Gauging Environmental Variation in the Rejuvenation Potential of Disturbed Natural Ecosystems

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Declaration

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

Kevin E Leeson BSc NatEnvWldMgt (Hons), PhD
20 April 2011

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Abstract

There can be no purpose more inspiring than to begin the age of restoration, reweaving the wondrous diversity of life that still surrounds us — EO Wilson

Ecological restoration is an expensive, time consuming and labour intensive activity. It is therefore important to understand the potential for disturbed natural ecosystems to recover without the need for intervention. This project investigates the rate of vegetation and soil recovery from different types of disturbance at 18 sites within four major ecosystems (grassy, dry sclerophyll, wet sclerophyll, and rainforest) in Tasmania. All sites have a known disturbance history (type and age). At each site, randomly located quadrats were placed in the disturbed and control areas and the percentage cover of species, bare ground and litter estimated using a modified Braun-Blanquet scale. The pH, N, P, C of surface soils from a subset of these quadrats was measured. Topographic and climatic data were obtained at the site level. Global non-metric multi-dimensional scaling was performed on the presence/absence data for all taxa. Bray-Curtis dissimilarity matrices were produced and these were used to examine similarities and dissimilarities between disturbed and control areas. Vectors were fitted for all variables and significance determined by 1000 randomisations. Sorted tables were used to indicate the abundance and presence or absence of taxa at site and ecosystem levels. Relationships between independent variables and the mean distances between control and disturbance vegetation and soils were determined at the site level. The type of initial disturbance (superficial or severe) rather than the time since cessation of the initial disturbance or other factors was the best single predictor of the recovery of both vegetation and soil. Restoration effort should be directed towards areas that are known (as determined from site history) to have been subjected to extensive soil and vegetation disturbance.

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หรับความช่วยเหลือในกระบวนกการเก็บข้อมูล และการสืบหาและกำจัดปลิง!

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Dedicated to the memory of the Pedder People and Lake Pedder
…a priceless asset, temporarily inundated

Lake Pedder before inundation. Image source: RPDC, Hobart

Table of Contents

Abstract i

Acknowledgements ii

Chapter 1 - Introduction and Aims of Thesis 1

Introduction 1

Overview of Global Ecosystem Degradation 2

Australian Perspectives on Environmental Degradation 5

Recovery of soils from disturbance 8

Alternative stable states 8

Predictors of ecosystem recovery 10

Economic considerations 11

Thesis aims and structure 12

Chapter 2 - General Methods 14

Introduction 14

Study Sites - Overview 14

Bioregions 15

Selection of Study Sites 17

Data Collection 19

Vegetation 19

Species Nomenclature 19

Quadrat environmental data 19

Soil samples 20

Site environmental data 20

Aerial Imagery 20

Data Analysis – Soils 21

Soil Preparation 21

Soil Analyses 22

Soil pH 22

Total Nitrogen 22

Extractable Phosphorus 22

Organic Carbon 22
Nitrogen: carbon ratio 23
Data Analysis - Vegetation 23
Chapter 3 – Grasslands and Grassy Woodland Ecosystems........ 25
Introduction 25
Aim of Chapter 28
Methods 28
Study site selection 28
Study Site Overview and Disturbance History 29
Campbell Town Hospital 29
Fosterville 31
Queens Domain 32
Results 34
Campbelltown Hospital 34
Fosterville 38
Queens Domain 41
Species distribution within grassy ecosystems 45
Soils 47
Discussion 49
Chapter 4 - Dry Sclerophyll Forest 51
Introduction 51
Aim of Chapter 54
Methods 55
Study site selection 55
Overview of Study Sites and Brief History 55
Coles Bay 55
Douglas Road 57
Kettering 59
Maria Island 60
Pottery Road 62

Wyre Forest Road 64
Results 65
Coles Bay 65
Douglas Road 69
Kettering 73
Maria Island 77
Pottery Road 81
Wyre Forest Road 86
Species distribution within dry sclerophyll ecosystems 90
Soils 94
Discussion 95
Chapter 5 – Wet Sclerophyll Forest 98
Introduction 98
Aim of Chapter 100
Methods 100
Overview of Study Sites and Brief History 101
Adamsfield 101
Butlers Gorge 103
Mount Field 105
Results – Vegetation 107
Adamsfield 107
Butlers Gorge 112
Mount Field 117
Species distribution within wet sclerophyll ecosystems 121
Soils 125
Discussion 126
Chapter 6 – Western Tasmanian Communities 129
Introduction 129
Rainforest 129
Mixed Forest 130

Ecological Processes 131
Recovery from disturbance other than fire 132
Aim of Chapter 133
Methods 133
Study Site Selection 133
Overview of Study Sites and Brief History 134
Kelly Basin 134
Lake Johnston 137
Lake Margaret 140
Nelson Falls 142
Strathgordon 144
Williamsford 145
Results 148
Kelly Basin 148
Lake Johnston 152
Lake Margaret 156
Nelson Falls 161
Strathgordon 166
Williamsford 171
Species distribution within rainforest ecosystems 175
Soils 180
Discussion 181
Chapter 7 – Variation in Ecosystem Recovery 185
Introduction 185
Methods 185
Derivation of site distance values for vegetation and soil 185
Derivation of disturbance variables 185
Data analysis 186
Results 187
Predictors of vegetation distance 187
Predictors of soil distance 192

The relationship between vegetation and soil distances 192

Discussion 193

The meaning of the models 193

Chapter 8 – Conclusions 197

References 202

Appendix A – Species Distribution 254

Appendix B – Species Frequency by Treatment 281

Appendix C – Soil Analyses 298

List of Figures

Figure 1. Map of Australia showing the amount of native vegetation which has been cleared or modified since European settlement. Source: National Land and Water Resources Audit 2001, Commonwealth of Australia, 2001 6

Figure 2. View of Tasmania showing the approximate delineation of the east – west geological boundary indicated by the diagonal white line. Image source: Google Earth, August 2005. 15

Figure 3. The nine bioregions of Tasmania. Source: Department of Primary Industries, Water and Environment. Source: Commonwealth of Australia, 2007..... 16

Figure 4. Image of Tasmania showing the approximate location of all study sites. **1** = Williamsford; **2** = Lake Johnston; **3** = Lake Margaret; **4** = Campbell Town Hospital; **5** = Fosterville; **6** = Kelly Basin; **7** = Nelson Falls; **8** = Butlers Gorge; **9** = Coles Bay; **10** = Mt Field; **11** = Maria Island; **12** = Adamsfield; **13** = Douglas Road, ; **14** = Strathgordon; **15** = Wyre Forest Road,; **16** = Pottery Rd,; **17** = Queens Domain, Hobart; **18** = Kettering. Image source: Google Earth, August 2005......................... 18

Figure 5. Distribution of grassy vegetation types in Tasmania c. 1800. Image Source: Kirkpatrick et al. (1988). 25

Figure 6. Location of study sites used in the grasslands study. 28

Figure 7. Oblique view of the Campbelltown Hospital study site in 2007. Approximate location of the study area is indicated by the arrow. Image Source: Google Earth. 29

Figure 8. A section of the old Campbelltown Hospital study site. Some of the remaining infrastructure is visible towards centre of the image. 30

Figure 9. Oblique aerial image of the Fosterville study site. The study area is immediately to the west of the waterbody in the centre of the image indicated by the arrow. Image source: Google Earth. 31

Figure 10. Interface between the disturbed (ploughed area) and control site (small remnant patch of grassy woodlands) at the Fosterville study site. 32

Figure 11. Aerial view of Queens Domain in 1957. Approximate location of the study site transect is indicated by the yellow line. 33

Figure 12. Aerial view of Queens Domain in 2007. Approximate location of the study site transect is indicated by the yellow line. Image Source: Google Earth, 2007. 33

Figure 13. General view of the disturbed area at the Campbelltown Hospital study site with remaining infrastructure visible in the centre of the image. The large trees present are *Eucalyptus viminalis*. 35

Figure 14. General view of the control area at the Campbelltown Hospital study site. 35

Figure 15. Two dimensional ordination of quadrats (1 = disturbed, 2 = control) at the Campbell Town Hospital study site (minimum stress = 0.276130). 37

Figure 16. Vector fitting from the Campbelltown Hospital study site. A = aspect, B = bare ground, L = litter cover, R = rock cover, S = slope, 1d2c = disturbed/control. . 37

Figure 17. Typical view of *Themeda triandra* within the control area (background) at the Fosterville study site. The rocks in the foreground are most likely a natural dolerite ridge but may have been further exposed following vegetation removal. 39

Figure 18. Two dimensional ordination of quadrats (1 = disturbed, 2 = control) at the Fosterville study site (minimum stress = 0.315739). 40

Figure 19. Vector fitting from the Fosterville study site. A = aspect, B = bare ground, E = elevation, R = rock cover, S = slope, 1d2c = quadrats. 41

Figure 20. Typical view of a sampling quadrat at the Queens Domain study site. 42

Figure 21. Two dimensional ordination (1 = disturbed, 2 = control) of quadrats at the Queens Domain site (minimum stress = 0.266643). 43

Figure 22. Vector fitting from the Queens Domain study site. S = slope, 1d2c = quadrats. 44

Figure 23. Ordination of quadrats from within all study sites in grassy ecosystems. Legend: CTH = Campbelltown Hospital; F = Fosterville; QD = Queens Domain; (d) = disturbed; (c) = control. 47

Figure 24. View of Tasmania showing the distribution of dry sclerophyll forest types. Image Source: Forest Education Foundation, 2007. 51

Figure 25. Approximate location of all study sites within the eastern Tasmanian bioregion. 55

Figure 26. View of undisturbed vegetation adjacent to the Coles Bay study site...... 56

Figure 27. Site of the disused cherry orchard at Douglas Road, Molesworth. 58

Figure 28. Regrowth of vegetation following disturbance at the Kettering study site. The main area of regrowth is directly behind the small shed on the left. 59

Figure 29. View of the area near the Maria Island study site c. 1910. The study site is located adjacent to the buildings at the centre of the image. Source: unknown 61

Figure 30. Undisturbed vegetation at the Pottery Road study site. 63

Figure 31. View of a section of the disturbance at the Wyre Forest Road study site. 64

Figure 32. Vegetation recolonisation following disturbance at the Coles Bay study area in 2004. 66

Figure 33. Typical view of control area at the Coles Bay study site. 66

Figure 34. Ordination of quadrats (1 = disturbed, 2 = control) from the Coles Bay study site (minimum stress = 0.164910). 68

Figure 35. Significant vectors from the Coles Bay site. Legend: B = bare ground; L = litter cover; 1d2c = disturbance. 68

Figure 36. Colonising *Acacia dealbata* and developing dense ground cover layer dominated by *Pteridium esculentum* at the Douglas Road study site. 70

Figure 37. Typical view within the control area at the Douglas Road study site. 70

Figure 38. Ordination of quadrats (1 = disturbed, 2 = control) from the Douglas Road study site (minimum stress = 0.284972). 72

Figure 39. Vectors for the Douglas Rd study site. Legend: A = aspect; B = bare ground; E = elevation; R = rock cover; S = slope; 1d2c = disturbance. 73

Figure 40. Secondary succession in the understorey at the Kettering study site. 74

Figure 41**.** Ordination of quadrats (1 = disturbed, 2 = control) at the Kettering study site (minimum stress = 0.152905). 76

Figure 42. Significant vectors from the Kettering study site. Legend: B = bare ground; E = elevation; L = litter cover; S = slope; 1d2c = disturbance. 76

Figure 43. A section of the Maria Island study site showing the transition in vegetation type from the disturbed region in the foreground through to mature undisturbed forest in the background. 78

Figure 44. Remains of infrastructure at the Maria Island study site 78

Figure 45. Ordination of quadrats (1 = disturbed, 2 = control) at the Maria Island study site (minimum stress = 0.196970). 80

Figure 46. Significant vectors at the Maria Island study site. B = bare ground; E = elevation; L = litter cover; R = rock cover; 1d2c = disturbance. 81

Figure 47. Vegetation recolonisation at the Pottery Road study site. Control area is in background. 82

Figure 48. General view of the disturbed area at the Pottery Road study site. 83

Figure 49. Ordination of quadrats (1 = disturbed, 2 = control) at the Pottery Rd study site (minimum stress = 0.216578). 85

Figure 50. Significant vectors at the Pottery Rd study site. Legend: E = elevation; 1d2c = disturbance. 85

Figure 51. View of *Acacia dealbata* recolonising a section of the disturbed area at the Wyre Forest Road study site. 87

Figure 52. General view of the control area at the Wyre Forest Road study site. 87

Figure 53. Ordination of quadrats (1 = disturbed, 2 = control) at the Wyre Forest Rd study site (minimum stress = 0.294215). 89

Figure 54. Significant vectors at the Wyre Forest Rd study site. Legend: A = aspect; E = elevation; S = slope; 1d2c = disturbance. 90

Figure 55. Ordination of all quadrats from study sites within dry sclerophyll communities. Legend: CB = Coles Bay; DR = Douglas Rd; K = Kettering; MI = Maria Island; PR = Pottery Rd; WF = Wyre Forest Rd; c = control; d = disturbed. . 94

Figure 56. View of Tasmanian showing the distribution of wet sclerophyll (including mixed) forest types. Image Source: Forest Education Foundation, 2007. Source: Kirkpatrick and Dickinson (1984). 98

Figure 57. Locations of wet sclerophyll study sites. 100

Figure 58. View of a section of the mine workings at Adamsfield c. 1930s. Image taken from near the more recent 1970s operations. The township can be seen towards the centre of the image. 101

Figure 59. Aerial view of Adamsfield c. 1958. The settlement and the site of the main diggings are visible as the disturbed area in the centre of the image. 102

Figure 60. Aerial view of the Adamsfield township in 2002. The settlement and the site of the main diggings are visible as the disturbed area in the centre of the image. 102

Figure 61. Oblique aerial view of the Butlers Gorge township in 1950. 104

Figure 62. A section of the study site at Mt Field in 2003. The disturbance was created in 1963. 106

Figure 63. Oblique aerial view of the Mt Field area. The location of the study site is indicated by the yellow arrow. Image Source: Google Earth. 106

Figure 64. View of recolonisation at the Adamsfield study site. 108

Figure 65. View of recolonisation within the former Adamsfield town site at the junction of two former main roads. 108

Figure 66. Two dimensional ordination of quadrats (1 = disturbed, 2 = control) from the Adamsfield study site (minimum stress = 0.192977). 111

Figure 67. Vector fitting from the Adamsfield study site. Legend: A = aspect, B = bare ground, E = elevation, L = litter cover, R = rock cover, S = Slope, 1d2c = disturbed/control. 112

Figure 68. General view of secondary succession (recolonisation) of a disturbed area at the Butlers Gorge study site. A section of the control area can be see towards the rear of the image. 113

Figure 69. View of recent recolonising shrubby vegetation at the Butlers Gorge study site. Undisturbed (remnant) vegetation can be seen towards the rear of the image. 113

Figure 70. Ordination of all quadrats (1 = disturbed, 2 = control) from the Butlers Gorge study site (minimum stress = 0.000450). 116

Figure 71. Vector fitting from the Butlers Gorge study site. A = aspect, B = bare ground, E = elevation, L = litter cover, R = rock cover, S = Slope, 1d2c = disturbed/control. 116

Figure 72. A section of the control area at the Mt Field study site. 118

Figure 73. Interface between the control and disturbed areas at the Mt Field study site. 118

Figure 74. Ordination of quadrats (1 = disturbed, 2 = control) from the Mount Field study site (minimum stress = 0.233455). 120

Figure 75. Vector fitting from the Mount Field study site. Legend: A = aspect, B = bare ground, L = litter cover, R = rock cover, S = Slope, 1d2c = disturbed/control. 120

Figure 76. Ordination of all quadrats within wet sclerophyll study sites. Site: A = Adamsfield; BG = Butlers Gorge; MF = Mount Field; c = control; d = disturbed.. 124

Figure 77. Map of Tasmania showing the location of all Western Tasmanian study sites. 134

Figure 78. The government-established town of West Pillinger is visible at the front of the image. The settlement at East Pillinger is visible towards the rear and left of the image. (Image source: State Library of Tasmania, W.L. Crowther Collection, ca. 1890. ADRI AUTAS001125298398). 135

Figure 79. View of Pillinger during construction circa 1898. Image Source: Queenstown Information Centre and Galley Museum, Queenstown Tasmania. 136

Figure 80. View of the Lake Johnston Nature Reserve. The study site is located to the left of the image. Source: DPIWE, 2001. Lake Johnston Nature Reserve Site Development Plan – 2001, p.1. 138

Figure 81. The Lake Margaret village in 1985. The study site is visible as the cleared area immediately to the left of the houses. Source: Lake Margaret Collection. 141

Figure 82. The study site at Nelson Falls is visible on the right of the image (ca. 1940). The remains of infrastructure are visible on the right towards the lower edge of the image. Image source: Queenstown Information Centre and Galley Museum, Queenstown Tasmania. 142

Figure 83. A view of part of the Strathgordon township (*ca.* 1970s). The study site, indicated by the arrow, is located near the transition in vegetation structure towards the rear of the image. Source: Aurora Energy. 144

Figure 84. Williamsford township in 1900. The old haulage line is visible on the left of the image. Source: Spurling Photo, Archives Office of Tasmania. 146

Figure 85. Typical view of dense understorey vegetation at the Kelly Basin control. 148

Figure 86. Typical view of understorey vegetation at the Kelly Basin disturbed area. 149

Figure 87. Two dimensional ordination of all quadrats (1 = disturbed, 2 = control) at the Kelly Basin study site (minimum stress = 0.209). 151

Figure 88. Vector fitting obtained for the Kelly Basin study site. B = bare ground; L = litter; R = rock cover; S = slope; 1d2c = disturbed/control. 151

Figure 89. Typical view of the study site at Lake Johnston 153

Figure 90. View of the Lake Johnston study site showing recolonisation 153

Figure 91. Two dimensional ordination of all quadrats (1 = disturbed, 2 = control) at the Lake Johnston study site (minimum stress = 0.275927). 155

Figure 92. Significant vectors at the Lake Johnston study site Legend: B = bare ground; L = litter cover, 1d2c = disturbance.. 155

Figure 93. View of the previously disturbed area at the Lake Margaret study site. This area is at an early stage of succession - indicated by the presence of immature forest.. 157

Figure 94. Typical view of understorey vegetation within the control area at Lake Margaret 157

Figure 95. Two dimensional ordination of all quadrats (1 = disturbed, 2 = control) at the Lake Margaret study site (minimum stress = 0.213055).................................. 159

Figure 96. Vectors obtained for the Lake Margaret study site. Legend: A = aspect; B = bare ground; E = elevation; L = litter cover; S = slope; 1d2c = disturbance........ 160

Figure 97. Typical view of the disturbed area at the Nelson Falls study site 162

Figure 98. View of the transition between control and disturbed areas at Nelson Falls. 162

Figure 99. Two dimensional ordination of all quadrats (1 = disturbed, 2 = control) at the Nelson Falls study site (minimum stress = 0.120551). 165

Figure 100. Significant vectors at the Nelson Falls study site Legend: B = bare ground; L = litter cover; 1d2c = disturbance.. 165

Figure 101. General view of disturbed area at the Strathgordon study site. 167

Figure 102. View of soil compaction at the Strathgordon study site. The image shows the location of a former residential site – most likely a residential driveway.......... 167

Figure 103. Two dimensional ordination of all quadrats (1 = disturbed, 2 = control) at the Strathgordon study site (minimum stress = 0.106277). 169

Figure 104. Significant vectors (P < 0.05) at the Strathgordon study site. Legend: A = aspect; B = bare ground; E = elevation; L = litter cover; S = slope; 1d2c = disturbance. 170

Figure 105. Typical view of disturbance at the Williamsford study site 172

Figure 106. Typical view of the control area (left) adjacent to a developed car parking area at the Williamsford study site... 172

Figure 107. Two dimensional ordination of all quadrats (1 = disturbed, 2 = control) at the Williamsford study site (minimum stress = 0.232119). 174

Figure 108. Significant vectors at the Williamsford study site. Legend: A = aspect; B = bare ground; E = elevation; L = litter cover; R = rock cover; S = slope; 1d2c = disturbance. 175

Figure 109. Ordination of all quadrats from within rainforest study sites. Legend: KB = Kelly Basin; LJ = Lake Johnstone; LM = Lake Margaret; NF = Nelson Falls; S = Strathgordon; W = Williamsford; d = disturbed; c = control.......... 180

Figure 110.Box plots of vegetation distance mean by disturbance class. The symbol shown in the boxes indicates the position of the mean value. The Nelson Falls outlier (NF) is also shown. 187

Figure 111. The relationship between vegetation distance and soil carbon in the disturbed area showing the regression line. Legend: A = Adamsfield; BG = Butlers Gorge; CB = Coles Bay; CT = Campbelltown Hospital; DR = Douglas Rd; F = Fosterville; K = Kettering; KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; MF = Mount Field; MI = Maria Island; NF = Nelson Falls; PR = Pottery Road; QD = Queens Domain; S = Strathgordon; W = Williamsford; WF = Wyre Forest Rd. Black symbols represent superficial disturbance, red symbols represent sever disturbance.......... 188

Figure 112. The relationship between vegetation distance and soil available phosphorus showing disturbance classes. Legend: 0 = Superficial disturbance; 1 = Severe Disturbance; A = Adamsfield; BG = Butlers Gorge; CB = Coles Bay; CT = Campbelltown Hospital; DR = Douglas Rd; F = Fosterville; K = Kettering; KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; MF = Mount Field; MI = Maria Island; NF = Nelson Falls; PR = Pottery Road; QD = Queens Domain; S = Strathgordon; W = Williamsford; WF = Wyre Forest Rd. 189

Figure 113. The relationship between vegetation distance and the predicted vegetation distance from the model including age since cessation of disturbance and pH of the disturbed area (FITS1). Legend: A = Adamsfield; BG = Butlers Gorge; CB = Coles Bay; CT = Campbelltown Hospital; DR = Douglas Rd; F = Fosterville; K = Kettering; KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; MF = Mount Field; MI = Maria Island; NF = Nelson Falls; PR = Pottery Road; QD = Queens Domain; S = Strathgordon; W = Williamsford; WF = Wyre Forest Rd..... 190

Figure 114. The relationship between vegetation distance and time since the cessation of disturbance, showing sites with pH in the disturbed area of < 4.5 = 0 and > 4.5 =1. Legend: A = Adamsfield; BG = Butlers Gorge; CB = Coles Bay; CT = Campbelltown Hospital; DR = Douglas Rd; F = Fosterville; K = Kettering; KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; MF = Mount Field; MI = Maria Island; NF = Nelson Falls; PR = Pottery Road; QD = Queens Domain; S = Strathgordon; W = Williamsford; WF = Wyre Forest Rd. 191

Figure 115. The relationship between soil distance and phosphorus in the soils of the disturbed area. Legend: A = Adamsfield; BG = Butlers Gorge; CB = Coles Bay; CT = Campbelltown Hospital; DR = Douglas Rd; F = Fosterville; K = Kettering; KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; MF = Mount Field; MI =

Maria Island; NF = Nelson Falls; PR = Pottery Road; QD = Queens Domain; S = Strathgordon; W = Williamsford; WF = Wyre Forest Rd. 192

Figure 116. The relationship between vegetation distance and soil distance showing disturbance type. Legend: 0 = Superficial disturbance; 1 = Severe Disturbance; A = Adamsfield; BG = Butlers Gorge; CB = Coles Bay; CT = Campbelltown Hospital; DR = Douglas Rd; F = Fosterville; K = Kettering; KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; MF = Mount Field; MI = Maria Island; NF = Nelson Falls; PR = Pottery Road; QD = Queens Domain; S = Strathgordon; W = Williamsford; WF = Wyre Forest Rd. 193

List of Tables

Table 1. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Campbelltown Hospital study site. * = non-native species. 36

Table 2. Mean values of soil properties obtained from the Campbelltown Hospital study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 38

