ (0.19, vertical dotted line at right) (p<0.001). .................................................................159
Fig. 4.7 Geographical distribution of Candidate-LHSGIF and all other Spotted Gum-Ironbark forest sample quadrats in the Sydney Basin from Analysis 2. .........................160
Fig. 4.8 Non-metric Multi Dimensional Scaling (2-dimensional) ordination of Analysis 2, showing the relationship between samples (Bray-Curtis similarity measure). Kruskal’s stress = 0.24 .................................................................161
Fig. 4.9 Non-metric Multi Dimensional Scaling (2-dimensional) ordination of Cessnock Spotted Gum Ironbark group from Analysis 2, showing the
relationship between three defined sub-groups at 37% similarity (Bray-Curtis similarity measure). Kruskal’s stress = 0.18. ..........................................................162

Fig. 4.10. Distribution of 999 random permutations of the ANOSIM test statistic $R$ for Analysis 2, and the true value of $R$ (0.65, vertical dotted line at right) (p<0.001). ........................................................................................................164

Fig. 4.11. Geographical distribution of seven floristic groups defined from Analysis 2........166

Fig. 4.12. Non-metric Multi Dimensional Scaling (2-dimensional) ordination of Analysis 3, showing the relationship between samples (Bray-Curtis similarity measure) and major groups defined at 19% similarity. Candidate-LHSGIF includes Cessnock Ironbark Forest, Hunter Floor Ironbark Forest and Hinterland Ironbark Forest. Kruskal’s stress = 0.21.........................................................167

Fig. 4.13. Distribution of 999 random permutations of the ANOSIM test statistic $R$ for Analysis 3, and the true value of $R$ (0.62, vertical dotted line at right) (p<0.001). ........................................................................................................168

Fig. 4.14. Geographical distribution of seven floristic groups defined from Analysis 3 (Eucalyptus fibrosa dominated). ........................................................................................................170

Fig. 4.15. Non-metric Multi Dimensional Scaling (2-dimensional) ordination of Analysis 4, showing the relationship between samples of Candidate-LHSGIF (Eucalyptus fibrosa-Corymbia maculata) and non Candidate-LHSGIF (Eucalyptus crebra-Corymbia maculata) from the Hunter Valley floor (Bray-Curtis similarity measure). Kruskal’s stress = 0.19 ...............................................................171

Fig. 4.16. Distribution of 999 random permutations of the ANOSIM test statistic $R$ for Analysis 4, and the true value of $R$ (0.35, vertical dotted line at right) (p<0.001). ........................................................................................................172

Fig. 4.17. Distribution of 999 random permutations of the ANOSIM test statistic $R$ for Analysis 4 (non Candidate-LHSGIF v Hunter Spotted Gum Ironbark Forest), and the true value of $R$ (0.22, vertical dotted line at right) (p<0.001). .................173

Fig. 4.18. Geographical distribution of samples representing Candidate-LHSGIF (Cessnock Spotted Gum Ironbark, Broken Back Spotted Gum Ironbark, Hunter Spotted Gum Ironbark) and non Candidate-LHSGIF from the Hunter Valley floor, as defined in Analysis 4.................................................................174

Fig. 4.19. Pre-1750 distribution of Candidate-LHSGIF within Wyong local government area, showing data collected during the map data acquisition phase of D-ism.................................................................175

Fig. 4.20. Comparison of Candidate-LHSGIF groups against species lists contained in Paragraphs 1 (‘Define) and 2 (‘Characterise’) of the Lower Hunter Spotted Gum–Ironbark Forest EEC determination (NSW Scientific Committee 2010b)........................................................................................................189

Fig. 4.21. Extract of sample dendrogram of NSWNPS (2000b) used to delineate LHSGIF........................................................................................................198

Fig. 5.1 Number of papers and preferred sample selection techniques published in the journals Pacific Conservation Biology, Austral Ecology, Australian Journal of Botany and Cunninghamia, from 2000-2011. .......................................................224
Fig. 5.2. Schematic representation of a Top-Down, Bottom-Up approach to sampling design for vegetation classification .......................................................... 231