Table 3. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Fosterville study site. * = non-native species. 39

Table 4. Mean values of soil analyses obtained from the Fosterville study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets....................... 41

Table 5. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Queens Domain study site. * = non-native species. 43

Table 6. Mean values of soil analyses obtained from the Queens Domain study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 44

Table 7. Summary of significant differences in frequencies of taxa between disturbed and control areas. C = more abundant in control, D = more abundant in disturbed, - = absent, insignificant or not tested, * = non-native species. CT = Campbelltown Hospital, F = Fosterville, QD = Queens Domain... 45

Table 8. Significant soil properties at all grasslands and grassy woodlands study sites. Significant differences and the higher values are denoted by D (disturbed) or C (control) at each study site. A missing value indicates no significant differences. Study sites: CTH = Campbelltown Hospital; F = Fosterville; QD = Queens Domain. 48

Table 9. Percentage frequency of all significant species at the Coles Bay study site (ordered by frequency in the disturbed column). * = non-native species................. 67

Table 10. Mean values of soil analyses obtained from the Coles Bay study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 69

Table 11. Percentage frequency of all species that significantly differed between the disturbed area and the control at the Douglas Road study site. * = non-native species. 71

Table 12. Mean values of soil analyses obtained from the Douglas Road study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 73

Table 13. Percentage frequency of all species that significantly differed between the disturbed area and the control at the Kettering study site. * = non-native species. ... 75

Table 14. Mean values of soil analyses obtained from Kettering study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 77

Table 15. Percentage frequency of all species that significantly differed between the disturbed area and the control at the Maria Island study site. * = non-native species. 79

Table 16. Mean values of soil analyses obtained from the Maria Island study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 81

Table 17. Percentage frequency of all species that significantly differed between the disturbed area and the control at the Pottery Road study site. * = non-native species. 84

Table 18. Mean values of soil analyses obtained from the Pottery Road study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 86

Table 19. Percentage frequency of all species that significantly differed between the disturbed area and the control at the Wyre Forest Road study site. * = non-native species. 88

Table 20. Mean values of soil analyses obtained from the Wyre Forest Road study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 90

Table 21. Summary of significant differences in frequencies of taxa between disturbed and control areas. C = more abundant in control, D = more abundant in disturbed, - = absent, insignificant or not tested, * = non-native species. CB = Coles Bay, DR = Douglas Road, K = Kettering, MI = Maria Island, PR = Pottery Road, WF = Wyre Forest Road. Shaded cells indicate a reversal in tendency. 91

Table 22. Significant soil properties at all dry sclerophyll study sites. Significant differences and the higher values are denoted by D (disturbed) or C (control) at each study site. A missing value indicates no significant differences. Study sites: CB = Coles Bay; DR = Douglas Road; K = Kettering; MI = Maria Island; PR = Pottery Road; WF = Wyre Forest Road. 95

Table 23. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Adamsfield study site. 109

Table 24. Mean values of soil analyses obtained from the Adamsfield study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 112

Table 25. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Butlers Gorge study site. * = non-native species. 114

Table 26. Mean values of soil analyses obtained from the Butlers Gorge study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 117

Table 27. Percentage frequency of all significant species at the Mt Field study site (ordered by frequency in the disturbed column). 119

Table 28. Mean values of soil analyses obtained from the Mount Field study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 121

Table 29. Summary of significant differences in frequencies of taxa between disturbed and control areas. C = more abundant in control, D = more abundant in disturbed, - = absent, insignificant or not tested, * = non-native species. A = Adamsfield, BG = Butlers Gorge, MF = Mount Field. Shaded cells indicate a reversal in tendency.. 122

Table 30. Significant soil properties at all wet sclerophyll study sites. Significant differences and the higher values are denoted by D (disturbed) or C (control) at each study site. A missing value indicates no significant differences. Study sites: A = Adamsfield; BG = Butlers Gorge; MF = Mount Field... 125

Table 31. Affinity between rainforest groups and dominant eucalypts within mixed forests as indicated by Gilbert (1959), Jarman et al. (1994), Duncan (1985) and Kirkpatrick et al. (1988)... 131

Table 32. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Kelly Basin study site............. 150

Table 33. Mean values of soil analyses obtained from the Kelly Basin study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 152

Table 34. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Lake Johnston study site. 154

Table 35. Mean values of soil analyses obtained from the Lake Johnson study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 156

Table 36. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Lake Margaret study site. * = non-native species. 158

Table 37. Mean values of soil analyses obtained from the Lake Margaret study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 161

Table 38. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Nelson Falls study site. * = non-native species. 163

Table 39. Mean values of soil analyses obtained from the Nelson Falls study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 166

Table 40. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Strathgordon study site. * = non-native species. 168

Table 41. Mean values of soil analyses obtained from the Strathgordon study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 171

Table 42. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Williamsford study site. * = non-native species. 173

Table 43. Mean values of soil analyses obtained from the Williamsford study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets. 175

Table 44. Summary of significant differences in frequencies of taxa between disturbed and control areas. C = more abundant in control, D = more abundant in disturbed, - = absent, insignificant or not tested, * = non-native species. KB = Kelly Basin, LJ = Lake Johnston, LM = Lake Margaret, NF = Nelson Falls, S = Strathgordon, W = Williamsford. Shaded cells indicate a reversal in tendency...... 177

Table 45. Significant soil properties at all rainforest study sites. Significant differences are indicated by the presence of letters and the higher values are denoted by D (disturbed) or C (control). Study sites: KB= Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; NF = Nelson Falls; S = Strathgordon; W = Williamsford. .. 181

Table 46. General linear model predicting vegetation distance from disturbance class (p = 0.001) and carbon (p = 0.006) in the soil of the disturbed area (C). Equation: Y=Xb +e; R^2 = 62.47; DF = 1.. 188

Table 47. General linear model predicting vegetation distance from disturbance class (p = 0.02) and phosphorus (p = 0.037) in the soil of the disturbed area (P).). Equation: Y=Xb +e. R2 = 53.7; DF = 1.. 189

Table 48. Multiple regression model predicting vegetation distance from age since disturbance (p = 0.026) and pH (p = 0.018) of the soil of the disturbed area (pH dist).Regression equation: Vegetation distance mean = 1.15 + 0.00328 Age – 0.124 pH distance; R^2 = 36.4; DF = 1.. 191

Table 49. General linear model predicting vegetation distance from type of disturbance and soil distance). Equation: Y=Xb +e; R^2 = 60.53; DF = 1............... 193

Chapter 1 - Introduction and Aims of Thesis

Introduction

In modern society there is an increasing awareness of degradation caused to natural ecosystems caused by anthropogenic activities and thus, a strong social demand for governments, businesses and land managers for restoration. The emerging academic discipline of restoration ecology is providing a sound scientific basis for restoration activities while the associated practice of ecological restoration provides solutions to facilitate or accelerate the process of secondary succession sensu Clements (1916). However, the process of actively mitigating or restoring degraded ecosystems is an expensive and time consuming exercise. To illustrate this, Woodworth (2006) has indicated that the government of the United States of America has a plan to spend at least $US8 billion restoring degraded areas within the Florida Everglades over a 30 year period between 2000 and 2030. Consequently, one of the most important issues that must be resolved is the rate at which degraded areas can potentially recover from disturbance towards a more desirable community or ecosystem without the need for expensive intervention (Bradshaw, 1992), the main focus of this research project.

Ecological restoration has been described as a means of improving ecological productivity in degraded lands, conserving biological diversity and mitigating the loss of ecosystems (e.g. Bradshaw, 1983, 1987a,b; Jordan et al., 1987; Cairns, 1993; Naveh, 1994, 1998; Turner, 1994; Cairns and Heckman, 1996; Hobbs and Norton, 1996; Lamb et al., 2005). It is facilitated through active human intervention and has been defined as '*an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability*' (SER, 2004). The recovery of an ecosystem is inextricably linked to secondary succession and has often been described as a 'development trajectory' (e.g. Hobbs and Norton, 1996; Simenstad and Thom, 1996; Dobson et al., 1997; Zedler and Callaway, 1999) where development through replacement of a series of community structures occurs over time. Although the concept of ecosystem development was initially suggested by Odum (1969), it was refined by Bradshaw (1983) as a two-step process involving: (1) the colonisation of adapted and adaptable species; and (2) the development of soils and accumulation of nutrients in soil and plants.

Developmental trajectories are strongly influenced by the type and intensity of initial disturbance and propagule availability. Accordingly, propagules can be profoundly affected by the availability of dispersal vectors (e.g. Guariguata and Ostertag, 2001; Price et al., 2001; Spence et al., 2010). In any one physical environment, differences in the above factors can result in trajectories that lead to alternative stable states, first proposed by Lewontin (1969). The definition of alternative stable states has been refined more recently by in work by Goffman et al. (2006), Andersen et al. (2009), Contamin and Ellison (2009), Briske et al. (2010) and others as discrete conditions separated by ecological thresholds. The changes may occur rapidly as a result of stochastic events or may operate relatively slower over long time periods from changes in local and global environmental conditions.

As a result of changes in local and global environments, Hobbs et al. (2009) have argued that many ecosystems are being '*rapidly transformed into new, non-historical configurations*'. Hobbs et al. (2009) suggest that ecosystems can be classified according to their extent of change and proposed that ecosystems can: maintain the historical configuration; develop hybrid qualities containing old and new elements; or form entirely novel systems. This may have profound implications not only active management of degraded areas, but also for the outcomes of unaided regeneration processes. Complex, non-linear and often unpredictable dynamics can occur in ecosystem development (Goffman et al., 2006), although short and medium term thresholds can be modelled to aid decision-making and management (Suding and Hobbs, 2009). This project examines secondary succession following anthropogenic disturbance. Within this context, it is anticipated that outcomes will contribute to understanding natural recolonisation and secondary succession and thus, allow better informed decisions on the necessity for expensive restoration.

Overview of Global Ecosystem Degradation

One of the major global concerns is biodiversity loss through species extinction and endangerment (WWF, 2000), the major cause of which has been identified as ecosystem degradation and habitat loss. Several major forms of habitat loss are generally recognised, including: the loss of areas used by wild species; degradation from vegetation removal and erosion; and fragmentation (UNDP, 1994). Examples of large scale habitat destruction have occurred within tropical rainforests, temperate forests and temperate grasslands where large areas have been logged, cleared, and/or subjected to extensive mining and agricultural activities.

Attempts to reverse trends in land degradation have received international attention. In 1992, *The Convention on Biological Diversity*, (which arose from *The Rio de Janeiro Earth Summit on Environment and Development, 1992*, ratified by 174 countries, including the European Community), called for the ecologically sound restoration of degraded ecosystems to promote the recovery of local biodiversity. One of the outcomes from this convention was that '…*restoration ecology should provide effective conceptual and practical tools for this task*'. Furthermore, the convention also sought to establish direction for achieving restoration outcomes and thus, sustainability. Specific statements from the convention relating to this indicated that '…*principles will include an integrated approach, establishment of better understanding of the nature and value of land and scarce water resources including sustainable management of natural resources and agricultural practices*'.

Following the Rio Earth Summit and the Convention on Biological Diversity, a further convention to address environmental issues, *The United Nations Convention to Combat Desertification*, was held in 1994. This convention indicated that the concept of desertification does not imply that '*deserts are steadily advancing or taking over neighbouring land*' but refers to processes of '…*land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities*'. This convention also recognised that '*patches of degraded land may develop hundreds of kilometres from the nearest desert but these can expand and join together, creating desert-like conditions*'. This has been recognised as an important issue because desertification contributes to environmental crises, such as the loss of biodiversity and global warming.

A primary objective from The United Nations Convention to Combat Desertification was to '…*develop integrated strategies that focus, on improved rehabilitation, conservation and the sustainable management of land and water resources*'. In order to achieve this, realistic goals and limits need to be assigned (see for example: Wyant et al., 1995Cairns and Heckman, 1996; Cooper, 1996; Higgs, 1999; Urbanska and Fattorini, 2000; Hobbs and Harris, 2001; Rees et al., 2001; Lunt, 2003; Thompson and Thompson, 2004). This is perhaps the most important component of restoration as it determines expectations, and initiates plans and actions, and requirements for monitoring programs (Ehrenfeld, 2000, Young, 2000). However, Aronson and Le Floc'h (1996); Box (1996); Cairns and Heckman (1996); Hobbs and Norton (1996); Kershner (1997); Goldstein (1999); The Society for Ecological Restoration (2002); Choi (2004); Miyawaki (2004); and Hilderbrand et al. (2005) have shown that the determination of realistic goals in most cases, has not been achieved. In addition, Government policies on development and extractive resource use often assume that ecosystem damage can be mitigated through restoration of degraded land or creation of new habitats and tend to ignore the services provided from functional ecosystems.

The term 'ecosystem services' was first used during the 1970s to describe well-functioning ecosystems and the benefits people receive from them, such as food, pest control, flood control, climate regulation and recreation (SCEP, 1970 in Meyerson et al., 2005). Historically, an awareness of the need to maintain functional ecosystems has existed largely through the visions of indigenous cultures and the values they have placed on Earth as a provider. This 'custodian role' assumed by many indigenous people has been summarised in the Native American proverb where '*We do not inherit the Earth from our parents; we borrow it from our children*'. Cairns (2001), Hobbs and Harris (2001), Carey (2003), Miyawaki (2004) have suggested that ecological restoration should form an integral component of any development activity. Furthermore, Hobbs and Harris (2001) concluded that the extent and rate of human-induced damage demands ecological restoration for our survival. However, ecological restoration is futile without environmental protection: '…*regrettably, ecological restoration and environmental protection are inseparable because restoration will be less necessary if the rate of destruction is markedly altered, and restoration itself, however well funded, will be temporary if environmental protection is inadequate*' Cairns (1995, p. 5).

To illustrate the above, large-scale rainforest clearance within the Amazonian Basin is a major cause of soil erosion (Bruijnzeel, 2004), loss of biodiversity (Da Silva et al., 2005) and displacement of indigenous people (Schwartzman and Zimmerman, 2005). This is undoubtedly having profound effects on ecosystem services including provision of clean water and air, carbon sequestration, pest and disease control and pollination of food crops. Yet, many examples exist where economic development is occurring in conjunction with conservation measures. One of the best examples occurs in North America where Collins Pine has sustainably harvested their forests for over 150 years. Yet, they are often criticised because their management practices have created forests that are ecologically rich and, not considered to be in accordance with current government thought (Suzuki, 2002).

Australian Perspectives on Environmental Degradation

As part of the social and economic development of Australia following European settlement, governments of the day encouraged the removal of native vegetation (Glanznig, 1995). Initially, the vegetation removal and clearance was performed to allow agricultural development and the establishment of settlements, townships and associated infrastructure. Before the 1860s most land clearance was centred near settlements and urban development, particularly in areas of native woodlands (Glanznig 1995). This was mainly driven by a dramatic increase in the availability of surplus labour after the 'gold rush'.

During the period following the gold rush, there was broad scale land clearance for agricultural activities, in particular, wheat production. This coincided with many technological advances in heavy machinery (Glanznig, 1995). As a result of government initiatives and advances in technology, as much land was cleared in the 50 years before 1990 as was cleared in the 150 years before 1940 (AUSLIG, 1990; Figure 1). Data from the Australian Bureau of Statistics (2010) indicates that since 1990, annual forest land conversion and reclearing has decreased from 561,000 hectares to 216,500 hectares in 2008. However, these figures do not differentiate between clearance of native and non-native vegetation, and it is the clearance of native vegetation that is a significant threat to terrestrial biodiversity (ABS, 2010).One of the major impacts from large scale native vegetation clearance is the modification to ecological processes such as hydrological cycles and subsequent rises in water tables and salinity problems (Commonwealth of Australia, 2010).

The Australian Bureau of Statistics has indicated that about 14% of Australia's total greenhouse emissions are from the direct result of burning and decay of vegetation and from soil disturbance releasing carbon into the atmosphere. The value and importance of maintaining the Australian native vegetation has been recognised by many concerned individuals and organisations as well as many governments. Yet, there is still much debate associated with decisions concerning land use within Australia. This has occasionally included examples of land management issues associated with forestry, mining, agriculture, and industrial development.

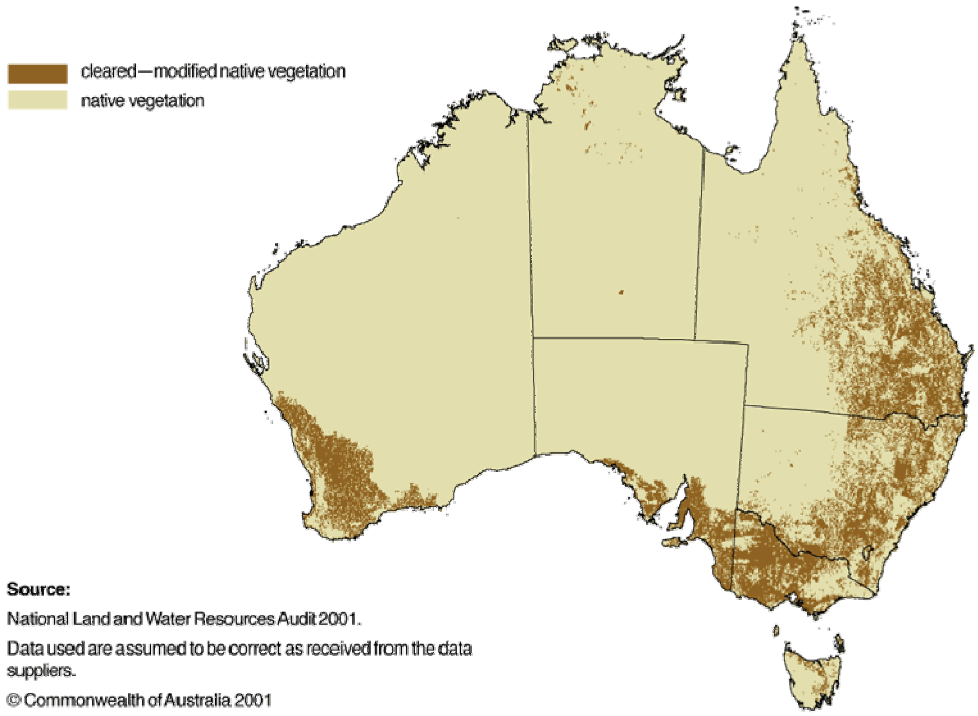

Figure 1. Map of Australia showing the amount of native vegetation which has been cleared or modified since European settlement. Source: National Land and Water Resources Audit 2001, Commonwealth of Australia, 2001.

Land clearance has been the major threat to conservation of soil, water and biodiversity in Australia (Australia - State of the Environment Report, 2006) and estimations from the Australian Bureau of Statistics (2010) indicated that during 2001, this was approximately 470 000 ha of which 90% (425 000 ha) was in one State, Queensland in northern Australia. Furthermore, data from the National Land and Water Resources Audit (Australian Native Vegetation Assessment, 2001) indicates that since European settlement, 'over 700,000 km^2 (20%) of woodland and forest have been cleared or thinned, primarily for the purpose of crops and grazing. In addition, a further 130,000 km^2 (35%) of mallee have been cleared since 1788, along with 20,000 km^2 (45%) of heath, over 60,000 km^2 of tussock grassland and smaller areas of other grasslands. The National Land and Water Resources Audit

(Australian Native Vegetation Assessment, 2001) documents a significant area of land that will probably require some rehabilitation or restoration effort within the near future.

Despite the amount of land clearance that has historically occurred within Australia, large areas of semi-natural and natural vegetation still are still present and in some areas it is still possible to observe few or no individual species of any plant species that was not present in the area before European settlement (Kirkpatrick, 1999). However, vegetation changes have occurred within some remnants subsequent to clearance (Ford et al., 2001; Bennett, 2003; Yates and Hobbs, 1997; Lunt and Bennett, 2000; Lunt and Spooner 2005). For example, the dominant genus has changed from *Eucalyptus* to *Callitris* in some parts of Australia (Lunt et al., 2006).

A part of the solution to reversing trends in the overall degradation of land within Australia may be gained through the practice of ecological restoration. Organisations such as the Ecological Society of Australia (ESA), the Environment Institute of Australia and New Zealand (EIANZ) and the Society for Ecological Restoration (SER) are active in promoting restoration ecology and the practice of ecological restoration within Australia and internationally and have been instrumental in developing and promoting restoration ecology as an emerging academic discipline.

The development of ecosystems following disturbance has also been documented in many long term examples by the Society for Ecological Restoration in different ecosystems and vegetation types. There are also many documented cases that demonstrate the development of soils and vegetation through primary succession such as that following volcanic eruptions and other significant stochastic events. However, these represent a small percentage of studies in ecosystem development.

The present research project investigates the role of disturbance and the regeneration potential of four different types of ecosystems (grasslands and grassy woodlands, dry sclerophyll communities, wet sclerophyll forest, and rainforest) (see Chapter 2). The project will provide insights into secondary succession and the rates of recovery following different types of disturbance in Tasmania. It is anticipated that outcomes will allow funding to be directed to those areas and situations where regeneration is least successful in terms of the original structure and composition.

Recovery of soils from disturbance

Disturbance to vegetation communities and ecosystems usually involve some impact on soils. The severity of the impact can have profound effects on the development of vegetation following the disturbance. Therefore, recovery of soil condition (i.e. structure, texture, nutrient status) is a fundamental requirement for the successful establishment and regeneration of vegetation communities. The rate of soil recovery is related to several factors including, the type of disturbance, type of soil and the physical location of the disturbed area. Felinks et al. (1998), and Wiegleb and Felinks (2001) demonstrated that sulphurous and carboniferous mine soils can remain devoid of vegetation for many decades if there is no active restoration. In a previous study, Mou et al. (1993) demonstrated that significant differences exist in composition and growth of vegetation among different disturbance classes. Mou et al. (1993) also suggested that the accumulation of recovering vegetation is often the principal mechanism limiting nutrient loss following large-scale disturbance of forest ecosystems.

One of the critical factors in the recovery of soils following disturbance is the accumulation of nutrients and organic matter, in particular, nitrogen and organic material. The removal of vegetation will undoubtedly have impacts on the rates of organic material accumulation within the soil profile. However, Turk and Graham (2009) have found that the biogeochemical cycling of nitrogen and carbon is most dynamic in the early stages of soil development and showed that organic carbon accumulates in the upper mineral horizons for at least a 100 year period following disturbance caused by debris flows while nitrogen accumulation is a slower process and occurs for greater than 240 years.

Alternative stable states

One of the major considerations for assessing the recovery of ecosystems following the cessation of disturbance is related to development trajectories and particular end points that may be considered as recovery from disturbance. However, Bradshaw (1987a) has suggested that ecosystems and particular end points are not fixed entities and may be in constant change along a development trajectory towards an alternative stable state or condition. Recently, there has been an increasing interest in ecological studies for determining the existence of alternative stable states or conditions (e.g. Bridgewater, 1990; Beisner et al., 2003; Franzen, 2004; Suding et al., 2004; Didham et al., 2005; Schröder et al., 2005; Young et al., 2005; Fukami and Lee, 2006; Hobbs et al., 2006; Hobbs and Suding, 2009; Warman and Moles, 2009; Washington-Allen et al., 2009; Zweig and Kitchens, 2009; D'Antonio, 2011, and many others). While perspectives on alternative stable states vary among ecologists, Beisner et al. (2003) have recently indicated that two major themes have emerged: (1) the assumption that environmental conditions remain constant with shifts in variables such as population density producing changes; and (2) the anticipation that changes to underlying parameters or environmental drivers facilitate change.

In addition to the concept of alternative stable states, recent attention has been given to the development of entirely new or novel ecosystems (e.g. Suding et al., 2004; Hobbs et al., 2006; Lindenmayer et al, 2008; Hobbs et al., 2009; Wilesy et al., 2009; Zweig and Kitchen, 2009). Novel ecosystems have been defined as differing in their species composition and/or function from past or present systems as a consequence of changes in species distribution, climate, and land use (Root and Schneider, 2006; Harris et al., 2006). Within this context, Hobbs et al. (2006) suggested that change is a '*normal characteristic of ecosystems in response to disturbance and environmental change, and species distributions have also varied considerably through time*'. As a consequence, Hobbs et al. (2009) have recently indicated that all ecosystems can be considered as novel within an appropriate temporal context.

There is an increasing recognition that ecosystem dynamics are complex, non-linear and often unpredictable (Wallington et al., 2005). This is considered as a significant management issue because sudden shifts in condition may indicate that an ecosystem is more vulnerable than it appears (Suding and Hobbs, 2009). As a result, it has been suggested by researchers such as Beisner et al. (2003), Suding et al. (2004), Schröder et al. (2005) Bestelmeyer (2006), Groffman et al. (2006), and Hobbs (2007) that threshold dynamics can apply to a broad range of ecosystems where a sudden shift to an alternative state is imposed once a particular ecological threshold is exceeded.

While it is generally recognised that multiple alternative states may exist within an ecosystem both temporally and spatially, it is inherently difficult to determine and must be supported by accurate data. Accordingly, those restoring degraded areas must consider this in relation to measures of success. One of the fundamental requirements for the restoration of degraded ecosystems is gaining an understanding of the factors that caused the initial degradation (Hobbs and Norton, 1996). The differences in disturbance regimes are likely to require different management approaches. Didham (2005) has indicated that '*if strongly abiotically or disturbance structured systems are more likely to exhibit catastrophic phase shifts in community structure that can be resilient to management efforts, then restoration ecologists will need to treat these systems differently to systems that are competitively structured in terms of the types of management inputs that are required*'.

Predictors of ecosystem recovery

Predictive indicators for ecosystem recovery following disturbance have significant value in restoration ecology. Some of the most recently used indicators have been nitrogen input (Strengbom et al. 2001; Evans et al., 2008), carbon and nitrogen (Baer, 2010), phosphorus availability (Tessier and Raynal, 2003), soil acidification and nitrification (Högberg et al., 2006), and climatic conditions (Tanja et al., 2003). Invertebrates have been widely used as biological indicators of restoration success (Bisevac and Majer, 1999; Longcore, 2003; Anderson and Majer, 2004; Majer et al., 2007; Nakamura et al., 2007; Wike et al., 2010).

One of the key requirements to further understand responses of ecosystems following disturbance is the need to undertake research and experimentation. Because the rates at which ecological processes operate, there is a need to dedicate long term periods for monitoring and subsequent data collection and analyses. Although predictors of recovery from disturbance can be unreliable, long term monitoring can identify any potential deficiency, provided that consideration is given to selection of appropriate monitoring criteria. However, variability of responses within ecosystems necessitates an understanding of feedback mechanisms in order that results from experimental manipulation can be integrated with patterns seen at broader scales (Hooper et al., 2005; Brancaleoni and Gerdol, 2006; DeLuca et al., 2008).

Economic considerations

Changes in land use are one of the major contributors to ecosystem degradation and should justify increased investment in restoration activities (Aronson and Vallejo (2006). Woodworth (2006) noted that restoration of degraded areas can require significant economic input. Typically, the required resources are provided by government departments or dedicated associations. Other organisations such as The Society for Ecological Restoration have a long term vision to improve overall ecological condition of degraded areas and are instrumental in providing direction to restoration projects.

The amount of funding allocated to any particular restoration project is proportional to the desired restoration outcomes. For example, if the objectives are to reinstate habitat for a single species, then typically this could be achieved within a relatively short time frame and with minimal effort. In contrast however, if it is desired to restore ecosystems to a similar (or at least functional) state in terms of what existed prior to disturbance, then usually longer term funding and greater restoration effort will be required. Ehrenfeld (2000) suggested three types of goals that should be considered during the design of restoration programs: species; ecosystem functions; and ecosystem services. All require different approaches and have advantages and disadvantages (Ehrenfeld and Toth, 1997; Ehrenfeld, 2000). For example, Harris and van Diggelen (2006) have noted that the species approach may rescue a single species from extinction, at local or global levels but ignores landscape and ecosystem level interactions which can result in the decline of habitat for other species.

An important consideration in restoration procedures is the addition of soil nutrients to enhance recolonisation rates. However, this can be an expensive exercise and in some situations may not be required. This is dependent on the type and severity of initial disturbance. Accordingly, Bainbridge (1990) has shown that the critical elements for a low cost rehabilitation are the introduction of appropriate seeds and the creation of conditions to facilitate rapid growth such as soil preparation. Where active restoration techniques are employed, consideration must also be given to ongoing monitoring and maintenance programs. Effectively, the cost per unit price (i.e. m^2) in 2009 may be up to AUD\$0.50/m^2.

In some cases however, the addition of fertilisers, in particular nitrogen, may be beneficial, for the vegetation establishment. For example, Boorman (1977) and Wright (1994) have demonstrated that addition of nitrogenous fertilisers is essential for establishment of dune grasses. High application rates are generally required (560 – 680 kg/ha) and the cost of this, as well as labour requirements, must be factored into the overall cost for restoration. While most large scale and also labour intensive restoration projects in areas such as the Florida Everglades are implemented through the recognition of an urgent issue, the required long term funding can be delayed for many years while economic debate occurs.

As a result, of economic considerations, many potential restoration projects are typically cost prohibitive. As an example, over large areas, soil preparation (and depending on location), in 2009, this was estimated to be up to AUD$100/ha. As a general guide, the cost associated with restoration of degraded areas also increases with the time taken to respond after the need to implement restoration activities is first identified (Clewell et al., 2005). However, the level of restoration to be selected ultimately depends on desired outcomes and ambition associated with the project (Harris and van Diggelen, 2006). Where economic decisions suggest that restoration funding is prohibitive, alternative methods of achieving a desired level of restoration must be sought. The most cost effective way of achieving this is to allow natural regeneration and succession to proceed until recovery occurs.

Thesis aims and structure

The principal aim of this thesis is to investigate the potential of disturbed areas within Tasmania to recover naturally following different kinds of disturbance in different environments. To understand the processes that enable or resist recovery, the following questions are asked:

- Is there a relationship between the type of initial disturbance and recovery?
- What are the most reliable predictors of ecosystem recovery following disturbance?
- Is there a correlation between vegetation recovery and the effects of disturbance on soils? and
- To what extent do local environmental conditions influence recovery from disturbance?

Chapter 2 outlines the general methods used throughout this study. Details of the methods utilised for site selection are given. Methods used for data collection, preparation and analyses are detailed and the techniques utilised for aerial image interpretation and terrestrial photography are outlined;

Chapter 3 contains the analysis and results of recovery of vegetation and soils from disturbance at sites located within grasslands and grassy woodlands;

Chapter 4 investigates vegetation and soil recovery after disturbance within Tasmanian dry sclerophyll communities;

Chapter 5 investigates vegetation and soil recovery from disturbance in wet sclerophyll forest;

Chapter 6 investigates vegetation and soil recovery from disturbance in the lowland ecosystems of western Tasmania;

Chapter 7 utilises the data from chapters 3 – 6 at the site level to develop predictive models for vegetation and soil recovery from disturbance; and

Chapter 8 provides a discussion regarding implications of the project for future management, continuing development of theoretical frameworks, and, the further development of restoration ecology within in a Tasmanian context.

Chapter 2 - General Methods

Introduction

This chapter provides details of the general methods utilised for this project: study site selection; aerial imagery preparation and interpretation; collation of climatic data (rainfall and temperature); collection of observational data (vegetation composition and structure, physical attributes and location); soil sampling procedures and sample preparation; soil chemical analyses: preparation of data for statistical analysis; and details of numerical analyses for chapters three to six.

Study Sites - Overview

All sites investigated in this project are located within the island state of Tasmania, the smallest state of Australia. The island of Tasmania is approximately 68 300 km^2 in area and is separated from the rest of Australia by the 300 km width of Bass Strait. Tasmania is strongly influenced by the sea and has a cool temperate climate with a strong maritime influence from the prevailing westerly 'Roaring Forties' wind stream. As a consequence, the western region has high mean annual rainfall, while the east has much less.

Climatic conditions and the geological diversity of Tasmania have strong influences on the distribution of the indigenous flora and fauna. One of the most notable influences is the strong east-west geological divide between Jurassic dolerite and older Pre-Cambrian rock types (Figure 2). This has been referred to as 'Tyler's Line' in the literature after recognition of differences in flora and fauna and limnology (see Shiel et al., 1989). With very few exceptions, such as the occasional granitic outcrop, the eastern half of Tasmania typically consists of Jurassic dolerite and sedimentary rocks of Ordovician, Permian and Triassic age. Jurassic dolerite is a basic igneous rock extruded below the land surface (Laffan and McIntosh, 2005) covering over one third of Tasmania and widespread within the central and eastern regions of the state. The western region is composed mainly of highly metamorphosed, siliceous Pre-Cambrian aged rock. In contrast to Jurassic dolerite, Pre-Cambrian rock types (the oldest in Tasmania) extend from near the Port Davey region in the southwest to Rocky Cape in the northwest.

In the western region, harder and erosion resistant rocks such as quartzite usually form the mountains while softer rock such as schist occur within valleys and lower lying areas. Landforms, soil types, soil nutrient status, and plant communities are very different within this western region to those in the eastern half of Tasmania.

Figure 2. View of Tasmania showing the approximate delineation of the east – west geological boundary indicated by the diagonal white line. Image source: Google Earth, August 2005.

Bioregions

The generally accepted definition of a bioregion is '*...a large area of land or water that contains a geographically distinct assemblage of natural communities that (a) share a large majority of their species and ecological dynamics; (b) share similar environmental conditions, and; (c) interact ecologically in ways that are critical for their long-term persistence*' (WWF, 2004).

Within an Australian context, bioregions are defined by the Department of Water, Environment, Heritage and Arts (DEWHA, 2007) as '*a geographic area characterised by a combination of physical and biological characteristics for example, terrain, climate and ecological communities*'.

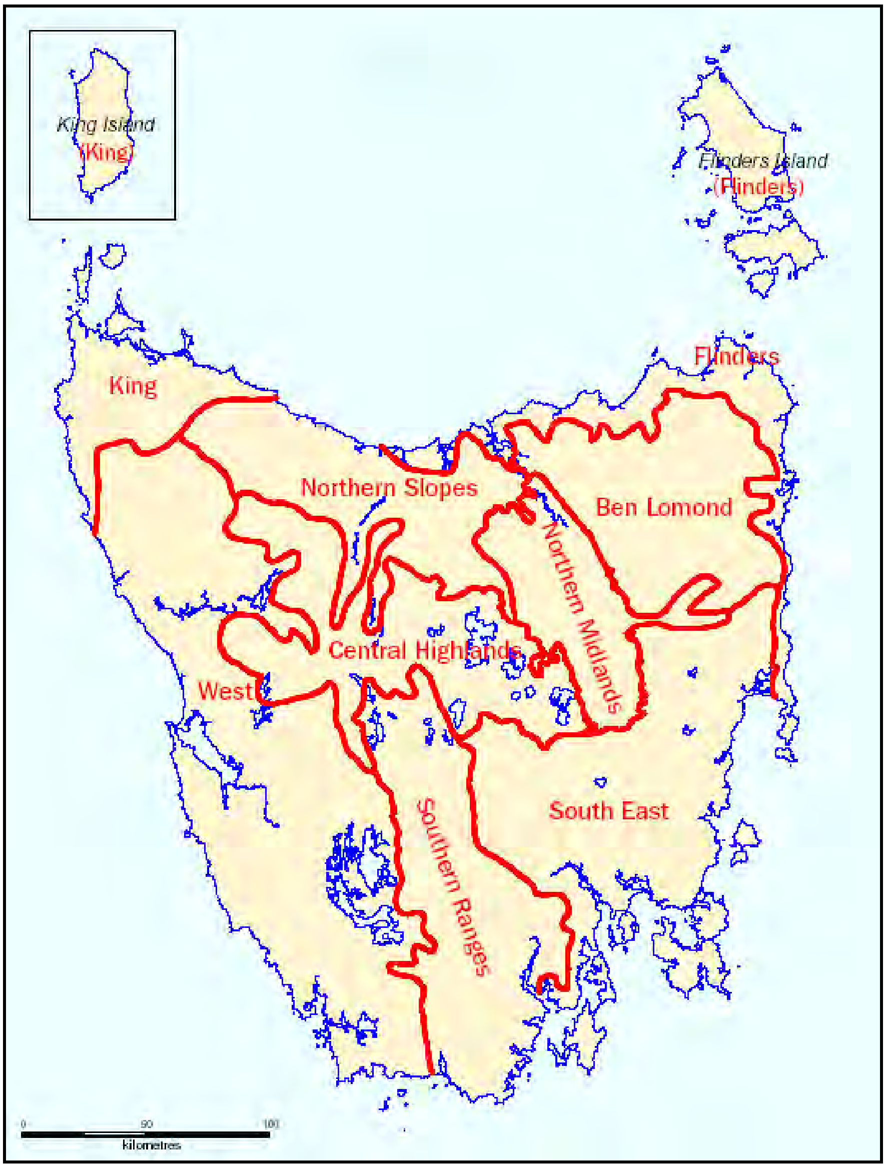

Figure 3. The nine bioregions of Tasmania. Source: Department of Primary Industries, Water and Environment. Source: Commonwealth of Australia, 2007.

Nine bioregions are recognised within Tasmania by the Interim Biogeographic Regionalisation of Australia (IBRA 6.1). They are Ben Lomond; Central Highlands; Flinders; King; Northern Midlands; Northern Slopes; South East; Southern Ranges; and West (Figure 3).

The present research project has examined a total of 18 sites within four of the IBRA bioregions: Northern Midlands (n = 3); South East (n = 6); Southern Ranges (n = 3); and West (n = 6), for their regeneration potential following different types of disturbance.

Selection of Study Sites

During the study site selection process, an attempt was made to choose sites that were subjected to a range of disturbance types, with a range of ages since disturbance and in different ecological conditions. The physical distance between control and disturbed sites was minimised in the selection process to ensure that recolonisation could occur from an adjacent seed source.

The sites occur within the West bioregion at Kelly Basin, Lake Johnson, Lake Margaret, Nelson Falls, Strathgordon, and Williamsford; in the Southern Ranges bioregion at Adamsfield, Butlers Gorge, and Mt Mawson in the Mt Field National Park; in the Northern Midlands bioregion at the old Campbelltown Hospital; the property of Fosterville, and the Queens Domain[1] near Hobart; and in the South East bioregion at Coles Bay, Douglas Rd, Kettering, Maria Island, Pottery Rd, and Wyre Forest Rd (Figure 4). The study sites are examined at the ecosystem levels of: grasslands and grassy woodlands; dry sclerophyll communities; wet sclerophyll forest; and rainforest.

The control sites were selected to represent the ecosystem which existed prior to disturbance. White and Walker (1997) have suggested that one of the most difficult issues associated with the repair of damaged or degraded ecosystems is the selection of appropriate control sites. An attempt was made to make the underlying physical conditions of the disturbed and control sites as similar as was possible by mapping disturbance boundaries using aerial imagery; the use of information from historical images; media and other reports; previous vegetation mapping (where available); and local knowledge related to the extent and age since disturbance and other site history information.

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[1] The Queens Domain study site is not located within the Northern Midlands bioregion. It has been included as part of this bioregion as it primarily consists of degraded grasslands and has broadly similar environmental characteristics to the other two sites within the Northern Midlands bioregion.

The type and severity of the initial disturbance was determined during the selection process for classification purposes and to facilitate data analyses. All study sites were classified according to the type of initial disturbance and this was simplified to either superficial (i.e. ploughed, slashed) or severe (i.e. mining, land clearance).

Sampling areas (quadrats) were selected to be as similar as was possible between the disturbance and adjacent controls in slope, aspect, geology and topographic position.

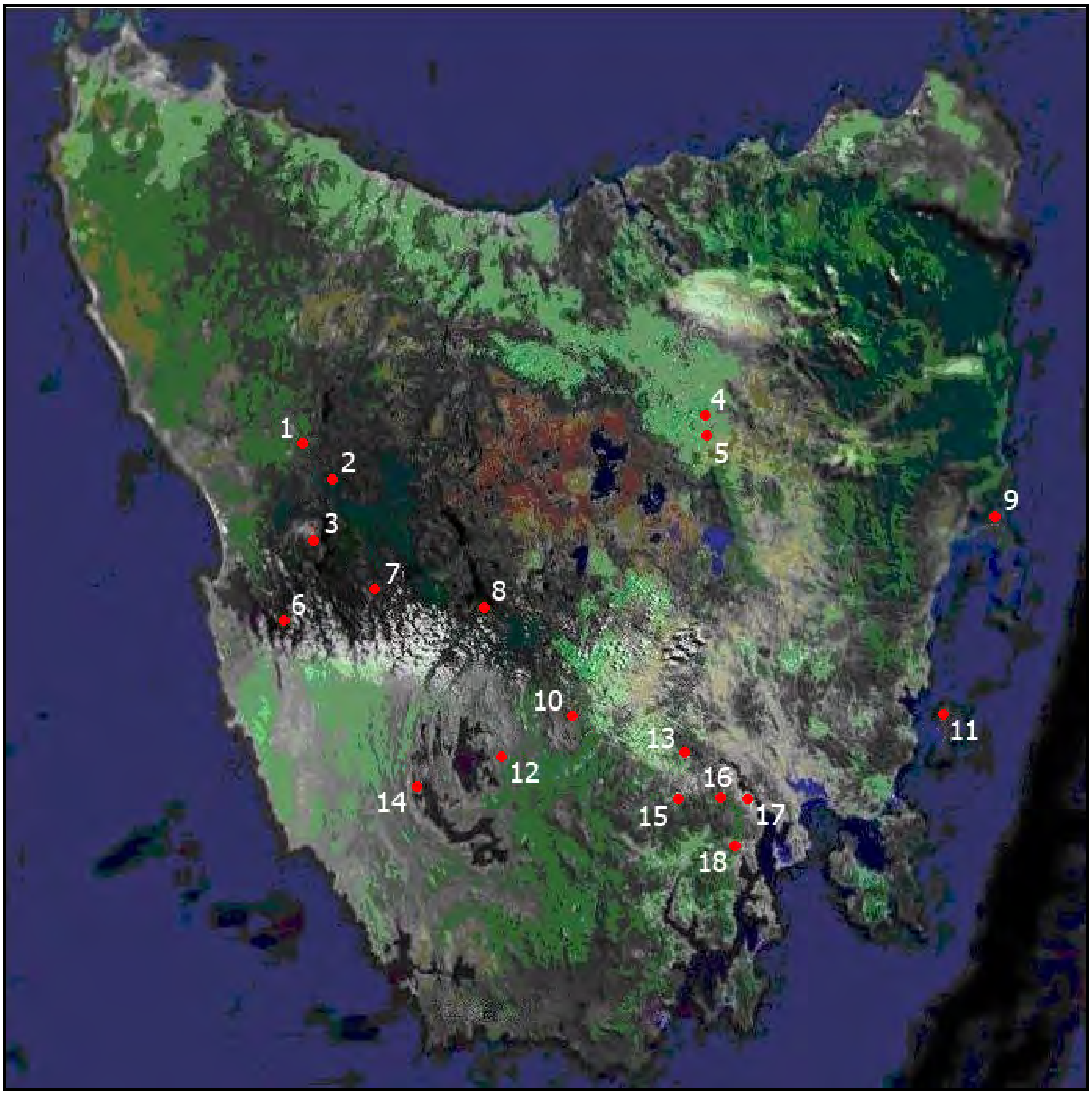

Figure 4. Image of Tasmania showing the approximate location of all study sites. **1** = Williamsford; **2** = Lake Johnston; **3** = Lake Margaret; **4** = Campbell Town Hospital; **5** = Fosterville; **6** = Kelly Basin; **7** = Nelson Falls; **8** = Butlers Gorge; **9** = Coles Bay; **10** = Mt Field; **11** = Maria Island; **12** = Adamsfield; **13** = Douglas Road, ; **14** = Strathgordon; **15** = Wyre Forest Road,; **16** = Pottery Rd,; **17** = Queens Domain, Hobart; **18** = Kettering. Image source: Google Earth, August 2005.

Data Collection

Vegetation

Eighty quadrats (40 disturbed, 40 control) were randomly located using a random number table within both the disturbed and control areas at most of the study sites. Exceptions to this were at Mount Field (n = 40), Pottery Road (n = 40) and Queens Domain (n = 54) where physical constraints prevented the placement of 80 randomly located quadrats. Species observed within each quadrat were recorded, and with the exception of the Queens Domain site, where presence/absence was noted, their cover-abundance was estimated using a modified Braun-Blanquet scale (absent = 0, 1-5% cover = 1; 6-25% = 2; 26-50% = 3; 51-75% = 4; >75% = 5).

For all quadrats, size was determined by the procedures outlined by Wiegert (1962). This involved developing species-area curves by plotting the cumulative number of species in a range of quadrats against the cumulative area of the quadrats ($2m^2$, $4m^2$, $25m^2$, $100m^2$, $400m^2$). The appropriate quadrat size, based on species-area curves, was determined to be 10m x 10m for the study sites at Adamsfield, Butlers Gorge, Campbelltown Hospital, Douglas Road, Kelly Basin, Kettering, Williamsford and Wyre Forest Road. For study sites located at Coles Bay, Fosterville, Lake Margaret, Maria Island, Mount Field, Nelson Falls, Pottery Road and Strathgordon quadrat size was 5m x 5m. The disturbance at Lake Johnston is a 2m wide linear transect (geological survey line). The adjoining area is the control for this study site. For data collection, the linear transect was divided into adjoining 2m x 2m quadrats. At the Queens Domain study site a randomly located line transect was used as the sampling method and this was divided into adjoining 1m x 1m quadrats along its entire length.

Species Nomenclature

Nomenclature for all vascular plant species follows Buchanan (2009).

Quadrat environmental data

Bare ground, rock cover and litter cover were estimated within each quadrat using the same modified Braun-Blanquet scale utilised for plant species abundance. Aspect and slope were measured within each quadrat by using a hand held Suunto compass and a clinometer.

Elevation data were initially collected with a handheld Garmin GPS unit and if necessary, adjusted by reference to the contour intervals on the relevant 1:25 000 scale Tasmap series. All easting and northing coordinates were verified within ±10 m accuracy and waypoints were recorded in the standard WGS 84 (AGD 66) datum.

Soil samples

A subset of soil samples (n = 10) was collected from within quadrats at the disturbed and control areas. The sampling points (quadrats) were determined from a random number table. Soil was collected from the surface to 10 cm depth.

Site environmental data

Data for mean daily minimum and maximum temperatures, and rainfall were obtained from information held in the Bureau of Meteorology (BOM) databases. The BOM database contains comprehensive climate records from many locations within Tasmania. This was accessed from the relevant webpage at www.bom.gov.au or from liaison with BOM staff where necessary.

Where no local weather stations (i.e. within close proximity to each individual study site) were available, the closest one to the site was used and data extrapolated to approximate local conditions. The rainfall model of Nunez et al. (1996) was used for sites remote from stations. The environmental lapse rate determined by Nunez and Colhoun (1986) was used to calculate the effect on temperature of elevational differences between stations and sites.

The geology and soil type of all sites was recorded. Soil types were classified following Isbell (1998). Surface geology was determined by a combination of field observations, Geoscience Australia 3-D models and the relevant Mineral Resources of Tasmania, Tasmania Geological Survey 1:250 000 scale mapping (DIER, date unknown).

Aerial Imagery

Following selection of study sites, the most recent aerial photographs were obtained and examined under a stereoscope (using 5 x magnification). These were scanned using a flat bed scanner at a minimum resolution of 800 dpi. All scanned images were stored electronically using .tif format as the preferred option. The online spatial database, Google Earth, was also accessed for aerial imagery for each study site and where suitable resolution was available the images were downloaded from Google Earth in .jpeg format. All images were used for further examination and as a reference for understanding details of the surrounding landscape.