List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>The five degrees of fidelity (Szafer &amp; Pawlowski 1927, in Kent &amp; Coker 2001)</td>
<td>7</td>
</tr>
<tr>
<td>1.2</td>
<td>Threatened Ecological Communities listed on the TSC Act 1995, with their basis of definition in sampling designs incorporating stratified random sampling.</td>
<td>20</td>
</tr>
<tr>
<td>2.1</td>
<td>Study areas used to illustrate mapping method.</td>
<td>52</td>
</tr>
<tr>
<td>2.2</td>
<td>Symbolic representation of progressive Rapid Data Point collection and inferred floristic strata boundary.</td>
<td>57</td>
</tr>
<tr>
<td>2.3</td>
<td>Pre-existing studies used for comparative purposes.</td>
<td>63</td>
</tr>
<tr>
<td>2.4</td>
<td>Vegetation communities defined for Werakata National Park over three studies.</td>
<td>85</td>
</tr>
<tr>
<td>2.5</td>
<td>Summary of overall accuracies calculated from confusion matrices for existing and current vegetation maps of the Edgeworth LES, Columbey National Park and Cessnock-Kurri study areas.</td>
<td>96</td>
</tr>
<tr>
<td>2.6</td>
<td>Use of D-ISM across differing scales.</td>
<td>99</td>
</tr>
<tr>
<td>2.7</td>
<td>Progression and cost of major classification and mapping products for the Central Coast of New South Wales.</td>
<td>102</td>
</tr>
<tr>
<td>3.1</td>
<td>Summary of Scribbly gum (Eucalyptus haemastoma, E. racemosa) populations under study, showing localities and main topographical features.</td>
<td>117</td>
</tr>
<tr>
<td>3.2</td>
<td>Summary of floristic groups. Top 80% of diversity for each group and percentage contributions shown.</td>
<td>125</td>
</tr>
<tr>
<td>3.3</td>
<td>ANOSIM results (Global R values) for pair-wise comparisons of location-based groups.</td>
<td>127</td>
</tr>
<tr>
<td>3.4</td>
<td>Summary of inferred environmental relationships for floristic groups, showing geological age, geological group/subgroup, and rainfall band.</td>
<td>130</td>
</tr>
<tr>
<td>3.5</td>
<td>Regional equivalent communities.</td>
<td>138</td>
</tr>
<tr>
<td>4.1</td>
<td>Summary of key features of the four data analyses.</td>
<td>154</td>
</tr>
</tbody>
</table>
Table 4.2  Percentage contributions to group species diversity of the five dominant ground and shrub species for the three Cessnock sub-groups, calculated using a SIMPER analysis in Primer (Clarke & Gorley 2006). ........................................162

Table 4.3  ANOSIM results (Global R values) for pair-wise comparisons of location-based groups for Analysis 2 (p < 0.001). .................................................................163

Table 4.4  ANOSIM results (Global R values) for pair-wise comparisons of location-based groups for Analysis 3 (p < 0.001). .................................................................167

Table 4.5  ANOSIM results (Global R values) for pair-wise comparisons of location-based groups for Analysis 4 (p < 0.001). .................................................................173

Table 4.6  Summary of Candidate-LHSGIF from the Sydney Basin. ..............................................175

Table 4.7  Summary of floristic composition for eleven defined units from Analysis 2 & Analysis 3. Top 90% of diversity shown for each unit and percentage contributions to overall diversity for that unit.......................................................176

Table 4.8  Comparison of Candidate-LHSGIF groups against the key characteristic species as listed in Paragraph 1 of the Lower Hunter Spotted Gum–Ironbark Forest EEC determination (NSW Scientific Committee 2010b). ........................................186

Table 4.9  Comparison of Candidate-LHSGIF groups against the full species list as contained in Paragraph 2 of the Lower Hunter Spotted Gum–Ironbark Forest EEC determination (NSW Scientific Committee 2010b). ..............................188

Table 4.10 Dichotomous key for field recognition of Candidate-LHSGIF groups defined in this study for the Sydney Basin.................................................................194

Table 4.11 Summary of reservation status of Candidate-LHSGIF communities .....................200