Where possible, electronic images were examined to determine the area of the initial disturbance footprint and to identify the presence of any significant landscape features. Following initial examination of aerial photographs and electronic images acquired from Google Earth, field work commenced at each selected study site. Each site was visited a minimum of two times, firstly to gain an understanding of its overall condition and vegetation structure, and later for data collection.

Data Analysis – Soils

Soil Preparation

Preparation of all soil samples for further analysis followed the procedures outlined in Rayment and Higginson (1992). This commenced within 24 hours of collection in order to minimise the potential effect of any microbial activity on nutrient status, in particular, the loss of nitrogen.

Initial preparation involved placing approximately 200 g of soil on an aluminium tray inside a laminar flow unit. All samples were air-dried for no less than 24 hours and checked following removal to ensure dryness. Any samples not completely dry following the initial drying period were returned to the laminar flow unit for an additional 24 hour period.

All samples were sieved through a 1.5 mm brass sieve to remove small rocks (>3 mm) and these were discarded. The remaining material was crushed to a fine consistency by hand with a mortar and pestle and sieved through a 0.5 mm sieve. All material not passing through the 0.5 mm sieve was discarded. All material passing through the 0.5 mm sieve was collected and placed inside sealed plastic bags until analysis could be undertaken. A total of 100 g of prepared soil was required in order for all analyses to be completed for each individual sample.

Soil Analyses

All prepared soil samples were analysed for percentage of total nitrogen, total carbon and total extractable phosphorus in the School of Geography and Environmental Studies at the University of Tasmania. All pH measurements were performed with equipment at the School of Agricultural Science at the University of Tasmania.

Soil pH

Soil pH was determined by following the methods outlined in Rayment and Higginson (1992). A single 20 litre volume of 0.01 M $CaCl_2$ solution was prepared. A 50 ml volume was added to 10 g of each prepared soil sample and the mixture placed inside a 150 ml container. Soil pH affects the uptake of cations and heavy metals (e.g. Lucas and Davis, 1961).

All prepared soil samples were placed in a tumbler for 30 minutes, removed, and allowed to settle for 10 minutes. Following the 10 minute settling period, the screw top was removed and a calibrated digital pH probe was inserted to a depth of 1.5 cm in the solution. The pH value was read directly from the digital display.

Total Nitrogen

Total nitrogen from all soil samples was determined using the Kjeldahl method described by Jackson (1958). Obtained values were calculated as the percentage of nitrogen. Previous work has shown that soil nitrogen is an important macronutrient for plant growth (e.g. Lawlor et al., 2001).

Extractable Phosphorus

Bray extractable phosphorus was determined by the methods described by Jackson (1958). All data were expressed as ppm. Phosphorus is considered to be an important macronutrient for plant growth (Beadle, 1953, 1954). Previous work has shown that available phosphorus is almost immeasurable in many Tasmanian soils (e.g. Adams et al., 1989; Laffan and Nielsen, 1997) and therefore, total phosphorus was used.

Organic Carbon

Determination of total organic carbon in all soil samples was conducted by following the procedures outlined in Rayment and Higginson (1992) for loss on ignition. The loss of organic material is determined as the total percentage of dry weight. Carbon (i.e. organic matter content) was selected as a means to determine soil fertility. Its content within the soil structure is widely regarded as an essential component of soil physical, chemical and biological fertility (DPIW, 2010).

Nitrogen: carbon ratio

The nitrogen: carbon (N:C) ratio was calculated from the above values. The N:C ratio of soil influences the rate of decomposition of organic matter and this results in the release (mineralisation) or immobilization of soil nitrogen (Janssen, 1996).

Data Analysis - Vegetation

All data were prepared for input into the ecological database, DECODA, by entering into a Microsoft Excel 2003 spreadsheet. The compiled spreadsheets were saved in .csv format as the preferred for electronic storage and input into DECODA and other statistical packages for further analyses.

For each study site and all quadrats, global non-metric multi-dimensional scaling (NMDS) was performed on the presence/absence data for all taxa using the default options in DECODA (Minchin, 2001). NMDS was chosen because it is considered robust for ecological data (Minchin, 1987a, b) and maximises rank-order correlation between distance measures and distance in ordination space and produces ordination diagrams which display the dissimilarity of sites in terms of composition (Faith and Norris, 1989). Stress indicates the goodness of fit between the site separation in the ordination diagram and dissimilarity values (Faith and Norris, 1989).

Using the procedures in DECODA, vectors for all variables were fitted to ordinations and their significance was determined by using 1000 randomisations. Sorted tables were created by ordering quadrats by scores on the vector for disturbance/control and ordering species by the average of the scores on this vector for the quadrats in which they occurred.

The ANOSIM test in DECODA was used to determine significance of the difference between floristic composition of the disturbed and control areas at each study site. The X^2 test was used to determine if individual taxa significantly varied in frequency between the disturbed and control quadrats at each site. Taxa with expected values of less than five were not tested and tables were produced in which the tested species were ordered by the ratio of their frequencies followed by their X^2 value.

The two sample t-test was used to test the significance of differences in soil variables between the disturbed area and the control at each study site.

Chapter 3 – Grasslands and Grassy Woodland Ecosystems

Introduction

Prior to European settlement, there were approximately 850 km^2 of native grasslands present in Tasmania (Figure 5). The majority occurred within the IBRA classified Northern Midlands bioregion (see IBRA, 2007). The grasslands present today are dominated by *Poa* tussock at elevations above 600 m while in lower elevations they are usually dominated by *Themeda triandra* and *Austrodanthonia* species (Kirkpatrick, 1999).

Figure 5. Distribution of grassy vegetation types in Tasmania c. 1800. Image Source: Kirkpatrick et al. (1988).

The lowland grassland communities generally exist as small fragmented remnants patches. As of 2009, 83% has been lost since European settlement (*EPBC Act 1999* Policy Statement 3.18). Accordingly, these areas are regarded as one of the most threatened ecological communities in Tasmania. Grassy woodlands covered approximately 4000 km^2 in 1800, but more than 90 % of their original area has been destroyed for agriculture (Kirkpatrick et al., 1988).

Recent data from ANRA (2008) suggests that the Northern Midlands bioregion, the stronghold for these grasslands and grassy woodlands ecosystems, contains at least 10 endemic plant species (including seven endemic orchids); a total of 24 nationally threatened plant species which have a restricted distribution in Tasmania, more than 180 plant and animal species listed by the Tasmanian Threatened Species Protection Act 1995 and 32 nationally threatened taxa. Therefore, understanding the recovery processes following physical disturbance is an important conservation issue.

Fire is recognised as an important factor in the maintenance of Tasmanian native grasslands as it restricts colonisation by tree and shrub species particularly in lowland grasslands (Kirkpatrick et al., 1988; Kirkpatrick, 1999). Tasmanian native grasslands can potentially support trees and shrubs. However, environmental factors such as moisture availability, seasonal drought, and shading by the grass sward limits woody plant establishment (Kirkpatrick, 1999). In addition, Kirkpatrick (1999) has suggested that where moisture penetrates below the grass roots, seedlings may not be able to penetrate below this zone before available moisture is depleted. Accordingly, it is likely that the establishment of some species may be inhibited by a dense grass cover (Fensham and Kirkpatrick 1992).

As a result of extensive impacts including land clearance and other agricultural practices, Kirkpatrick (1999) has concluded that grasslands and associated grassy ecosystems are the most transformed of any vegetation type within Tasmania and, therefore, their conservation value is high. As a result, there is a need to evaluate the recovery rates of these ecosystems after disturbance. While this has been done for recovery from burning and/or grazing in Tasmania and elsewhere in Australia (e.g. Tothill, 1971; Jackson, 1973; Groves, 1974; Gibson and Kirkpatrick, 1979; Scarlett and Parsons, 1982; Kirkpatrick, 1986; Anderson et al., 1988; Kirkpatrick et al., 1988; Sharp, 1994; Fensham and Fairfax, 1996; Lunt, 1998; Morgan, 1998; Hobbs and Huenneke, 1999; Kirkpatrick, 1999; Eddy, 2000, 2002; Hobbs, 2002; Martin and Green, 2002; McIntyre, 2002; Morgan, 2003; Parr and Anderson, 2006; Whelan et al., 2006; Rehwinkel, 2007 a,b; Penman et al., 2008; Yates et al., 2008; NBSRTG, 2009), their rate of recolonisation following physical disturbance of soils is rarely documented in the literature, although ploughing was shown to negligibly affect one semiarid grassland (Lewis et al., 2010). Hirst et al. (2003, 2005) has shown that understanding the processes of disturbance and recovery in grasslands and grassy woodland communities is vital for their conservation management. Stuwe and Parsons (1977) investigated the species composition of small remnant patches of native grassland vegetation west of Melbourne on the basalt plains. They concluded that species composition is more likely to be related to disturbance history rather than environmental conditions. Areas with different types of management had vegetation with distinctly different composition. It has also been noted that soil properties can influence the floristic composition of grassy vegetation (Kirkpatrick, 1999).

A long term study conducted in North America at the WK Kellogg Biological Station has provided important insights into understanding the mechanisms of succession within agricultural land following abandonment (i.e. Gross and Emery, 2007). This study investigated the role of soils relative to the rate of recovery following land abandonment. Although only three sites were investigated, it showed that differences in community structure and patterns are related to past land use, age of succession, soil fertility and geographic location (Gross and Emery, 2007). One of the most important considerations relative to the redevelopment of grassland communities following abandonment of agricultural land is the level of soil disturbance. It is known that the duration and type of agricultural activity affects nutrient availability, soil carbon, organic matter, and soil structure (Compton and Boone, 2000; Fraterrigo et al., 2005; Standish et al., 2007). Cramer et al. (2007) also suggest that, in the Australian wheat belt, soil modification from cultivation and competition from non-native annual species are important barriers to the regeneration of native species.

It is known that cultivation of soil will reduce surface heterogeneity and microsites necessary for seedling establishment (Cramer et al, 2007). This may affect the rates of recovery from soil disturbance in grassland areas. Another possible barrier to the regeneration of many native species is fertiliser addition. Fertilisers have been used historically in attempts to improve conditions for crops and pasture grasses, in particular, fertilisers relatively high in available phosphorus have been utilised extensively for this purpose. Australian native plants are generally adapted to low soil phosphorus and following abandonment of agricultural land subjected to fertiliser application, there may initially be a greater response from non-native species (Hobbs and Atkins 1988, 1991; Hester and Hobbs, 1992).

Aim of Chapter

In this chapter the vegetation composition, community structure and soil properties of three disturbed grassy ecosystem sites within the Northern Midlands[2] bioregion are examined and compared against adjacent undisturbed control sites.

Methods

Study site selection

Three study sites were selected as part of the grasslands and grassy ecosystems study (Figure 6). Two of these sites, Campbelltown Hospital and Fosterville are located within the Northern Midlands bioregion and the other at Queens Domain near Hobart is located within the South East bioregion.

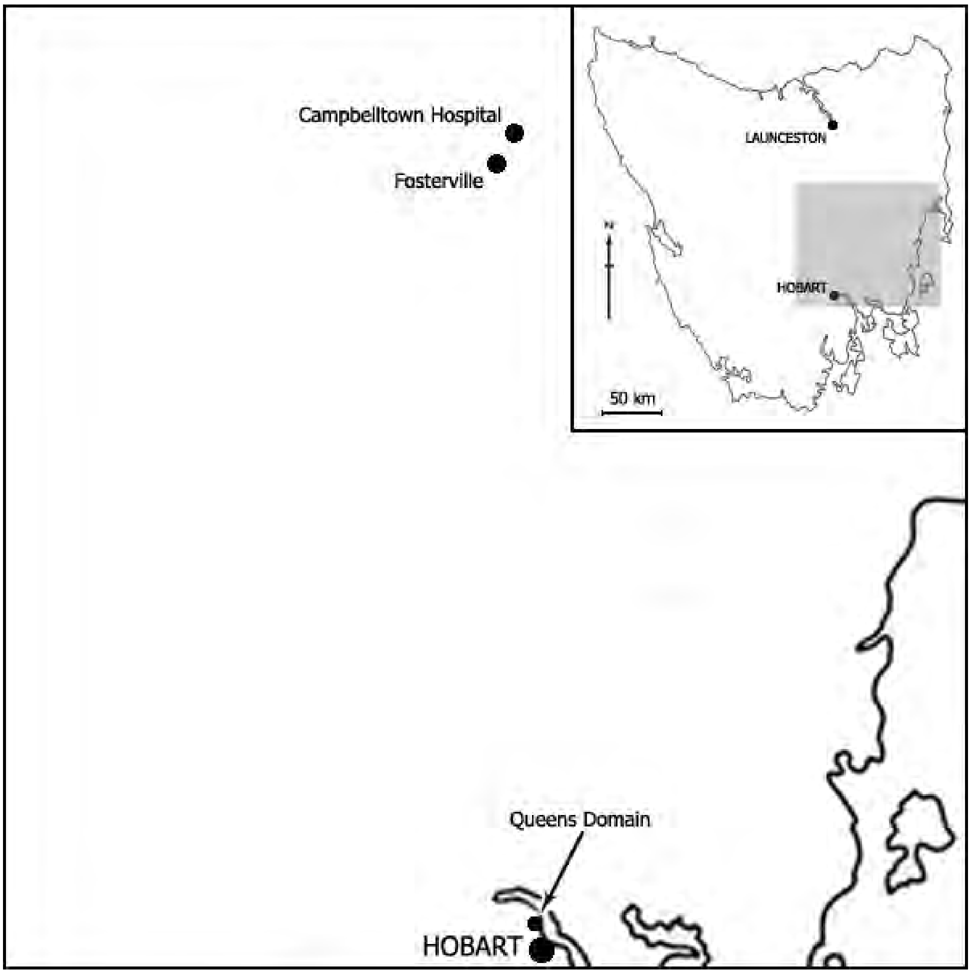

Figure 6. Location of study sites used in the grasslands study.

[2] The Queens Domain site has been included in the Northern Midlands because of similarities in floristic composition and environmental conditions.

Study Site Overview and Disturbance History

Campbell Town Hospital

The former Campbell Town Hospital, approximately 5 km west of the township of Campbell Town (Figure 7) was established as a rehabilitation centre for returning soldiers during and after the Second World War (Box, 1992). The study site is located within the boundaries of the former hospital site.

Figure 7. Oblique view of the Campbelltown Hospital study site in 2007. Approximate location of the study area is indicated by the arrow. Image Source: Google Earth.

The remains of foundations and other infrastructure are still visible at this study site (Figure 8). The surrounding vegetation consists mostly of grassy woodland which is grazed by domestic livestock and native grazing mammals. Initially, the area was cleared to facilitate development of the hospital infrastructure in the mid 1800s. Following commencement of the Second World War, the facility was administered by the Australian Military as a rehabilitation hospital. It was abandoned in 1946.

Figure 8. A section of the old Campbelltown Hospital study site. Some of the remaining infrastructure is visible towards centre of the image.

Climate

Climatic data were collected at Campbelltown for the 15 years between 1964 and 1988 by the Bureau of Meteorology. The monitoring station at Campbelltown is located in relatively close proximity to the Campbelltown Hospital study site within a similar environment. Thus, the data collected during its operation are considered to be a reliable approximation of local conditions at this study site.

Campbelltown received a mean annual rainfall of 562.8 mm and the wettest months generally occurred between October and January. However, mean rainfall does not exceed 60 mm in any month. Rainfall is spread evenly throughout the year, but February is considerably drier than other months, receiving a mean of 24 mm.

The mean daily maximum temperature at Campbelltown is 17.6º C with February being the warmest month with a mean daily maximum of 24.6º C. The annual average mean daily minimum temperature is 4.8º C and the coldest months are June and July with a mean daily minimum temperature of 0.3º C.

Geology and soil

At the study site the local geology is mostly Quaternary sands that are gradational, sandy, reddish-brown and free draining to 1 m or more in depth with occasional embedded dolerite rocks up to 30 cm across.

Fosterville

Fosterville is located near the township of Campbelltown in the Northern Midlands region of Tasmania. During the late 1970s, the study site (Figure 9) was ploughed in preparation for sowing with exotic pasture species. The project was abandoned when conditions for establishing exotic pastures were found to be unfavourable. Formal revegetation treatment has never been applied to the site and all vegetation present within the disturbed area is a result of secondary succession (Figure 10). Vegetation is primarily native grasslands with patches of grassy woodland. The area is currently grazed by domestic livestock and also by native grazing mammals.

Figure 9. Oblique aerial image of the Fosterville study site. The study area is immediately to the west of the waterbody in the centre of the image indicated by the arrow. Image source: Google Earth.

Figure 10. Interface between the disturbed (ploughed area) and control site (small remnant patch of grassy woodlands) at the Fosterville study site.

Climate

The Fosterville study site is located in close proximity (i.e. within approximately 2 km) of the Campbelltown Hospital site and therefore, climatic conditions at this site expected to be similar.

Geology and soil

Soils within the Fosterville site have developed on Quaternary sands and are similar in texture and structure to those at the Hospital site (see above).

Queens Domain

The study site at Queens Domain is located approximately 2 km from the Hobart CBD adjacent to the Derwent River (Figure 11 Figure 12). Between 1959 and 1966, a large area on a north facing slope was ploughed and planted with exotic trees in an attempt to 'improve aesthetic appearance' (Hobart City Council, date unknown). The majority of the planted trees have died and a few individuals remain. Prior to ploughing, the aerial image (Figure 11) suggests that the area supported *Themeda triandra* tussock grassland with scattered large trees of *Eucalyptus viminalis*.

Figure 11. Aerial view of Queens Domain in 1957. Approximate location of the study site transect is indicated by the yellow line.

Figure 12. Aerial view of Queens Domain in 2007. Approximate location of the study site transect is indicated by the yellow line. Image Source: Google Earth, 2007.

Climate

Climatic data have been collected at the nearby Botanic Gardens, less than one km from the study site, since 1841, a total of 168 years. The Botanic Gardens receives a mean annual rainfall of 566.5 mm with the wettest months generally from October to December. However, mean rainfall does not exceed 55 mm in any month. Rainfall, on average, is spread evenly throughout the year with February being slightly drier than other months with a mean of 39.2 mm.

The mean daily maximum temperature is 17.0º C. The warmest month is January with a mean daily maximum of 23.1 ºC. The annual average mean daily minimum temperature is 7.8º C with the coldest month, July, having a mean daily minimum temperature of 3.1º C.

Geology and soil

The Department of Primary Industry and Fisheries (1993) soil mapping (1: 100 000 scale) describes the study site as having '*moderately well drained black soils developed on Jurassic dolerite bedrock and colluvium on low undulating land*'. The black soils (vertosols in the classification of Isbell (2002)) are approximately 15 cm deep with embedded dolerite rocks mostly 10 cm across and occasionally larger.

Results

Vegetation

Campbelltown Hospital

A total of 28 species (21 native, 7 non-native) were recorded from within 80 quadrats (disturbed = 40, control = 40) at the Campbelltown Hospital study site. Four species, *Acacia dealbata*, *Acetosella vulgaris*, *Poa labillardierei* and *Pteridium esculentum* were common to both the control and disturbed quadrats (Figure 13, Figure 14).

From the 28 species recorded at the Campbelltown Hospital study site, a total of 25 were present within the disturbed quadrats and 19 were present within the control quadrats. There were no species recorded that were common to all quadrats in either the control or disturbed quadrats. Further details of species distribution are provided in Appendix A and Appendix B.

Figure 13. General view of the disturbed area at the Campbelltown Hospital study site with remaining infrastructure visible in the centre of the image. The large trees present are *Eucalyptus viminalis*.

Figure 14. General view of the control area at the Campbelltown Hospital study site.

Species composition was significantly different between the control and disturbed areas (ANOSIM, R = 0.6103, P < 0.001). Among the species that significantly varied in their frequency by treatment, the tree *Eucalyptus amygdalina* was confined to the disturbed quadrats, as were the wallaby grass, *Austrodanthonia* spp., and the non-native herb, *Plantago lanceolata* (Table 1).

Several grasses and graminoids were concentrated in the disturbed area, while also occurring in the control. The deep-rooted perennial grass, *Themeda triandra*, showed the reverse pattern and was concentrated within the control quadrats (Table 1). As shown in Table 1, there was one native and two non-native species confined to the control quadrats.

Table 1. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Campbelltown Hospital study site. * = non-native species.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	X^2	**P**
Austrodanthonia spp.	0.00	95.0	72.381	<0.001
**Plantago lanceolata*	0.00	30.0	48.000	<0.001
Eucalyptus amygdalina	0.00	25.0	11.429	0.001
Lomandra longifolia	7.50	60.0	24.654	<0.001
Juncus spp.	15.00	57.5	15.632	<0.001
Austrostipa spp.	32.50	60.0	6.084	0.014
Poa labillardierei	67.50	87.5	4.588	0.032
Themeda triandra	62.50	22.5	13.095	<0.001
Gonocarpus tetragynus	30.00	0.0	14.118	<0.001
**Agrostis capillaris*	35.00	0.0	16.970	<0.001
**Picris* spp.	21.25	0.0	21.587	<0.001

The disturbed and control quadrats occupy discrete areas. However, the disturbed quadrats occupy a larger area in ordination space (Figure 15) and this indicates that vegetation composition is less uniform within this area compared to the control.

The variables bare ground (R = 0.2583, P = <0.001), rock cover (R = 0.4406, P = 0.001), litter cover (R = 0.6871, P = <0.001), slope (R = 0.5371, P = <0.001) and aspect (R = 0.5371, P = <0.001) had significant vectors (Figure 16).

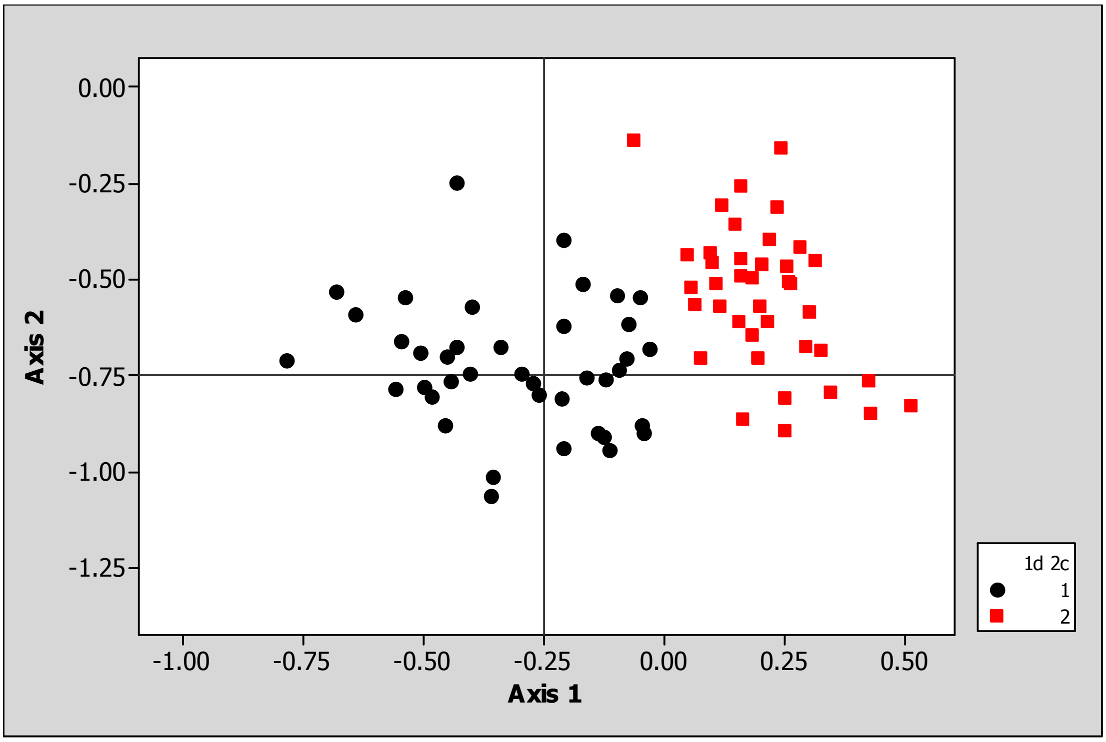

Figure 15. Two dimensional ordination of quadrats (1 = disturbed, 2 = control) at the Campbell Town Hospital study site (minimum stress = 0.276130).

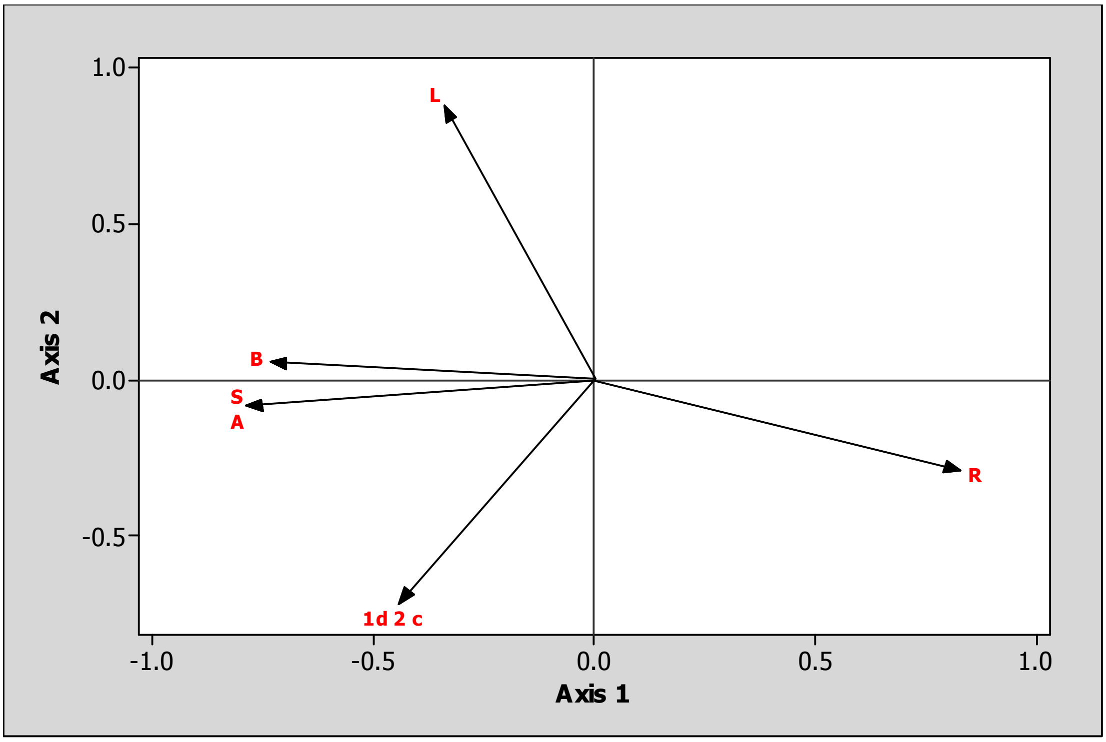

Figure 16. Vector fitting from the Campbelltown Hospital study site. A = aspect, B = bare ground, L = litter cover, R = rock cover, S = slope, 1d2c = disturbed/control.

Soils

There were significant differences in nitrogen (P = 0.017) and the nitrogen to carbon ratio (P = 0.047) between control and disturbed areas at the Campbelltown Hospital study site, with values being higher for the disturbed area than the control (Table 2).

Table 2. Mean values of soil properties obtained from the Campbelltown Hospital study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	4.5 (0.066)	0.08 (0.016)	7.04 (1.0)	2.74 (0.19)	34.25 (4.7)
Control	4.7 (0.056)	0.062 (0.011)	5.93 (1.3)	1.5 (0.21)	24.19 (0.99)
T	-0.58	2.67	0.90	0.04	-2.30
P	0.572	0.017	0.381	0.972	0.047

Fosterville

A total of 34 species (23 native, 11 exotic,) were recorded from within 80 quadrats (disturbed = 40, control = 40) at the Fosterville study site (Appendix A). Of the 34 species, 26 occurred within the disturbed quadrats, 18 occurred in the control, and 11 were common to both areas. Two taxa, *Austrostipa* spp. and *Themeda triandra* had a high frequency within both the control and disturbed quadrats. Species composition was significantly different between the control and disturbed areas (R =0.9030, P = <0.001). Of the species that significantly varied in their frequency by treatment, a total of seven were confined to the disturbed quadrats (Table 3). However, only one of these, *Pteridium esculentum*, was a native species, with the remaining six being non-native grasses and herbaceous taxa (Table 3).

Two native grasses, *Austrostipa* spp. and *Themeda triandra* were present within both the disturbed and control areas (Figure 17). *Austrostipa* spp. was concentrated in the disturbed quadrats but also occurred within the control at a lower frequency while *Themeda triandra* was concentrated within the control quadrats but occurred within the disturbed area at a lower frequency (Table 3). Six taxa (three native, three non-native) were concentrated in the control quadrats and were not present within the disturbed quadrats (Table 3). In particular, the invasive non-native grass, *Agrostis capillaris*, was present within the control quadrats at a relatively high frequency while being absent from within the disturbed area (Table 3).

Table 3. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Fosterville study site. * = non-native species.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	X^2	**P**
**Leontodon taraxacoides*	0.00	95.00	72.381	<0.001
**Cynosurus cristatus*	0.00	67.50	40.755	<0.001
**Bromus catharticus*	0.00	62.50	36.364	<0.001
**Aira caryophyllea*	0.00	55.00	30.345	<0.001
**Oxalis corniculata*	0.00	27.50	12.754	<0.001
Pteridium esculentum	0.00	25.00	11.429	0.001
**Sonchus asper*	0.00	25.00	11.429	0.001
Austrostipa spp.	40.00	80.00	13.333	<0.001
Themeda triandra	97.50	85.00	3.914	0.048
**Briza minor*	30.00	0.00	14.118	<0.001
Acianthus caudatus	37.50	0.00	18.462	<0.001
Poa rodwayi	37.50	0.00	18.462	<0.001
**Picris* spp.	45.00	0.00	23.226	<0.001
Plantago varia	47.50	0.00	24.918	<0.001
**Agrostis capillaris*	60.00	0.00	34.286	<0.001

Figure 17. Typical view of *Themeda triandra* within the control area (background) at the Fosterville study site. The rocks in the foreground are most likely a natural dolerite ridge but may have been further exposed following vegetation removal.

Results from the two dimensional ordination at the Fosterville study site (Figure 18) show that the control and disturbed areas form two discrete groups. The ordination suggests that there is a closer relationship within the groups rather than between them. Vegetation within the control occupies a smaller area in ordination space and this suggests it is more uniform than the disturbed area.

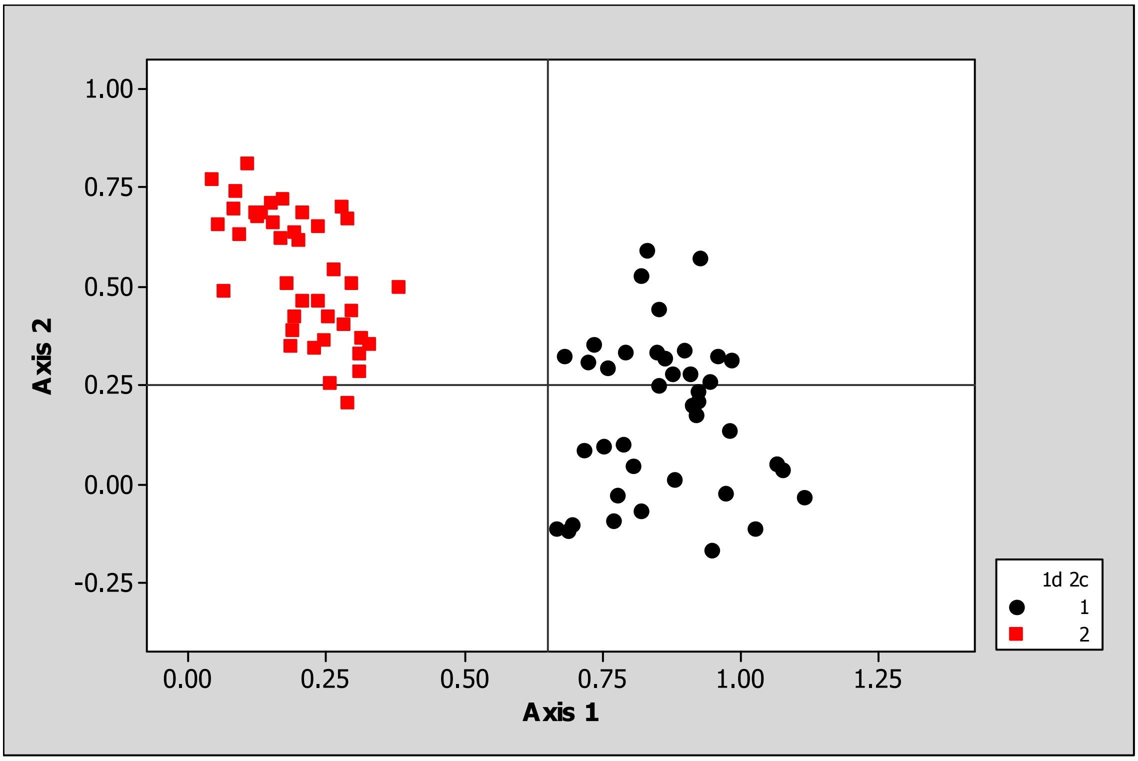

Figure 18. Two dimensional ordination of quadrats (1 = disturbed, 2 = control) at the Fosterville study site (minimum stress = 0.315739).

Vectors obtained from the two dimensional solution at the Fosterville study site are shown below in Figure 19. All measured variables, except for disturbance, had similar directions in the two-dimensional solution.

Vectors displayed in Figure 19 are bare ground (R = 0. 4926, P =0.002), elevation (R = 0.8591, P = <0.001), rock cover (R = 0.3406, P = 0.059), and disturbed quadrats. The disturbance vector (R =0.8338, P = <0.001) was independent of all other vectors at the Fosterville study site.

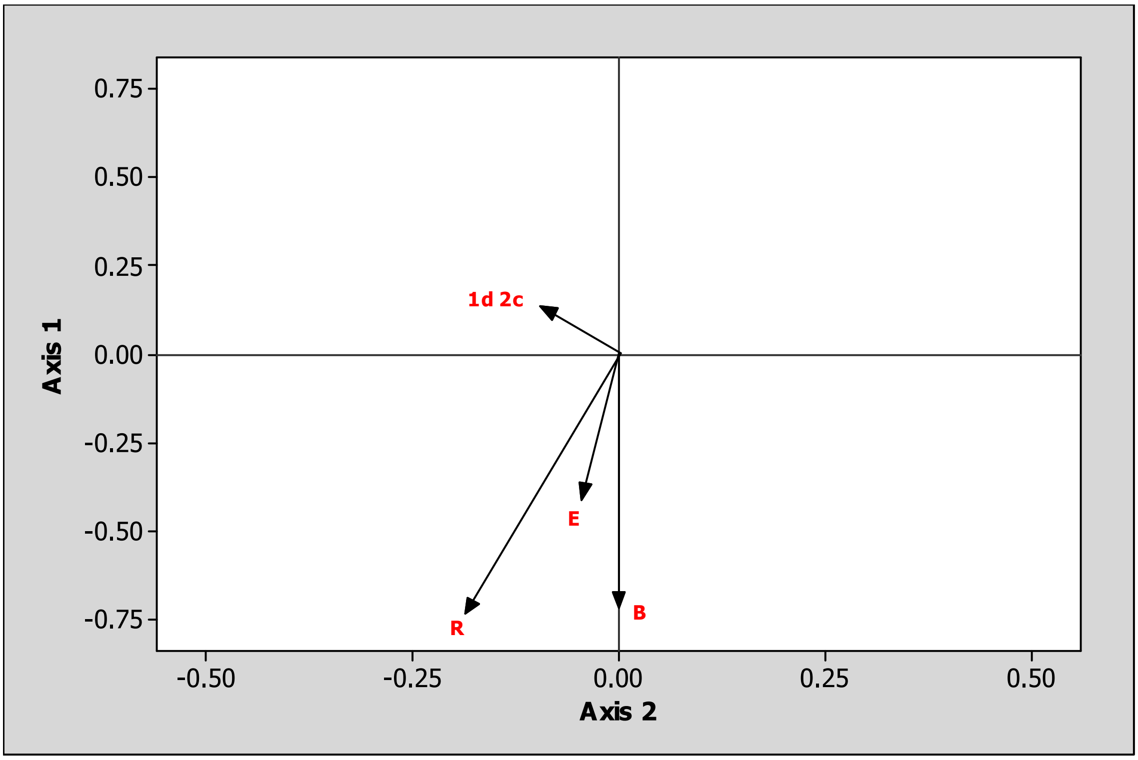

Figure 19. Vector fitting from the Fosterville study site. A = aspect, B = bare ground, E = elevation, R = rock cover, S = slope, 1d2c = quadrats.

Soil analysis

Soil pH (P = <0.001), carbon (P = 0.001) and the nitrogen to carbon ratio (P = 0.012) differed between the disturbed area and control, with the soils being more acid and containing higher levels of carbon in the control quadrats and having a higher N:C ratio in the disturbed quadrats.

Table 4. Mean values of soil analyses obtained from the Fosterville study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	4.7 (0.033)	0.100 (0.012)	3.804 (0.44)	1.16 (0.36)	128.8 (17)
Control	4.38 (0.025)	0.114 (0.020)	4.189 (0.93)	4.96 (0.83)	43.5 (25)
T	7.69	-0.62	-0.38	-4.21	-3.12
P	<0.001	0.545	0.714	0.001	0.012

Queens Domain

A total of 39 species (26 native, 13 exotic) were recorded from within 54 (1m x 1m) quadrats along a single line transect at the Queens Domain study site (Figure 20).

Four native taxa, *Acaena echinata*, *Geranium potentilloides*, *Linum marginale* and *Themeda triandra* were common within the control and disturbed quadrats.
Two non-native species, *Plantago lanceolata* and *Romulea rosea* were common in both the control and disturbed quadrats. Details of the species distribution between the disturbed and control sites for the Queens Domain study site are provided in Appendix A and Appendix B.

Figure 20. Typical view of a sampling quadrat at the Queens Domain study site.

Species composition was significantly different between the control and disturbed areas (R =0.4215, P = <0.001). Among the species that significantly varied in their frequency by treatment, one native taxon, *Austrodanthonia* spp. and three non-native taxa, *Poterium polygamum*, *Fumaria bastardii* and *Sonchus asper*, were concentrated within the disturbed quadrats and also occurred within the control quadrats at lower frequencies (Table 5). Two native taxa, *Poa rodwayi*, and *Themeda triandra*, were concentrated in the control quadrats but also occurred within the disturbed quadrats at lower frequencies (Table 5). No species were recorded that were confined only to the disturbed or control quadrats.

Two native grasses, *Austrodanthonia* spp. and *Themeda triandra*, were recorded from all quadrats within the disturbed and control areas respectively.

Table 5. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Queens Domain study site. * = non-native species.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	X^2	**P**
Austrodanthonia spp.	3.45	100.00	50.133	<0.001
**Sonchus asper*	3.45	88.00	39.254	<0.001
**Fumaria bastardii*	10.34	44.00	7.919	0.005
Themeda triandra	100.00	40.00	24.092	<0.001
Poa rodwayi	58.62	12.00	12.514	<0.001
**Poterium polygamum*	48.28	4.00	13.119	<0.001

Results from the two dimensional ordination at the Queens Domain site (Figure 21) clearly indicate that a continuum currently exists between the control and disturbed areas and this is consistent with expansion of *Themeda triandra* observed at the study site and shown in Appendix A.

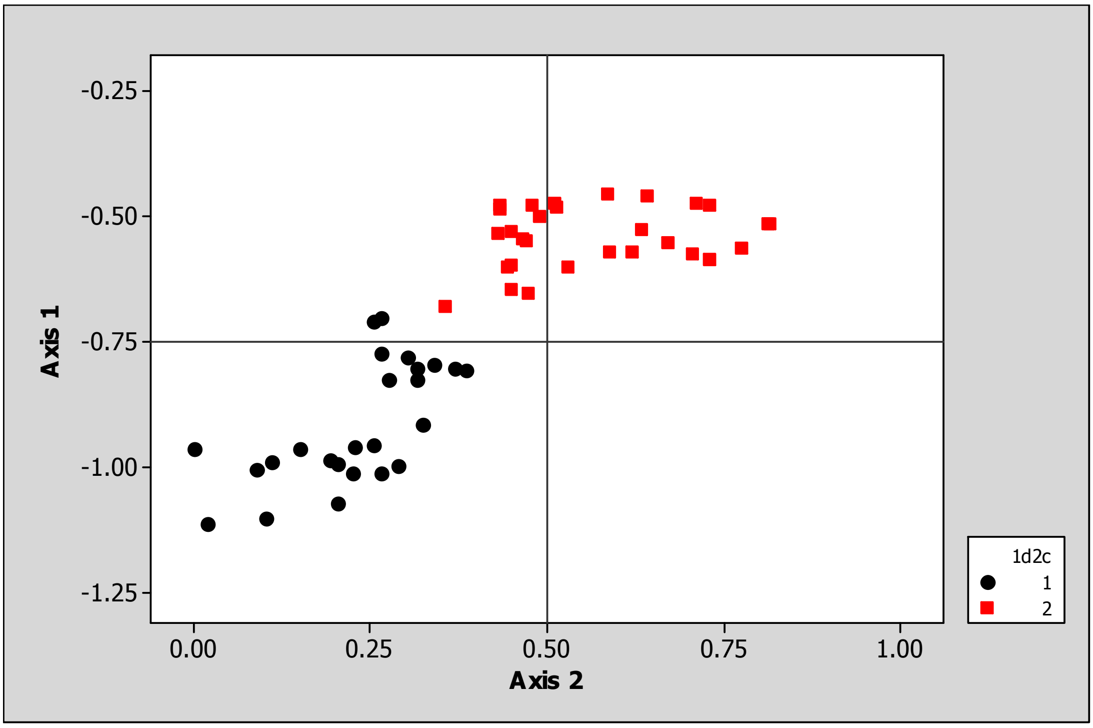

Figure 21. Two dimensional ordination (1 = disturbed, 2 = control) of quadrats at the Queens Domain site (minimum stress = 0.266643).

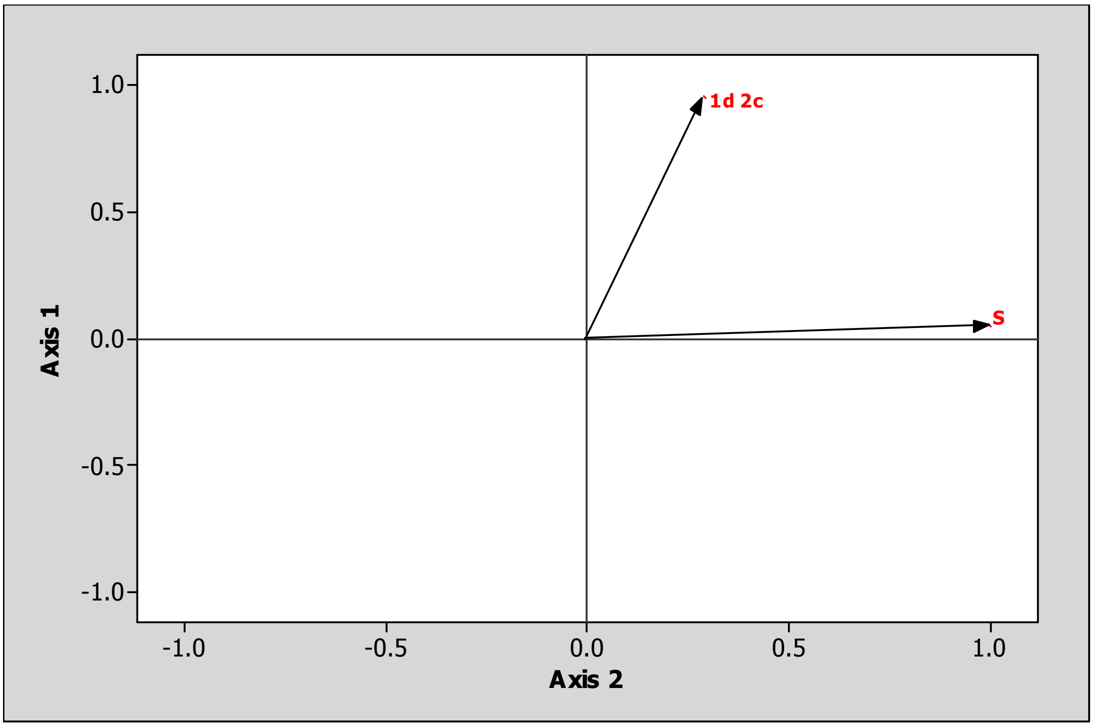

Figure 22. Vector fitting from the Queens Domain study site. S = slope, 1d2c = quadrats.

The results of vector fitting for the Queens Domain site are shown in Figure 22. One variable (1d 2c) is considered significant (R = 0.9043, P = <0.001). Slope appeared to have minimal effect and there was no effect of other variables at this site.

Soils

The soil was more acid within the control quadrats (p = <0.001) than the disturbed ground, but otherwise very similar (Table 6).

Table 6. Mean values of soil analyses obtained from the Queens Domain study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	5.52 (0.041)	0.47 (0.053)	11.92 (1.5)	6.63 (1.4)	14.8 (3.3)
Control	4.92 (0.053)	0.45 (0.055)	11.54 (1.3)	9.3 (1.2)	20.76 (1.8)
T	-8.87	-0.32	-0.19	1.42	1.59
P	<0.001	0.75	0.853	0.173	0.136

Species distribution within grassy ecosystems

From the 75 species recorded within the grasslands and grassy woodlands study sites (see Appendix A and Appendix B for details), *Themeda triandra* and *Cirsium vulgare* were present in the disturbed and control quadrats at all sites.

The ANOSIM results (Table 1, Table 3, Table 5, Table 7), indicate that significant differences exist in species composition by treatment between the disturbed and control areas at all sites investigated. Of the species that significantly differed between the disturbed area and the control, a total of eight were present only within the control, six were present only within the disturbed quadrats and 10 were present in both the control and disturbed quadrats. The deep rooted perennial grass, *Themeda triandra*, varied significantly between the control and disturbed areas at all study sites and was more abundant in the control. Within the disturbed quadrats, *Austrodanthonia* spp. was more abundant than in the control at the Campbelltown Hospital and Queens Domain sites, *Austrostipa* spp. was more abundant at the Campbelltown Hospital and Fosterville sites and *Sonchus asper* was more abundant at the Fosterville and Queens Domain study sites (Table 7).

Table 7. Summary of significant differences in frequencies of taxa between disturbed and control areas. C = more abundant in control, D = more abundant in disturbed, - = absent, insignificant or not tested, * = non-native species. CT = Campbelltown Hospital, F = Fosterville, QD = Queens Domain.

	Site		
Taxon	**CT**	**F**	**QD**
Austrostipa spp.	D	D	-
Austrodanthonia spp.	D	-	D
**Sonchus asper*	-	D	D
**Plantago lanceolata*	D	-	-
Poa labillardierei	D	-	-
Eucalyptus amygdalina	D	-	-
Juncus spp.	D	-	-
Lomandra longifolia	D	-	-
**Aira caryophyllea*	-	D	-
**Bromus catharticus*	-	D	-
**Cynosurus cristatus*	-	D	-
**Leontodon taraxacoides*	-	D	-
**Oxalis corniculata*	-	D	-

Taxon	Site CT	F	QD
Pteridium esculentum	-	D	-
**Fumaria bastardii*	-	-	D
Themeda triandra	C	C	C
**Picris* spp.	C	C	-
**Agrostis capillaris*	C	C	-
Poa rodwayi	-	C	C
Gonocarpus tetragynus	C	-	-
**Briza minor*	-	C	-
Plantago varia	-	C	-
Acianthus caudatus	-	C	-
**Poterium polygamum*	-	-	C

Of the 24 species shown above in Table 7, twelve are non-native. The non-native species are concentrated in neither the disturbed area nor the control. A total of four species were more common in the control while eight were more common within the disturbed areas (Table 7).