Table 5.1  Recommended sample selection techniques detailed for State and Territory guidelines in Australia.................................................................219
Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>API</td>
<td>Aerial Photographic Interpretation</td>
</tr>
<tr>
<td>D-ISM</td>
<td>Data-informed Sampling and Mapping</td>
</tr>
<tr>
<td>ESUs</td>
<td>Environmental Sampling Units</td>
</tr>
<tr>
<td>EEC</td>
<td>Endangered Ecological Community, a legal entity</td>
</tr>
<tr>
<td>EPBC Act</td>
<td>Environment Protection &amp; Biodiversity Conservation Act 1999 (Australia)</td>
</tr>
<tr>
<td>FCNSW</td>
<td>Forestry Commission of New South Wales</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographical Information System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>ha</td>
<td>hectares</td>
</tr>
<tr>
<td>km</td>
<td>kilometres</td>
</tr>
<tr>
<td>LEP</td>
<td>Local Environment Plan</td>
</tr>
<tr>
<td>LGA</td>
<td>Local Government Area</td>
</tr>
<tr>
<td>LHCCREMS</td>
<td>Lower Hunter &amp; Central Coast Regional Environmental Management Strategy</td>
</tr>
<tr>
<td>NP</td>
<td>National Park</td>
</tr>
<tr>
<td>NSW</td>
<td>New South Wales</td>
</tr>
<tr>
<td>NSWNPWS</td>
<td>NSW National Parks and Wildlife Service</td>
</tr>
<tr>
<td>NSWDECC</td>
<td>NSW Department of Environment and Climate Change</td>
</tr>
<tr>
<td>NSWOEH</td>
<td>NSW Office of Environment and Heritage</td>
</tr>
<tr>
<td>NVITS</td>
<td>NSW Native Vegetation Interim Type Standard</td>
</tr>
<tr>
<td>pre-1750</td>
<td>pre-European settlement of Australia</td>
</tr>
<tr>
<td>RDP</td>
<td>Rapid Data Point</td>
</tr>
<tr>
<td>TEC</td>
<td>Threatened Ecological Community, a legal entity</td>
</tr>
<tr>
<td>TSC Act</td>
<td>Threatened Species Conservation Act 1995 (NSW)</td>
</tr>
<tr>
<td>VDA</td>
<td>Vehicular Data Acquisition</td>
</tr>
<tr>
<td>WDA</td>
<td>Walked Data Acquisition</td>
</tr>
<tr>
<td>4WD</td>
<td>Four Wheel Drive vehicle</td>
</tr>
</tbody>
</table>
Abstract

Although steeped in history, the identification and classification of vegetation communities is rarely capable of addressing the full diversity of vegetation in an area, specifically those communities that are rare or of restricted distribution. This has proven particularly problematic for land managers who are charged with the responsibility of balancing human progress with meaningful conservation. However, in order to enable improvements in the detection of restricted or rare vegetation communities, it is necessary to revisit where the classification of vegetation began, and to determine how current day classification and mapping procedures are undertaken.

As detailed in Chapter 1 (General Introduction), the Zurich-Montpellier school of vegetation classification, established in the early 20th Century in Europe, outlined the basic building blocks of the current-day discipline of vegetation science. Within this school, the two central themes of sampling unit (‘quadrat’) and vegetation community (‘association’) are pivotal, and provide a mechanism for establishing order in a seemingly chaotic environment. Other workers argued for individualistic approaches and questioned the validity of a vegetation community. In recent decades, particularly in Australia, there has been a shift away from the ideals of the Zurich-Montpellier school, specifically that involving sampling design. Detailed, ground-based sampling, classification and mapping has transitioned into one where environmental surrogates, remotely accessed data (aerial photography, satellite imagery), and computer modelling takes precedence. At the same time, there has been an increasing demand for accurate, local-scale map products to inform land-use and conservation planning, and to satisfy legislative requirements for the protection of biodiversity. This juxtaposition of broad, regional-scale classification and mapping products onto local-scale landscapes and land conflicts is an unproductive dichotomy that requires resolution.

A new paradigm for the classification and mapping of vegetation at local and regional scales is outlined in this study, incorporating new methods based on old principles to
facilitate inclusion of rare and restricted communities in land-use planning. *Data-informed Sampling and Mapping* (D-iSM), outlined in **Chapter 2**, is illustrated through three common scenarios in natural resource management: assessment of vegetation for the development industry, defining and classifying vegetation within conservation reserves, and identifying significant vegetation within a sub-regional context. All seven steps in the new paradigm are detailed for each scenario, and the results are compared to previous classification and mapping for the three study areas, highlighting considerably improved accuracies. Central to the D-iSM method is the old adage, from the Zurich-Montpellier school, *know your study area well*, combined with preferential (non-random) sampling to ensure a thorough and representative dataset. For larger regional, State or National contexts, there is provision within D-iSM to incorporate ‘cutting-edge’ 3-dimensional interpretation of high resolution aerial images to overcome perceived shortfalls (financial, time, access constraints) in using the technique across extensive or rugged regions. Benefits of the D-iSM method include more efficient and more representative sampling, more realistic and repeatable classifications, considerably higher user accuracy in vegetation mapping, increased ability to detect and map rare vegetation communities and ready application to a range of classification and mapping projects.