The ordination diagram (Figure 23) indicates that a closer relationship exists within each group (i.e. individual study sites) rather than between them. No evidence exists to suggest a continuum currently exists between the study sites. The control quadrats at all sites occupy a larger area in ordination space than the disturbed. This indicates a greater difference in composition exists between the control sites compared to the disturbed areas (Figure 23).

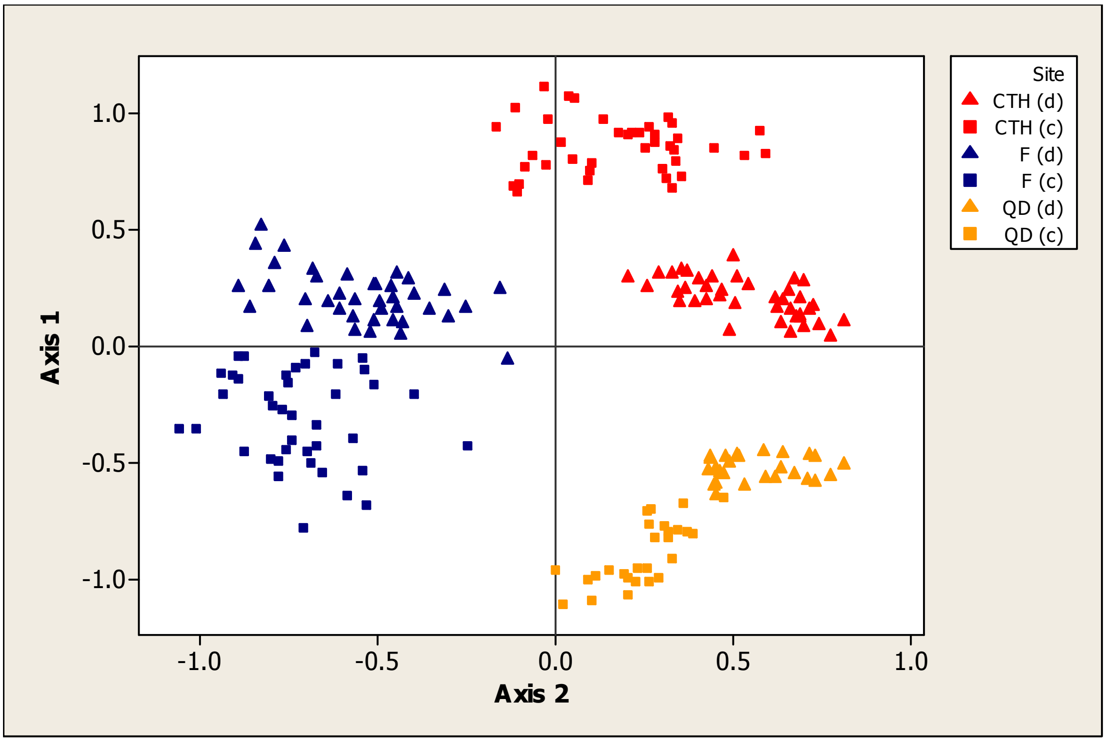

Figure 23. Ordination of quadrats from within all study sites in grassy ecosystems. Legend: CTH = Campbelltown Hospital; F = Fosterville; QD = Queens Domain; (d) = disturbed; (c) = control.

Soils

Soil analyses from the three grasslands study sites have indicated that with the exception of phosphorus, there are significant differences in measured soil properties at all sites examined (Table 8).The pH values were significantly different between the disturbed and control only at the Fosterville and Queens Domain sites. The Campbelltown site exhibited significant differences only in the nitrogen and N:C values while the Fosterville site was significantly different in pH, carbon and N:C values (Table 8). At the Queens Domain study site, pH was the only significantly different property and the higher value was obtained from the disturbed area (Table 8). Although this may be a result of fertiliser addition it may also relate to the type and level of initial disturbance. It is known that disturbance at Queens Domain was less intensive than the other sites and differences may be partially explained by variation in soil type as outlined by Kirkpatrick and Gilfedder (1999), Mokany et al. (2006), DPIPWE (2009) and others. Although it is accepted that disturbance in grasslands and grassy woodlands can be necessary for the maintenance of species diversity (Gilfedder and Kirkpatrick, 1994, Lunt, 1997, Kirkpatrick et al., 2005, Lewis et al. 2010), the capacity for soil types to support different communities may also requires consideration within a management context.

Table 8. Significant soil properties at all grasslands and grassy woodlands study sites. Significant differences and the higher values are denoted by D (disturbed) or C (control) at each study site. A missing value indicates no significant differences. Study sites: CTH = Campbelltown Hospital; F = Fosterville; QD = Queens Domain.

	Study site		
Property	**CTH**	**F**	**QD**
pH	-	D	D
N	D	-	-
P	-	-	-
C	-	C	-
N:C	D	D	-

Soil pH was significantly different at the Fosterville and Queens Domain study sites with the higher values recorded in the disturbed areas (Table 8). This may be a result of the disturbance history (both sites have been ploughed) and it might be reasonable to suggest that some mixing of the soil horizons may have occurred thus, influencing local soil pH values.

Significant differences in nitrogen levels were found only at the Campbelltown Hospital site with the higher value recoded within the disturbed area. (Table 8).This site has been subjected to less intense disturbance than the other sites and it seems likely that nitrogenous fertiliser may have been applied in an effort to encourage vegetation growth. Accordingly, this may partially explain the higher levels of nitrogen found within the disturbed area at this site.

There were no discernable differences in phosphorous between the disturbed and control areas at any of the sites examined (Table 8) while significant differences with soil carbon, between the disturbed area and control, were recorded at the Fosterville site, with the higher value recorded within the control (Table 8). The N:C ratio was higher in the disturbed than the control area at both the Campbelltown Hospital and Fosterville sites.

Discussion

Changes in soil properties caused through anthropogenic disturbance are well documented (e.g. Vitousek et al., 1979, Vitousek and Matson, 1985; Adams and Attiwill, 1988, 1991; Rab, 1994; Wang et al., 1998; Evans and Belnap, 1999; Holmes and Zak, 1999; Knops and Tilman, 2000; Moroni et al., 2002; Murty et al., 2002). The physical soil disturbance from land use practices that occurred at the three grassland sites has produced differences from the control that could be expected given the nature of the soils, which typically have free calcium in the lower horizons (see Cotching, 2009) leading to an increase in surface soil pH when ploughed, as at Fosterville and the Domain. In contrast, the Campbelltown hospital site was largely disturbed by the addition of buildings and the deposition of wastes associated with them (e.g. Specht et al., 1974; Tiller, 1992; Ahel et al., 1998; Kingery et al., 1994; Van der Sloot et al., 1996; Grieve, 2001; Meuser and Van der Graaf, 2011), rather than mixing of the soil. It is therefore, not surprising that N is higher here than in the controls, but not at the other two sites. The higher N:C ratios in the disturbed soils rather than within the control soils at the Fosterville site could be another product of ploughing, which not only mixes surface soil organic material to depth, but also causes its oxidation (see for example: Harpstead et al., 2001; White, 2006; Paul, 2007; Rayment and Lyons, 2011).

The high component of nitrogen-fixing species in grassy ecosystems ensures little difference between ploughed and unploughed land. Although, there is a scarcity of published literature related to this, one study by Willems et al. (1993) found that if nitrogen was omitted from experimental plots, nitrogen-fixing species exhibited a tendency to increase in abundance. Accordingly, this may partially explain the lack of differences in soil nitrogen between ploughed and unploughed land at Fosterville and the Queens Domain sites. At the Campbelltown Hospital site the higher level of the N:C ratio in the disturbed soils may relate to their anthopogenically-induced high nitrogen levels. The relative distributions of native grass genera between the disturbed and control areas is consistent with previous observations, in that *Themeda* and *Poa* are not favoured by disturbance while *Austrodanthonia* and *Austrostipa* can prosper as a result of it (e.g. Specht, 1970; McIntyre, 2002; Lunt and Morgan, 1999; 2002; Foster, 2001; Prober et al., 2002; Cole et al. 2005; Lenz and Facelli, 2005).

The re-establishment of the deep-rooted perennial dominant C4 grass, *Themeda triandra*, within disturbed areas is important for the restoration of native grasslands (e.g. Adair and McDougall, 1987; Phillips, 1999; McDonald, 2000). As at the three study sites, Tunstall and Edwards (1995) record recolonisation by the perennial grass, *Themeda triandra*, in areas that had been ploughed or otherwise disturbed. This colonisation is slow, less than 2.0 m per annum (O'Connor and Everson, 1998), a speed consistent with an invasion from west to east with the prevailing winds of the species in the disturbed area at the Domain. The observation of Hagon (2006) that establishment of *Themeda triandra* in disturbed areas is unaffected by the presence of weed species is consistent with the data from all three sites.

Mechanical ploughing and associated fertilisation are among the most damaging disturbances for native grassy ecosystems (Stuwe 1986; Lunt 1991; Kirkpatrick et al. 2005), although the work of Lewis et al. (2009) shows, along with the present study, that ploughing by itself can be followed by recovery. In an African study, Belsky (1986) previously demonstrated that recovery of ploughed areas was not affected by the presence of non-native species which were hypothesised to prolong the early stages of succession.

Disturbance tends to favour a set of widespread, well-dispersed ruderal species, whereas many of the species that dominate in the recent absence of disturbance are more local competitors, finely adjusted to a limited range of conditions. These relationships mean that disturbance results in a reduction of intersite variability, as was evident in Figure 19. A similar phenomenon occurs after fire in alpine vegetation (Kirkpatrick and Dickinson, 1984).

Chapter 4 - Dry Sclerophyll Forest

Introduction

Dry sclerophyll forests within Tasmania occur mainly within the South East and Ben Lomond bioregions with some areas extending into the Central Highlands, Flinders, Northern Midlands, Northern Slopes, and Southern Ranges bioregions (Figure 24). Dry sclerophyll forest is usually dominated by eucalypt species and occasionally by *Callitris* species or *Allocasuarina verticillata*. It is typically characterised by a multi-layer under storey dominated by scleromorphic species (Duncan, 1999). There are affinities between Tasmanian dry sclerophyll forest and woodlands and those in other parts of Australia (Duncan, 1999).

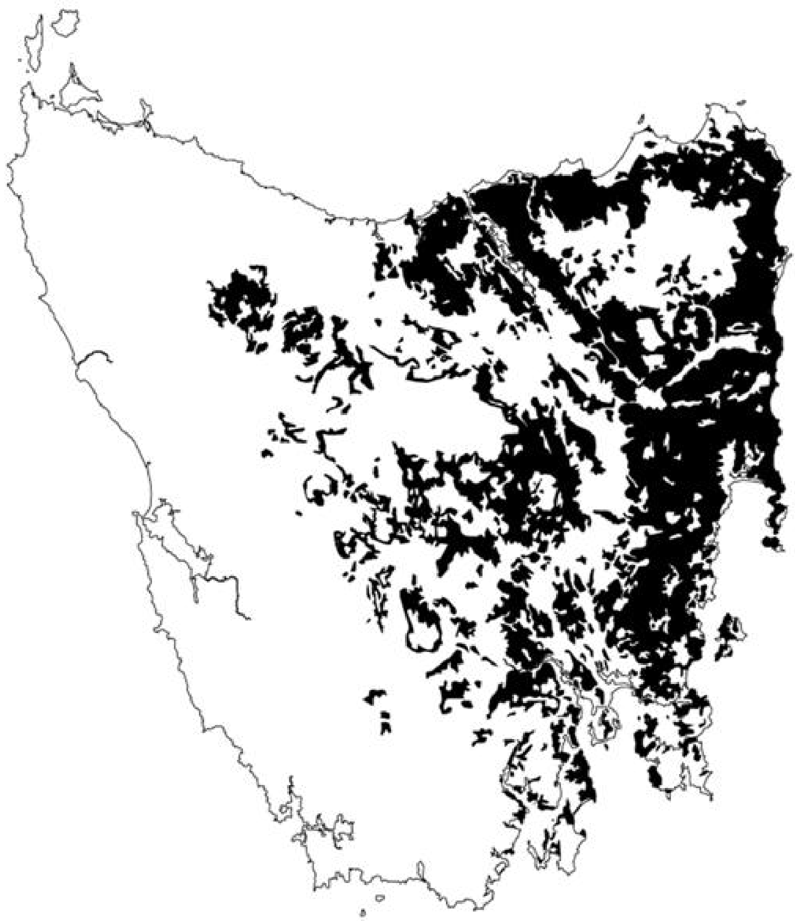

Figure 24. View of Tasmania showing the distribution of dry sclerophyll forest types. Image Source: Forest Education Foundation, 2007.

At a broad scale, soil fertility within dry sclerophyll communities of Tasmania is often low (particularly phosphorus, nitrogen and trace elements) when compared to other areas (i.e. Beadle, 1968, 1981; Specht, 1972, 1981; Reid et al., 1999). Many plants within these areas of low soil fertility have shown adaptations to optimise absorption and use of soil nutrients (Bowen, 1986). Nutrients can be effectively stored in underground rhizomes, lignotubers and other subsurface vegetative organs and these enable regeneration following disturbance events such as fire, browsing or unfavourable seasons (Duncan, 1999).

Fires are more frequent within dry sclerophyll communities than rainforest or wet sclerophyll forest. The physical attributes of some species allow survival after fire, with some being fire-promoting (Gill, 1975; Mount, 1979; Ashton, 1981; Dickinson and Kirkpatrick, 1985; Tolhurst, 1996; Cremer, 2004). Many dry sclerophyll species produce large quantities of seed which can remain viable for long periods until disturbance or fire induces germination responses (Purdie, 1977a,b; Gill, 1981; Ashton, 1986; Auld and O'Connell, 1991; Enright et al., 1997). Many Tasmanian dry sclerophyll species (i.e. most of those in the Proteaceae and Myrtaceae) have woody capsules from which seed is released after fire. Many, in particular *Eucalyptus* species, recover vegetatively following fire from lignotubers or epicormic buds (e.g. Purdie, 1977; Guo and Sinclair, 1993; Bellingham and Sparrow, 2000; Knox and Clarke, 2005).

Dry sclerophyll forest communities generally fall within the woodland and open-forest structural classes of Specht (1970). Variation in species composition and structure of these communities is related to geology and soil type (Beadle, 1968; Specht, 1970; Gill, 1981), climate (Gillison and Walker, 1981; Duncan, 1999), and fire history (Jones, 1969; Gill, 1975; Purdie, 1977a,b; Mount, 1979; Shea et al., 1979; Ashton, 1981; Specht, 1981; Dickinson and Kirkpatrick, 1985; Florence, 1996; Neyland and Askey-Doran, 1996; Duncan, 1990, 1999; Jurskis, 2005). Generally, dry sclerophyll communities are multi-aged stands of eucalypts with an understorey consisting of hard leaf shrubs, grasses, sedges and bracken fern (Forest Education Foundation, 2010). However, the Forest Education Foundation (2010) has indicated that on exposed coastal areas, dry sclerophyll forest can also be dominated by she-oak (*Allocasuarina* spp.) or Oyster Bay Pine (*Callitris rhomboidea*).

According to Duncan (1999), dry sclerophyll forests have been subjected to more irreversible damage than other forest types in Tasmania. Many of these communities contain rare species yet they are poorly reserved and threatened by modification for agriculture activities and settlement (Duncan, 1999). A recent report by Balmer et al. (2004) suggests that 714 076 ha of dry forest types are present in Tasmania, of these, only 18 337 ha are securely reserved within the Tasmanian Wilderness and World Heritage Area (TWWHA). An additional 28 862 ha are reserved elsewhere in secure conservation reserves outside the TWWHA (Balmer et al., 2004).

Previously, Mount (1979) suggested that the flammable nature of litter from most dry sclerophyll vegetation is likely to encourage a natural fire frequency between 4 – 20 years, a range consistent with data from fire scars from the Eastern tiers (von Platen et al. in press). However, the variation in fire frequency has more recently been explained by variation in characteristics of the understorey (e.g. Duncan, 1999). Accordingly, the natural fire frequency will be lowest in those areas where there is greater moisture availability and higher in areas where drier conditions exist. In some dry sclerophyll communities, particularly in lower rainfall areas, productivity may be reduced and there will generally be lower levels of fuel (litter) present. As a result, expected fire frequency would normally be lower.

In other areas of Australia, a study by Cole et al. (2008) has evaluated sites in the Ravensworth State Forest near Newcastle with respect to their potential for natural recovery and thus, their restoration and reconstruction. This is a long term study that is investigating the removal of barriers such as logging and grazing that are limiting natural regeneration processes. An important component of this research has shown that after a 14 year period, a dry sclerophyll understorey is establishing in some parts and is comprised of a number of genera from Mimosaceae, Fabaceae and Asteraceae. In addition, this study has considered '…*the development of ecological models to determine inhibiting factors to ecosystem development*' and suggests that the models should be readily transferable to other regions.

Other studies within the Victorian Goldfields region have investigated ecological restoration in Box and Ironbark forests following disturbance from mining (see Bellette, 1998, 1999). Although the study by Bellette (1998) investigated active restoration, it showed that an understanding of rehabilitation within disturbed post-mining landscapes in these areas is still in its infancy. Thus, a need to understand processes of regeneration following disturbance within these landscapes will help inform natural resource management agencies to make better informed strategic decisions (Zerger and Filmer, 2008).

The validity of relay floristic successional models in Australian dry sclerophyll communities has been challenged (e.g. Purdie and Slatyer, 1976; Noble and Slatyer, 1981). A study by Purdie (1977) found that succession typically follows an initial composition model in which the majority of species that will eventually be dominant following disturbance will be present immediately after the disturbance. There are few studies that have focussed on this within a Tasmanian context and therefore, the regeneration potential of these communities. A study by Dickinson and Kirkpatrick (1987) in major types of eucalypt forest found that rates of change in species cover were significantly greater in burnt areas compared to clearfelled and control areas. In addition, Ross et al. (2002) found that the effects of anthropogenic disturbance and fragmentation reduced native species richness and enhanced weed invasion while in contrast, fire tended to promote native species richness but did not increase non-native species richness.

There are many factors that may potentially inhibit or enhance the natural recovery of degraded communities following disturbance. These include the type and severity of initial soil disturbance, rainfall patterns and other edaphic factors. For example, Fox et al. (1996) found that canopy cover increased with time since disturbance on 17 year old cleared and mining sites and was comparable to the cover of 11 year old burnt sites. After 17 years of regeneration, the vegetation structure of cleared and sand mined sites did not resemble a pre-disturbance state (Fox et al. 1996).

Aim of Chapter

This chapter reports on six anthropogenically disturbed sites (Figure 25) in dry sclerophyll communities within the South East bioregion of Tasmania. Vegetation species composition and soils are compared between disturbed areas and adjacent undisturbed control sites.

Figure 25. Approximate location of all study sites within the eastern Tasmanian bioregion.

Methods

Study site selection

A total of six accessible sites with a known disturbance history located within dry sclerophyll communities in the South East bioregion were selected. An attempt was made to select sites with different environments and original vegetation types.

Overview of Study Sites and Brief History

Coles Bay

The Coles Bay study site is located approximately 120 km north east of the Hobart CBD on the Freycinet Peninsula. A linear disturbance at the Coles Bay study site was created during the construction of an underground telecommunications upgrade to service the town of Coles Bay. The disturbance is approximately 5 m wide and about 1 km long through the property that was accessed for the study site.

The region of Coles Bay receives approximately 600 mm rainfall per annum with a mean annual temperature of approximately 19ºC. Prior to disturbance, a coastal heath community dominated by species including *Acacia sophorae*, *Banksia marginata*, *Epacris impressa*, *Kunzea ambigua*, *Leptecophylla juniperina*, *Leptospermum scoparium*, and *Lomandra longifolia* was present (Figure 26). Field observations of *Banksia marginata* nodes suggest that the area had been burnt approximately 20 years ago.

Figure 26. View of undisturbed vegetation adjacent to the Coles Bay study site.

Climate

Rainfall data have been collected at by the Bureau of Meteorology at Coles Bay since 1961 and are considered to be reliable. The rainfall data indicate that the Coles Bay region receives a mean annual rainfall of 685.5 mm. Generally, rainfall is spread evenly throughout the year although long-term data suggests that the period from July to August is slightly wetter than most of the rest of the year. December is the wettest month with a mean rainfall of 74.1 mm. February is the driest month with a mean rainfall of 46.7 mm.

No temperature data are available for the Coles Bay area. Temperature conditions for the Coles Bay study site have been extrapolated from data collected at Friendly Beaches, approximately 14 km to the north. Data have been collected from this site since 1997.

The environmental lapse rate (Nunez and Colhoun, 1986) indicates that the annual mean daily maximum temperature is 19 ° C. The warmest months occur between December to February with a mean daily maximum temperature of 22.5 ° C. The coldest months occur from June to August with a mean daily minimum temperature of 14.3 ° C.

Geology and soils

The majority of the underlying geology within the Coles Bay region is composed of Devonian aged granitic material. Granite typically underlies most of the north of the east coast of Tasmania, with major outcrops occurring at Freycinet Peninsula (Coles Bay), Maria Island, and the Tasman Peninsula. The soils at the study site are mostly Pleistocene wind-blown sand over granite bed rock.

A typical soil profile at the study site comprises a shallow organic layer (less than 5 cm depth) with an A horizon (containing small amounts of partially decomposed organic matter) up to 10 cm depth. There is a slow gradation to a darker greyish medium grained sandy material until the B horizon is reached at approximately 50 cm below the surface.

Douglas Road

A former cherry orchard was established at the study site located in Douglas Road at Molesworth (Figure 27). It is located adjacent to an undisturbed mature dry sclerophyll forest. Following abandonment of the orchard, it appears that the area was sown with non-native grass species in order to create an improved pasture. Local evidence indicates that the orchard was established during the 1950s. Although the adjacent mature forest has been subjected to burning, it seems likely that the last significant fire event at this locality was in 1967. This also seems to be the most likely date when the orchard was abandoned.

Figure 27. Site of the disused cherry orchard at Douglas Road, Molesworth.

Climate

Rainfall data has been collected in close proximity to the Douglas Road study site since 1995. The mean annual rainfall is 538.4 mm. The data suggest that there is no particular seasonal pattern associated with rainfall and it tends to be sporadic and variable between successive years. Some of the driest periods in recent years have been recorded during the winter months while in contrast, some of the wettest months have been recorded during the summer period.

No temperature data are available for the Douglas Road area. Temperatures have been extrapolated from data at New Norfolk, approximately 6 km to the northwest. Climate data (rainfall) were collected at the New Norfolk site from 1873 to 1983. However, temperature data were only collected between 1965 and 1983. The environmental lapse rate determined by Nunez and Colhoun (1986) indicated that the annual mean daily maximum temperature at the Douglas Road study site is 16.4 ° C with the warmest months generally occurring from December to March with a mean daily maximum temperature of approximately 17.2 ° C. The coldest months are from June to August, with a mean daily minimum temperature of 6.1 ° C.

Geology and soils

The underlying geology at the Douglas Road study site is sandstone. The upper horizon of the soil consists of a shallow organic layer (< 5 cm) and this is underlain by light greyish sandy loam containing rocks up to 15 cm across and approximately 15 cm depth. Below 15 cm, there is a slow gradational change into coarser and slightly darker material in the B horizon.

Kettering

The study site at Kettering (Figure 28) is located approximately 37 km south of Hobart. Kettering is a coastal township near the D'Entrecasteaux Channel. During the early 1800s, the area was settled by Europeans. Prior to European settlement the 'Oyster Cove' tribe of Tasmanian Aboriginal people had inhabited the area. In the 1830s, the area attracted wood cutters because of the abundant forests which could be utilized to supply the growing settlement of Hobart. The study site is located within a broad area that has been previously utilised for timber harvesting. However, the study site at Kettering represents an area of recent land clearance and local evidence indicates that this occurred in 1983.

Figure 28. Regrowth of vegetation following disturbance at the Kettering study site. The main area of regrowth is directly behind the small shed on the left.

Climate

A weather station is located approximately 3 km north of the Kettering study site. Annual rainfall data has been collected at this station since 1908. Data for some years is incomplete. The mean annual rainfall within the immediate area is 872.6 mm. The wettest months occur from July to October with a mean monthly value of 84.2 mm. The driest months occur between January to March with a mean monthly value of 59.7 mm.

There is no local temperature data available for the study site and mean temperature values have been used from a weather station approximately 3 km north of the study site. The weather station is similar in elevation to the study site. Temperature data are only available for a four year period.

During the data collection period, mean daily maximum temperature was approximately 15 ºC. The warmest months are between December to March with a mean daily maximum temperature of approximately 20.5 ºC. The mean daily minimum temperature between May to August was 3.6 ºC.

Geology and soils

The underlying geology at the Kettering study site is Jurassic dolerite. The surface of the area has large rocks with some in excess of 30 cm across. The soil material has been subjected to some mixing between the different horizons but is generally a black clay loam with incorporated rocks up to 10 cm across.

Maria Island

Maria Island has been used for many activities. Whalers established camps on the island in the early 1800s. In 1825, a penal settlement was established by Lt Governor Arthur for '*convicts who committed offences in the colony, but whose crimes were not 'so flagrant a nature' that they should be banished to Macquarie Harbour*' but was abandoned in 1832. During 1842 - 1850, a convict probation station was established on the island. This was done to house convicts who, under the 1840s probation system, were '*…withdrawn from private service and congregated in government stations'*.

It was used as a base for the Italian entrepreneur Diego Bernacchi during the late 1800s and early 1900s. In 1884, Bernacchi secured a long term lease for the island and during this period Darlington became known as San Diego. A cement works was established in the late 1880s to take advantage of local limestone deposits. However, the enterprise failed and subsequent attempts to re-establish the operation in the 1920s were also unsuccessful after only a few years of operation.

At different periods since the 1830s, the island was utilized for sheep grazing and other agricultural purposes until declared as a National Park in 1972. Historical evidence suggests that the area of the study site was utilised for housing and /or accommodation (Figure 29). Presumably, some of the dwellings were built for settlers and may have also been used by Bernacchi to house staff.

Figure 29. View of the area near the Maria Island study site c. 1910. The study site is located adjacent to the buildings at the centre of the image. Source: unknown

Climate

Maria Island is strongly maritime because of its small size. Rainfall is generally spread evenly throughout the year but because of high evapo-transpiration, effective rainfall is greatest during the winter months (Parks and Wildlife Service, 1997). The mean annual rainfall at Darlington (study site location) is 667 mm with the highest rainfall occurring in June and the driest month being September.

There are no temperature data available for the study site. Data from the nearby township of Orford give a mean daily maximum temperature of 21.5 ° C. The warmest months are between December to February with a mean daily maximum of 21.4 ° C. The coldest months are from June to August with a mean daily minimum temperature of 10.3 ° C.

Geology and soils

Gradational black soils formed on Jurassic dolerite are found at the study site. The organic layer, depending on location and structure of the vegetation, is generally up to 5 cm depth.

The topsoil is generally a black clay loam and is less than 10 cm in depth. Large rocks up to 50 cm across and occasionally larger are incorporated into the soil profile and also occur on the surface.

Pottery Road

The site at Pottery Road, near Hobart is located within a disused small farm (Figure 30). The area is completely surrounded by dry sclerophyll forest. There has been mixing of topsoil and subsoil material at the site. The remains of some infrastructure and construction material (i.e. bricks, concrete) are still visible.

Figure 30. Undisturbed vegetation at the Pottery Road study site.

Climate

There are no local climate data available for the Pottery Road study site. However, several long term weather stations are in close proximity to the site. Data have been utilised from Strickland Reserve (collected between 1961 – 1990), approximately 1.5 km to the south of the study site.

Mean annual rainfall is approximately 960 mm with the wettest months being July to September with a monthly mean value of 94.6 mm. The mean daily maximum temperature is 16.9 ºC. The warmest months are between December and March with a mean daily maximum temperature of 21.1 ºC. The coldest months occur between June and August with a mean daily minimum temperature of 5.0 ºC.

Geology and soils

The soils present at the Pottery Road study site are podzolics formed on Permian mudstone (DPIWE 2001). Generally, the topsoil is shallow (less than 10 cm) and is fine grained semi-consolidated material. It has a greyish texture and contains small angular to sub-angular fragments up to 3 cm across.

It is likely that the soils present at this site would become hydrophobic after a short period of dryness. The subsoil and other layers are not particularly well horizonated and parent material is reached a short distance (10-20 cm) below the surface.

Wyre Forest Road

A recently cleared small area in Wyre Forest Road at Molesworth is surrounded by native vegetation that has been subjected to frequent burning. Some non-native species have established within the study area as a result of the land owners attempt to establish improved pasture.

Since the project was abandoned there has been no attempt to stabilize or rehabilitate the area and all species present within the disturbed area have established through the processes of secondary succession. Shallow mudstone-derived soils are present over the entire site. Most of the original topsoil has either been eroded or removed by machinery during the clearing process in the disturbed area.

Figure 31. View of a section of the disturbance at the Wyre Forest Road study site.

Climate

There are no local climate data available for the Wyre Forest Road study site. However, rainfall data have been collected in close proximity to the study site since 1995 and is a reasonable approximation of local conditions. Mean annual rainfall is 538.4 mm and distributed evenly throughout the year with substantial inter-annual variability. This is identical to the nearby Douglas Road study site where some of the driest months in recent years have been recorded during the winter period. In contrast, some of the wettest months have been recorded during the summer.

Geology and soils

The majority of the Wyre Forest Road study site is underlain by Permian mudstone on which podzolic soils have formed. Some larger coarse sandstone rocks up to 20 cm across are present on the surface in the control area. The soil horizons are weakly defined and coarse sandy loam topsoil is generally less than 5 cm in total depth is present within most of the area. Some mixing of subsoil and topsoil has occurred as a result of ploughing in attempts to improve conditions for non-native pasture species and erosion has been severe in places.

Results

Coles Bay

Vegetation

A total of 39 species (36 native, three non-native) were recorded within 80 quadrats (disturbed = 40, control = 40) at the Coles Bay study site (Figure 32, Figure 33). Three taxa, *Leptocarpus tenax*, *Kunzea ambigua*, and *Leptospermum* spp. were common within both the control and disturbed quadrats. One taxon, the fern *Pteridium esculentum*, was recorded from all disturbed and control quadrats at this study site.

From the 39 species recorded, a total of 28 were present in the disturbed quadrats and 28 were present within the control. There were ten native taxa that occurred only within the control quadrats. One native taxon, *Epacris impressa*, was recorded within all control quadrats. There was one native taxon, *Melaleuca* spp., present within all control quadrats and this was also present within 39 quadrats in the disturbed area.

Figure 32. Vegetation recolonisation following disturbance at the Coles Bay study area in 2004.

Figure 33. Typical view of control area at the Coles Bay study site.

There were significant differences in species composition between the control and disturbed areas (ANOSIM, R =0.9652, P < 0.001). Among the species that varied significantly in their frequency by treatment, there were five taxa concentrated in the disturbed quadrats that were absent in the control (Table 9). The small tree, *Banksia marginata*, was confined to the control quadrats and one native grass, *Austrostipa* spp., was concentrated in the disturbed quadrats but also had a lower frequency in the control. The native tree, *Callitris rhomboidea* and native herbaceous plant, *Stylidium graminifolium*, showed the reverse tendency and were concentrated in the control quadrats while occurring at a lower frequency within the disturbed quadrats (Table 9). Details of species distribution are presented in Appendix A and Appendix B.

Table 9. Percentage frequency of all significant species at the Coles Bay study site (ordered by frequency in the disturbed column). * = non-native species.

Species	Control (% frequency)	Disturbed (% frequency)	X^2	P
Geranium spp.	0.00	100.00	80.000	<0.001
Leptospermum scoparium	0.00	70.00	48.000	<0.001
**Agrostis capillaris*	0.00	57.50	32.281	<0.001
Dillwynia sericea	0.00	52.50	28.475	<0.001
Acacia verticillata	0.00	25.00	11.429	0.001
Juncus pallidus	5.00	70.00	36.053	<0.001
Leptospermum spp.	5.00	20.00	4.114	0.043
Oxylobium ellipticum	5.00	30.00	8.658	0.003
Austrostipa spp.	15.00	80.00	33.885	<0.001
Exocarpos strictus	15.00	37.50	5.230	0.022
Lomandra longifolia	45.00	12.50	10.313	0.001
Oxalis perennans	45.00	7.50	14.528	<0.001
Callitris rhomboidea	60.00	17.50	15.221	<0.001
Stylidium graminifolium	70.00	17.50	22.400	<0.001
Lycopodium deuterodensum	92.50	20.00	42.717	<0.001
Banksia marginata	77.50	0.00	50.612	<0.001

Results from the ordination (Figure 34) suggest that the disturbed area and control are separated into largely discrete groups. However, only a moderate relationship exists within the individual groups and the vegetation is more uniform in the control compared to the disturbed area.

Vectors obtained from the two dimensional solution (Figure 35) show that bare ground ($R = 0.903$, $P < 0.001$), litter cover ($R = 0.692$, $P < 0.001$), and disturbance ($R = 0.972$, $P < 0.001$) were significant in ordination space. Litter cover and disturbance were similar in direction while bare ground was in the opposite direction.

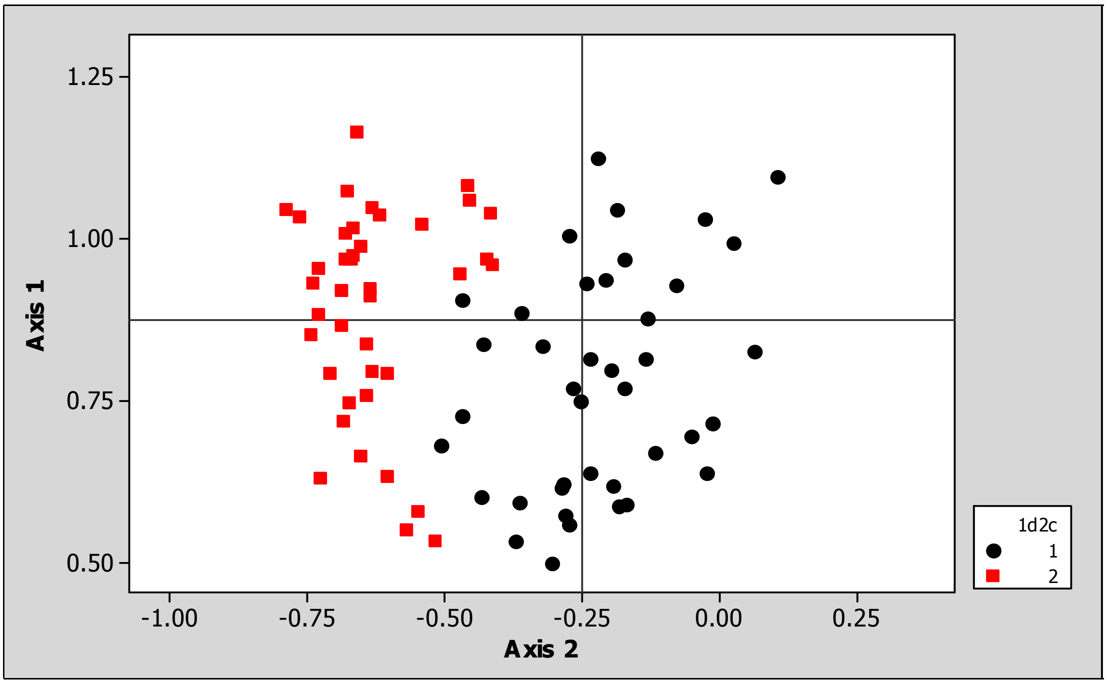

Figure 34. Ordination of quadrats (1 = disturbed, 2 = control) from the Coles Bay study site (minimum stress = 0.164910).

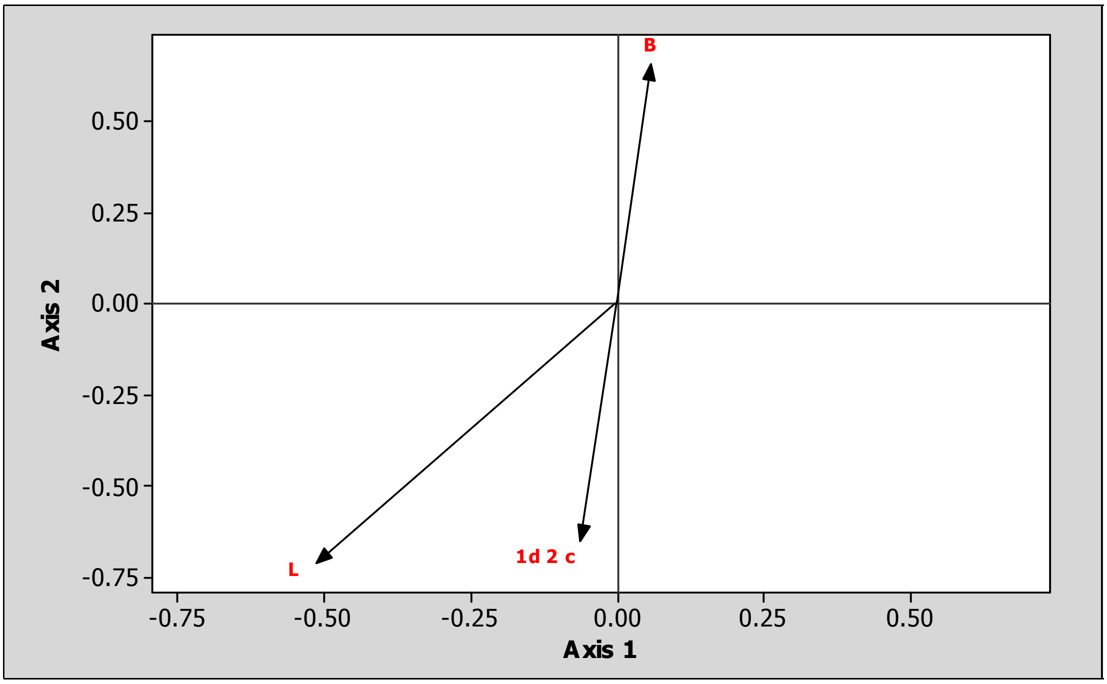

Figure 35. Significant vectors from the Coles Bay site. Legend: B = bare ground; L = litter cover; 1d2c = disturbance.

Soils

There were significant differences in soil properties between the disturbed and control areas for soil pH (P = <0.001), the percentage of soil nitrogen (P = 0.025), and the percentage of total carbon (P = <0.001) (Table 10). The soil was slightly more acid within the control and also contained a lower percentage of nitrogen and carbon.

Table 10. Mean values of soil analyses obtained from the Coles Bay study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	4.48 (0.05)	0.079 (0.008)	7.04 (2.0)	2.74 (0.13)	41.2 (8.9)
Control	4.16 (0.04)	0.062 (0.009)	5.93 (1.1)	1.5 (0.093)	50.2 (24)
T	4.92	-1.32	-0.48	-7.68	0.36
P	<0.001	0.025	0.639	<0.001	0.729

Douglas Road

Vegetation

A total of 32 species (26 native, 6 non-native) were recorded from within 80 quadrats (disturbed = 40, control = 40) at the Douglas Road study site (Figure 36, Figure 37). Of these, nine native species, *Acacia dealbata*, *Dichondra repens*, *Epacris impressa*, *Eucalyptus obliqua*, *Exocarpos strictus*, *Leptospermum scoparium Leptecophylla juniperina*, and *Pteridium esculentum* were common within both the control and disturbed quadrats. A total of 30 species occurred within the disturbed area and 22 within the control.

The disturbed quadrats contained a high frequency of *Acacia dealbata*, *Bursaria spinosa*, *Dodonaea viscosa*, *Eucalyptus globulus*, *Exocarpos strictus*, *Leptospermum scoparium* while others with a lower frequency included *Billardiera longiflora*, *Diplarrena moraea*, *Epacris impressa*, *Lissanthe strigosa*, *Pteridium esculentum*, *Senecio lineariifolius*, and *Themeda triandra*. Two non-native taxa, *Holcus lanatus* and *Senecio vulgaris* had a high frequency in the disturbed quadrats.

Figure 36. Colonising *Acacia dealbata* and developing dense ground cover layer dominated by *Pteridium esculentum* at the Douglas Road study site.

Figure 37. Typical view within the control area at the Douglas Road study site.

Species composition was significantly different between the control and disturbed areas (ANOSIM, R =0.8224, P < 0.001). Among the species that varied significantly by treatment, a total of 12 were confined to the disturbed quadrats (Table 11). There were no species that were confined to the control quadrats (Table 11). Two *Senecio* species (*S. vulgaris* and *S. leariifolius*) were concentrated within the disturbed quadrats but were also present in the control at lower frequencies.

Two native taxa, *Dillwynia glaberrima* and *Exocarpos strictus*, were recorded within all control quadrats. One native grass, *Austrostipa* spp., was concentrated in the disturbed quadrats but also occurred within the disturbed quadrats at a lower frequency (Table 11). Further details of species distribution are provided in Appendix A and Appendix B.

Table 11. Percentage frequency of all species that significantly differed between the disturbed area and the control at the Douglas Road study site. * = non-native species.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	X^2	**P**
Billardiera longiflora	0.00	75.00	50.612	<0.001
Diplarrena moraea	0.00	75.00	48.000	<0.001
Leptospermum scoparium	0.00	75.00	48.000	<0.001
Bursaria spinosa	0.00	67.50	40.755	<0.001
Themeda triandra	0.00	60.00	38.519	<0.001
Dodonaea viscosa	0.00	55.00	30.345	<0.001
Comesperma volubile	0.00	50.00	26.667	<0.001
**Acetosella vulgaris*	0.00	45.00	23.226	<0.001
Allocasuarina monilifera	0.00	30.00	14.118	<0.001
**Cirsium vulgare*	0.00	30.00	14.118	<0.001
**Geranium molle*	0.00	27.50	12.754	<0.001
Senecio linearifolius	10.00	60.00	21.978	<0.001
Austrostipa stipoides	12.50	42.50	9.028	0.003
**Senecio vulgaris*	30.00	85.00	24.757	<0.001
Exocarpos strictus	100.00	75.00	12.754	<0.001
Leptecophylla juniperina	87.50	62.50	6.667	0.010
Leptospermum scoparium	92.50	42.50	22.792	<0.001
Dillwynia glaberrima	100.00	25.00	48.000	<0.001

The quadrats from the Douglas Road study site have separated into two largely discrete groups in two dimensional ordination space (Figure 38).

The ordination diagram suggests stronger similarities within the control than the disturbed area. Consequently, vegetation is more uniform within the control than the disturbed area. Although the disturbed and control quadrats occupy different areas in ordination space, there is a slight overlap visible in the diagram (Figure 38).

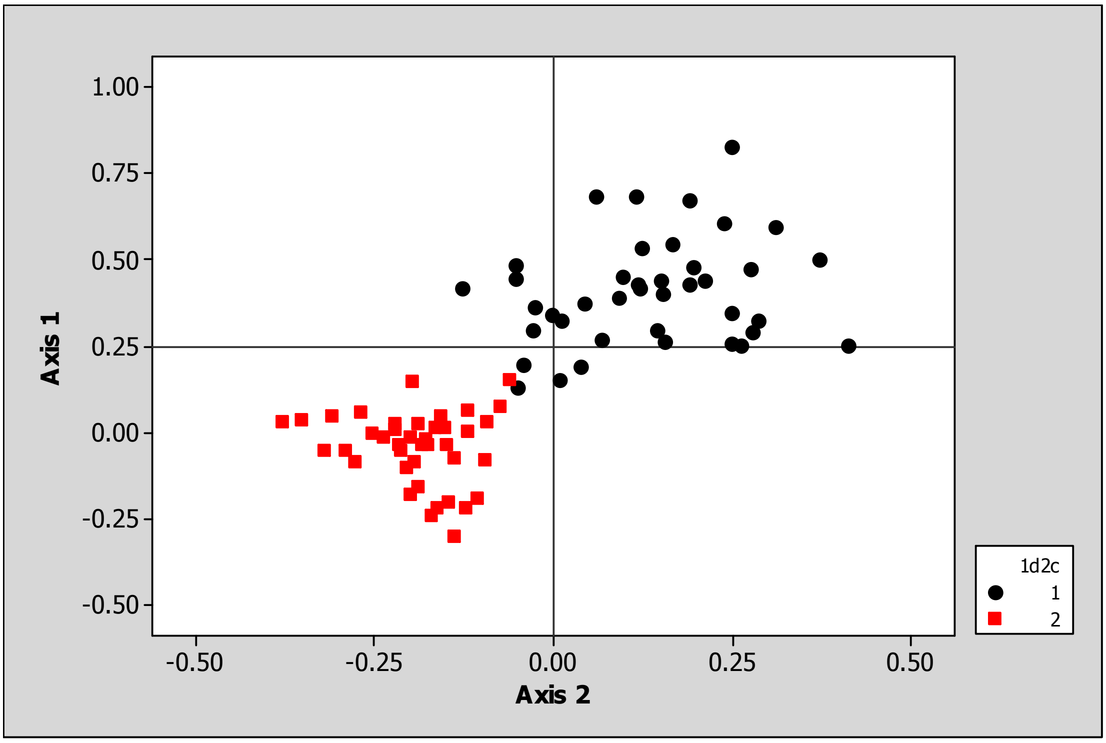

Figure 38. Ordination of quadrats (1 = disturbed, 2 = control) from the Douglas Road study site (minimum stress = 0.284972).

Vectors obtained from the two dimensional solution for the Douglas Road study site are shown in Figure 39. Elevation and rock cover were identical in direction. Slope was in a similar direction. Aspect and bare ground were opposite and similar in their direction. The disturbance vector was independent of elevation, litter cover, rock cover and slope.

Significant vectors (Figure 39) were aspect ($R = 0.677$, $P < 0.001$), bare ground ($R = 0.393$, $p = 0.020$), elevation ($R = 0.743$, $P < 0.001$), rock cover ($R = 0.492$, $P < 0.001$), slope ($R = 0.402$, $P = 0.006$), and disturbance ($R = 0.949$, $P < 0.001$).