In **Chapter 3** (Defining New Communities), D-iSM has been applied to vegetation dominated by Scribbly Gum eucalypts (*Eucalyptus haemastoma*, *E. racemosa*: Myrtaceae) from Triassic Narrabeen and Permian sediments on the Central Coast of New South Wales. A preferential sampling strategy, combined with numerical classification analysis, has been used to compare the floristic composition of nine field-observed stands of native vegetation where Scribbly Gums are characteristic. Five of the nine vegetation types defined in this study were not sampled or classified during previous regional classifications using environmentally stratified random sampling techniques. Significantly, the five newly identified communities possibly represent the most threatened communities in the region: three are already listed as Threatened Ecological Communities in New South Wales (Kurri Sands Swamp Woodland, Quorrobolong Scribbly Gum Woodland, Kincumber Scribbly Gum Forest), and at least two further communities may be equally threatened. These outcomes highlight short-
comings of the environmentally stratified random sampling approach, relative to preferential sampling. They also demonstrate that classification projects incorporating a stratified random sampling methodology based on environmental variables should acknowledge the potentially undetected presence of significant vegetation communities due to deficiencies in survey design and issues of scale (resolution). Implementing a preferential sampling strategy, either in place of, or in combination with, a broader stratification is more likely to uncover such communities. Such an approach would require a thorough knowledge of a study area prior to or acquired during a project, and the flexibility to incorporate additional samples when necessary.

A similar yet different approach has been implemented in Chapter 4 (Refining Existing Communities), to illustrate how use of the D-iSM method can significantly improve the delineation and definition of vegetation communities originally defined by other methods. It also reiterates that vegetation classification is a dynamic process, and that with increased data collection and understanding of an area or vegetation type, a classification should evolve to better reflect current knowledge. In New South Wales, the Lower Hunter Spotted Gum – Ironbark Forest (LHSGIF), originally defined in 2000, was listed as a Threatened Ecological Community within the Sydney Basin Bioregion under the Threatened Species Conservation Act 1995 in 2005. Uncertainties in the on-ground recognition of this community and difficulties in distinguishing it from closely related communities in the decade since its inception have been common place. In part, these problems were caused by a sampling regime based on environmental stratification, which failed to adequately sample all variations within the region. With additional preferential sampling, this chapter uses numerical classification to review the floristic composition of Lower Hunter Spotted Gum-Ironbark Forest, and resolves many of the uncertainties established over ten years of its application in the Hunter region. Using the results of four different analysis datasets, eleven groups of candidate-LHSGIF have been defined, including one group occurring 250 km to the south of the Hunter Valley, on the South Coast of New South Wales near Nowra. As a separate case study, it also presents the results of pre-1750 mapping of candidate-LHSGIF, using the D-iSM method, over the Wyong local government area where traditionally it has not been previously identified. The extent of variation shown within
LHSGIF throughout the Sydney Basin highlights the need to be more prescriptive with
descriptions of communities listed as threatened under legislation, and more
importantly, to ensure that classifications supporting such communities have
confidently addressed all known variations.

In Chapter 5 (General Discussion), it is reiterated that implementing a more ground-
based approach to classification and mapping, particularly for local- and regional-scale
classification products, will significantly improve the detection and recognition of rare
and restricted vegetation communities. The successful detection and mapping of rare
communities is conditional upon a number of key themes in vegetation science. One of
the most influential of these is that of sample selection: how sample locations are
chosen within the wider environment. As has been shown in this thesis, adoption of a
simple change in the way that sampling is undertaken (preferential rather than
random) can dramatically improve the detection and definition of rare communities.
The D-iSM approach to classification and mapping encapsulates the core principles of
direct sampling of observed variations, rather than relying on chance that such
variations will be captured by an environmental stratification. The collection of
ground-data points prior to establishing a sampling framework enables more efficient
and representative sampling and results in a more reliable vegetation map with lasting
relevance.

Existing standards and guidelines for vegetation classification vary throughout
Australia and the world. In Australia, it is suggested that a re-setting of the focus is
required so that classification in general, and detection of rare communities in
particular, can be more reliably documented to bring them onto an equal footing with
knowledge on rare and threatened plant taxa. This shift in focus, away from
environmentally stratified random sampling and towards preferential sampling, can be
facilitated through the D-iSM process. Seven critical steps in thinking are outlined for
this shift to occur: (1) raising the perception and value of rare vegetation communities;
(2) improved use of public money in regional classifications; (3) improved reporting in
the development industry; (4) improved assessment of conservation reserves; (5)
review of existing threatened communities; (6) review of listing structure in threatened
species legislation; and (7) continued establishment of a hierarchical classification of Australian vegetation.

In conclusion, the simple conceptual framework of Top-Down, Bottom-Up information processing has been used to illustrate why this re-focusing is necessary, and to facilitate the change in thinking required for vegetation scientists in Australia. Classifications established on Bottom-Up theory will provide more reliable and accurate information than Top-Down classifications. Further research on adequacy of sampling, definition of community boundaries, transient and keystone communities are highlighted as the logical next steps in improving local-scale classification for land-use planning and conservation. However, perhaps even of more interest than any of these is the issue of whether or not biodiversity management should shift from a community approach to a species approach. As community resolutions improve, such questions will invariably be posed.