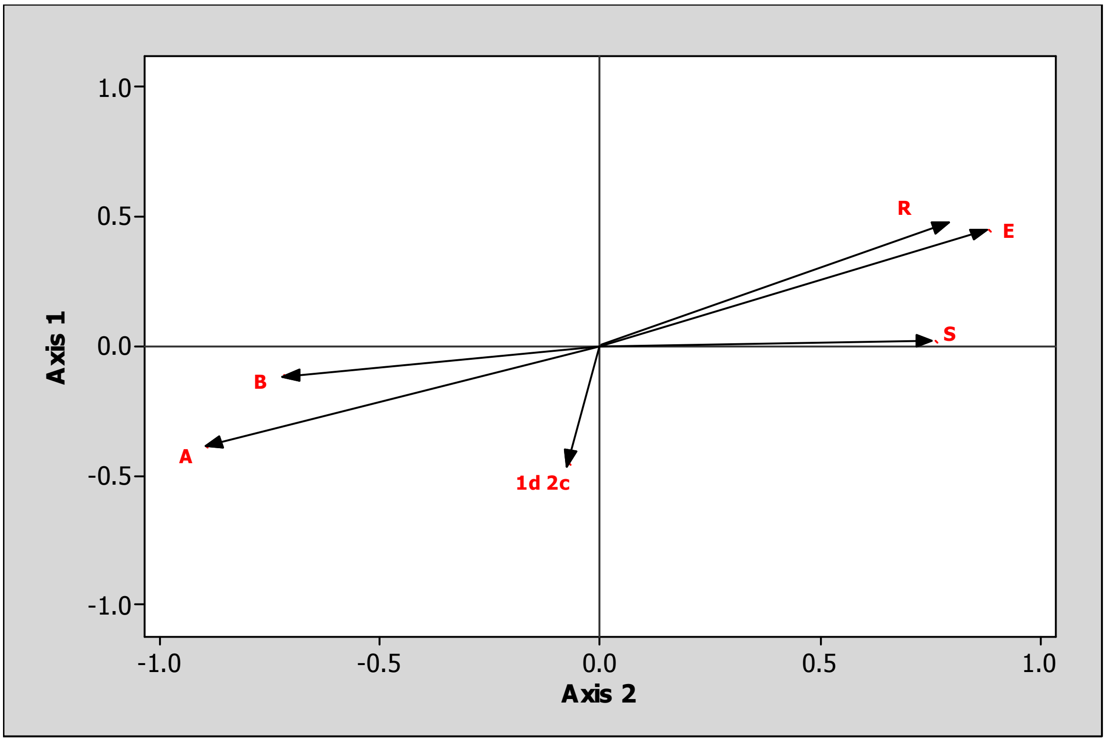

Figure 39. Vectors for the Douglas Rd study site. Legend: A = aspect; B = bare ground; E = elevation; R = rock cover; S = slope; 1d2c = disturbance.

Soils

There were significant differences in the nitrogen to carbon ratio (P = 0.016) between the control and disturbed area at the Douglas Road study site (Table 12). The nitrogen to carbon ratio was lower in the disturbed area than the control. No differences in soil pH, nitrogen, phosphorus and carbon were recorded between the two groups.

Table 12. Mean values of soil analyses obtained from the Douglas Road study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	4.28 (0.081)	0.248 (0.017)	7.80 (1.2)	5.64 (0.30)	23.33 (1.6)
Control	4.33 (0.079)	0.203 (0.014)	11.4 (3.3)	6.14 (0.42)	30.84 (2.3)
T	0.44	-2.10	1.01	0.97	2.69
P	0.665	0.051	0.336	0.347	0.016

Kettering

Vegetation

A total of 40 species (36 native, 4 non-native) were recorded from within 80 quadrats (disturbed = 40, control = 40) at the Kettering study site (Figure 40).

The vegetation at this site is generally multi-layered with a dense understorey (Figure 40). A total of six native taxa, *Dichondra repens*, *Dillwynia sericea*, *Exocarpos strictus*, *Glycine clandestina*, *Juncus pallidus* and *Pultenaea juniperina* were found to be common within both control and disturbed quadrats.

From the 40 species recorded at this study site, 31 were present within the control and 36 occurred within the disturbed area. One non-native species, *Centaurium erythraea*, had a high frequency within both the control and disturbed quadrats. There were no species recorded that were present within all quadrats in either the control or disturbed areas at this study site.

Three non-native taxa *Centaurium erythraea*, *Erica lusitanica* and *Senecio vulgaris* were recorded. *C. erythraea* is generally evenly distributed throughout the disturbed area and the control while *E. lusitanica* and *S. vulgaris* are confined to disturbed quadrats.

Figure 40. Secondary succession in the understorey at the Kettering study site.

Species composition was significantly different between the control and disturbed quadrats (ANOSIM, R =0.5035, P < 0.001). All species that varied significantly in their frequency by treatment, with the exception of *Exocarpos cupressiformis*, were mostly shrubs, graminoids and small herbaceous plants. Three native taxa, *Astroloma humifusum*, *Clematis aristata* and *Leptospermum* spp. were confined to the disturbed quadrats and two, *Correa reflexa* and *Exocarpos cupressiformis* were confined to control quadrats (Table 13). Further details of species distribution are provided in Appendix A and Appendix B.

Table 13. Percentage frequency of all species that significantly differed between the disturbed area and the control at the Kettering study site. * = non-native species.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	X^2	**P**
Clematis aristata	0.00	57.50	32.281	<0.001
Astroloma humifusum	0.00	25.00	11.429	0.001
Leptospermum spp.	0.00	16.00	20.000	<0.001
Lomatia tinctoria	20.00	55.00	10.453	0.001
Acianthus spp.	60.00	87.50	7.813	0.005
Pultenaea juniperina	62.50	85.00	5.230	0.022
Pultenaea daphnoides	75.00	100.00	11.429	0.001
Wahlenbergia spp.	75.00	45.00	6.373	0.012
Glycine clandestina	100.00	57.50	21.587	<0.001
Centaurium erythraea	65.00	30.00	9.825	0.002
Coprosma hirtella	35.00	0.00	16.970	<0.001
Exocarpos cupressiformis	62.50	0.00	36.364	<0.001
Correa reflexa	87.50	0.00	62.222	<0.001

The two dimensional ordination of the quadrats from the Kettering study site (Figure 41) shows a considerable overlap in ordination space. The control quadrats appear to be more similar to each other as suggested by the relatively smaller area occupied in ordination space. Accordingly, this indicates that vegetation is more uniform within the control than the disturbed quadrats. However, as shown in (Figure 41) there is a strong continuum that currently exists between the two groups at the Kettering study site indicated by overlapping of the control and disturbed quadrats ordination space.

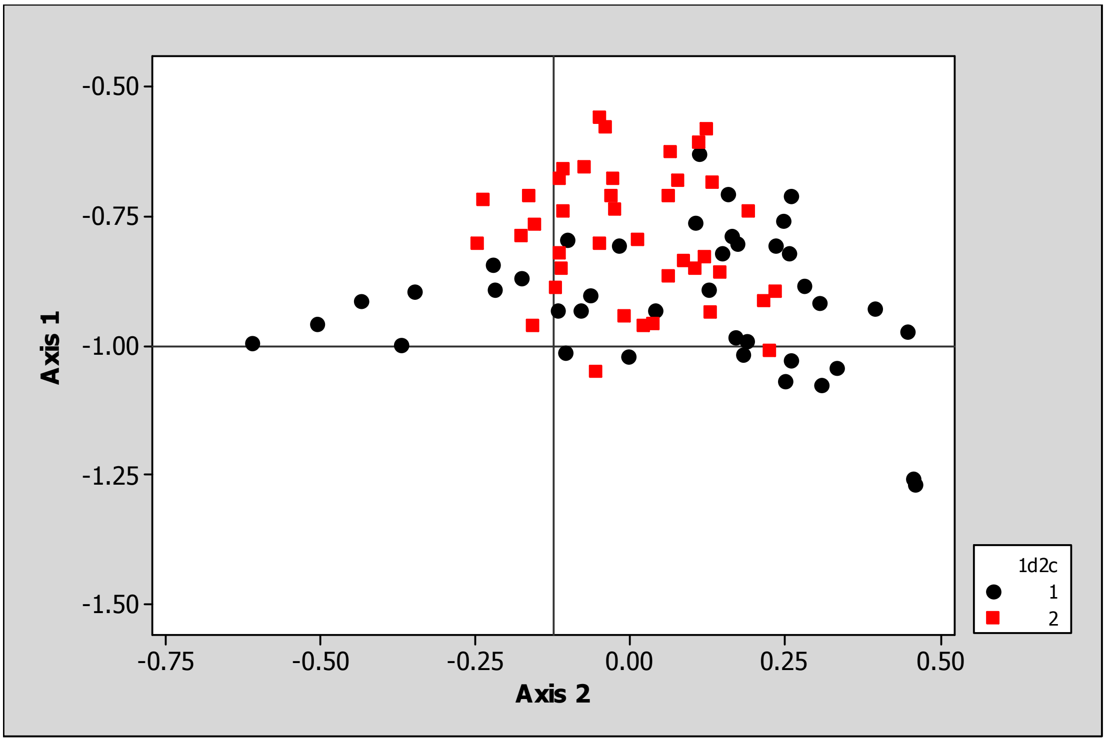

Figure 41**.** Ordination of quadrats (1 = disturbed, 2 = control) at the Kettering study site (minimum stress = 0.152905).

Vectors obtained for the two dimensional solution for the Kettering study site are shown below in Figure 42. Litter and slope were almost identical in direction. The direction of aspect, elevation and disturbed quadrats were in the opposite direction.

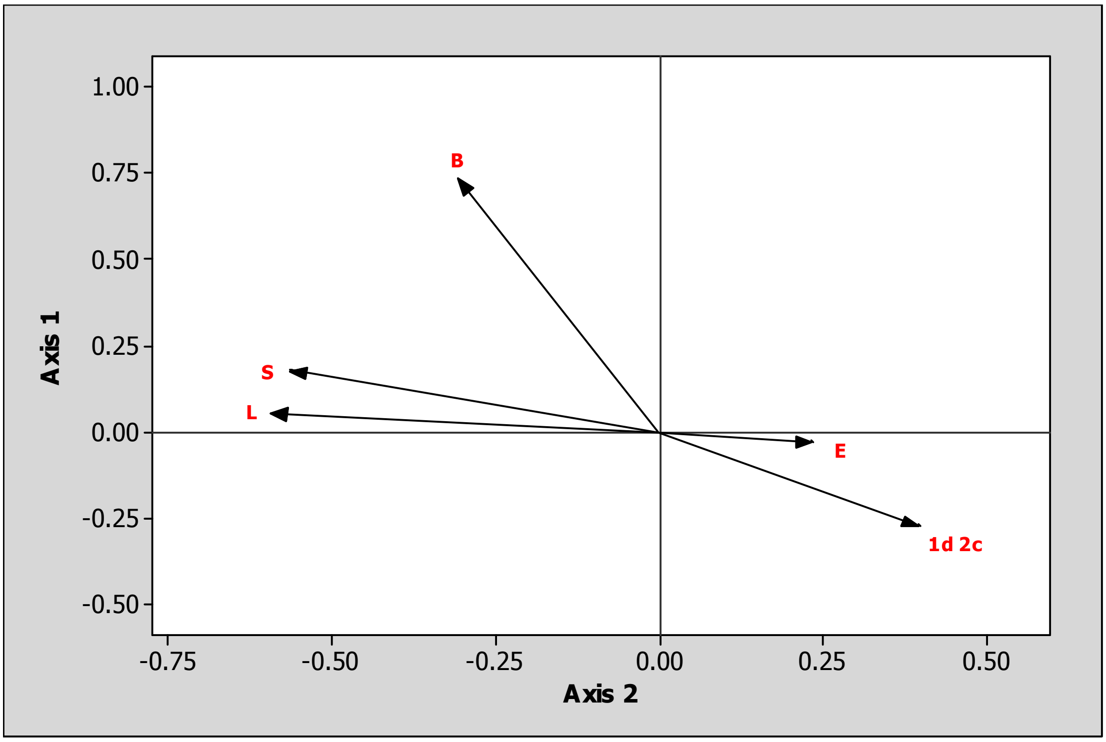

Figure 42. Significant vectors from the Kettering study site. Legend: B = bare ground; E = elevation; L = litter cover; S = slope; 1d2c = disturbance.

The significant vectors (Figure 42) were bare ground (R = 0.784, P < 0.001), elevation (R = 0.783, P < 0.001), litter cover (R = 0.515, P < 0.001), slope (R = 0.640, P < 0.001), and disturbance (R = 0.885, P < 0.001). There were no significant relationships with aspect and rock cover at this study site.

Soils

There was a significant difference in soil pH (P = <0.001) between the control and disturbed area at the Kettering study site (Table 14). At this site, the soil was more acidic within the disturbed area than the control.

Table 14. Mean values of soil analyses obtained from Kettering study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

	Mean Values of Soil Properties				
	pH	**N**	**P**	**C**	**N:C**
Disturbed	4.44 (0.067)	0.082 (0.027)	4.79 (0.77)	5.11 (0.85)	155 (48)
Control	5.18 (0.055)	0.108 (0.024)	6.27 (1.3)	4.32 (0.31)	91 (42)
T	8.51	0.70	0.96	-0.088	-1.02
P	<0.001	0.495	0.351	0.400	0.324

Maria Island

A total of 29 species (23 native, 6 non-native) were recorded from within 80 quadrats (disturbed = 40, control = 40) at the Maria Island site (Figure 43, Figure 44). From these, six taxa occurred only within the control area and 15 occurred only within the disturbed area. One taxon, *Cassinia aculeata*, was recorded from all control quadrats.

Of the 29 species recorded at the study site, 24 were present within the disturbed area. Two taxa, *Senecio vulgaris* and *Trifolium repens* were confined to the control while *Agapanthus praecox*, *Carduus tenuifolius* and *Plantago lanceolata* were confined to the disturbed area. There were no species recorded that had a high frequency within both the disturbed and control areas. Further details of species distribution are provided in Appendix A and Appendix B.

Figure 43. A section of the Maria Island study site showing the transition in vegetation type from the disturbed region in the foreground through to mature undisturbed forest in the background.

Figure 44. Remains of infrastructure at the Maria Island study site

Species composition was significantly different between the disturbed and control areas (ANOSIM, R =0.9634, $P < 0.001$). Among the species that varied significantly in their frequency by treatment, six taxa, *Cotula reptans*, *Euchiton* spp., *Hydrocotyle hirta*, *Lepidosperma lineare*, *Picris angustifolia*, and *Plantago lanceolata* were confined to the disturbed area (Table 15). With the exception of the graminoid, *Lepidosperma lineare*, all of these are herbaceous plants. Two taxa, *Acianthus* spp., and *Pomaderris pilifera* were confined to the control quadrats (Table 15).

Three species, *Austrostipa* spp., *Bursaria spinosa*, and *Verbascum virgatum* were concentrated within the disturbed quadrats but also occurred within the control quadrats at a lower frequency (Table 15). In contrast, five species, *Acianthus* spp., *Allocasuarina monilifera*, *Cassinia aculeata*, *Exocarpos strictus*, and *Glycine clandestina* concentrated within the control quadrats and also occurring in relatively low frequencies within the disturbed quadrats (Table 15). Further details of species distribution are provided in Appendix A.

Table 15. Percentage frequency of all species that significantly differed between the disturbed area and the control at the Maria Island study site. * = non-native species.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	X^2	**P**
Lepidosperma lineare	0.00	70.00	43.077	<0.001
**Plantago lanceolata*	0.00	40.00	20.000	<0.001
Euchiton spp.	0.00	65.00	38.519	<0.001
Cotula reptans	0.00	90.00	65.455	<0.001
Hydrocotyle hirta	0.00	30.00	16.970	<0.001
Picris angustifolia	0.00	27.50	12.754	<0.001
Cassinia aculeata	100.00	10.00	65.455	<0.001
Exocarpos strictus	75.00	7.50	37.602	<0.001
Allocasuarina monilifera	57.50	2.50	28.810	<0.001
Austrostipa spp.	20.00	75.00	26.467	<0.001
Glycine clandestina	50.00	2.50	23.309	<0.001
Bursaria spinosa	17.50	67.50	20.460	<0.001
**Verbascum virgatum*	15.00	55.00	14.066	<0.001
Pomaderris pilifera	60.00	0.00	34.286	<0.001
Acianthus spp.	72.50	0.00	45.490	<0.001

The two dimensional ordination of all quadrats from the Maria Island study site indicates that the control and disturbed quadrats are floristically distinct (Figure 45). The diagram suggests that there is a closer relationship within the two groups rather than between them and the vegetation is more uniform in the control. There is no evidence that a continuum currently exists between the control and disturbed groups.

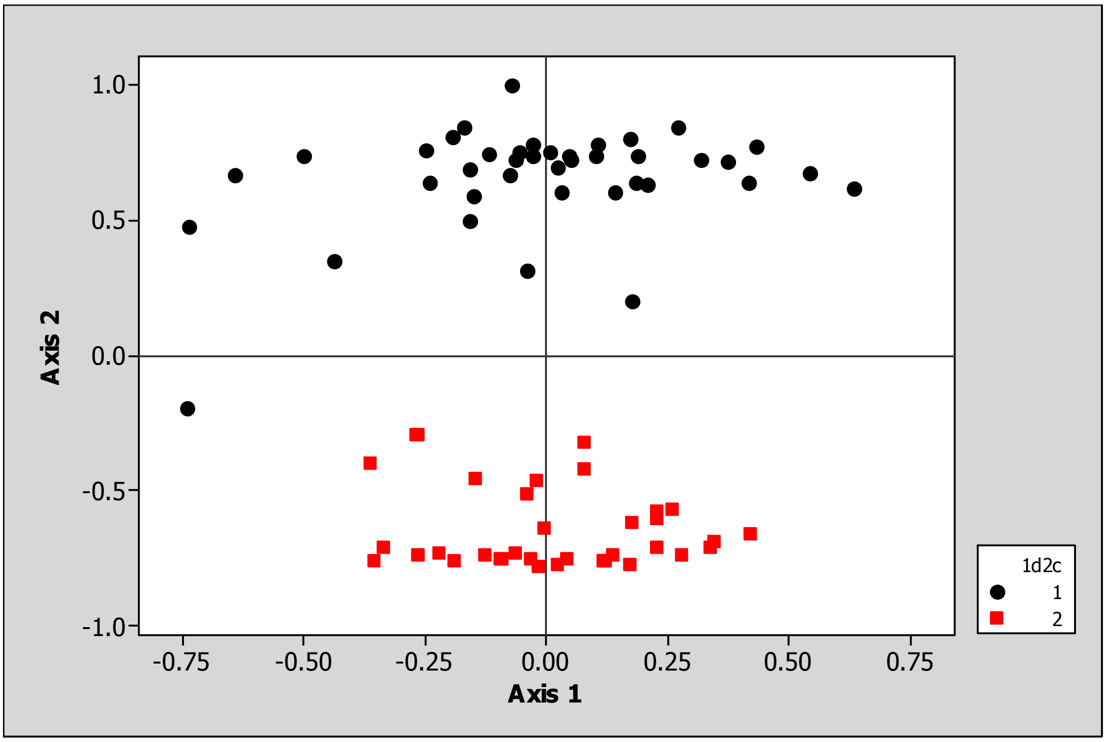

Figure 45. Ordination of quadrats (1 = disturbed, 2 = control) at the Maria Island study site (minimum stress = 0.196970).

Vectors obtained for the two dimensional solution for the Maria Island study site are shown below in Figure 46. Rock cover, litter and elevation were in similar directions. The disturbance vector was orthogonal to bare ground.

The significant vectors were bare ground ($R = 0.7006$, $P < 0.001$), elevation ($R = 0.7008$, $P < 0.001$), litter cover ($R = 0.772$, $P < 0.001$), rock cover ($R = 0.416$, $p = 0.004$), and disturbance ($R = 0.969$, $P < 0.001$).

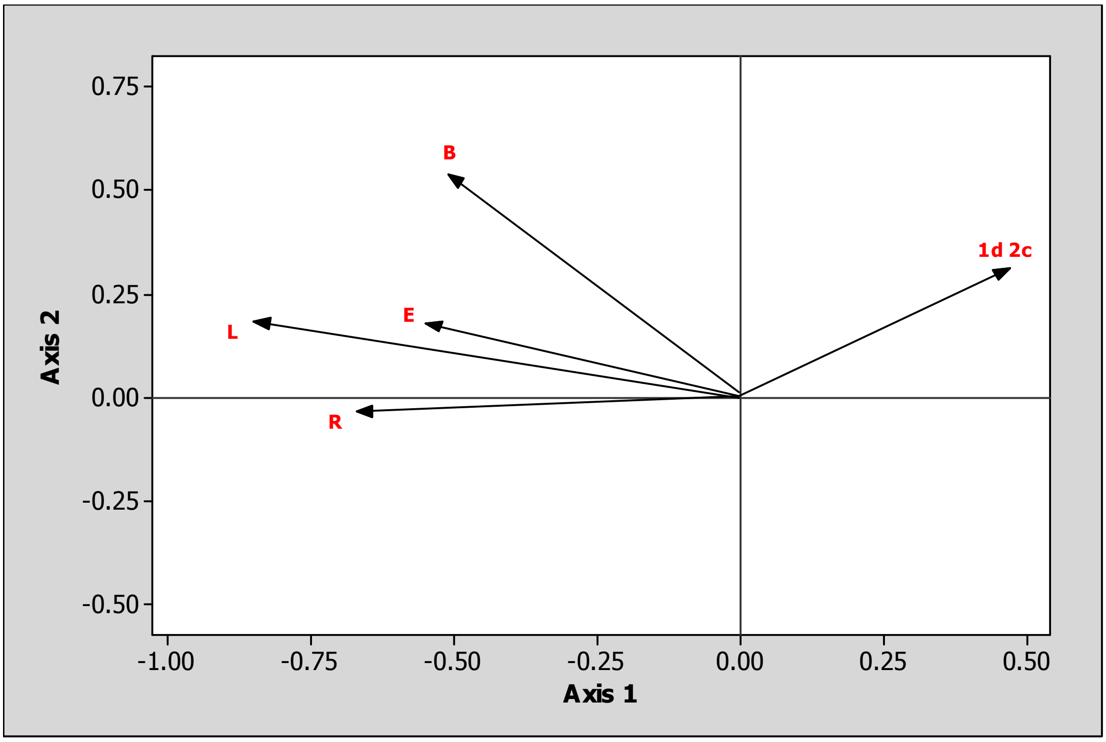

Figure 46. Significant vectors at the Maria Island study site. B = bare ground; E = elevation; L = litter cover; R = rock cover; 1d2c = disturbance.

Soils

There were no significant differences in measured soil properties between the control and disturbed area at this study site (Table 16).

Table 16. Mean values of soil analyses obtained from the Maria Island study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	5.2 (0.33)	0.29 (0.031)	7.37 (0.47)	4.56 (1.1)	21.7 (3.5)
Control	5.3 (0.33)	0.21 (0.025)	7.40 (1.2)	6.23 (1.1)	23.0 (4.0)
T	0.43	1.93	0.03	1.10	0.24
P	0.674	0.070	0.977	0.285	0.811

Pottery Road

A total of 50 species (43 native, seven non-native) were recorded from within 40 quadrats (disturbed = 20, control = 20) at the Pottery Road study site (Figure 47, Figure 48). Four native species, *Austrostipa* spp., *Diplarrena moraea*, *Exocarpos strictus*, and *Lepidosperma laterale* were common in the control and disturbed areas.

From the 50 species recorded, 44 were present within the control and 29 within the disturbed area. Two non-native species, *Senecio vulgaris* and *Acetosella vulgaris* were common within the control and disturbed quadrats with *A. vulgaris* present at a higher frequency within the control. Of the seven non-native species recorded, three taxa *Dactylis glomerata*, *Rumex crispus* and *Verbascum virgatum* were confined to the disturbed quadrats.

Figure 47. Vegetation recolonisation at the Pottery Road study site. Control area is in background.

Figure 48. General view of the disturbed area at the Pottery Road study site.

Species composition was significantly different between the control and disturbed areas (ANOSIM, R =0.9400, P < 0.001). Among the species that varied significantly in their frequency by treatment, seven were confined to the disturbed quadrats and six were confined to the control (Table 17). One taxon, *Allocasuarina verticillata*, occurred within all disturbed quadrats with one other tree, *Eucalyptus globulus*, also occurring at a high frequency within the disturbed quadrats (Table 17).

The native perennial species, *Senecio lineariifolius*, was confined to the disturbed quadrats and occurred at a high frequency (Table 17). The taxa, *Acetosella vulgaris*, *Epacris impressa*, *Glycine clandestina*, *Leptospermum scoparium*, and *Wahlenbergia stricta*, were concentrated within the control quadrats and also occurred within the disturbed quadrats at a lower frequency (Table 17). Further details of species distribution are shown in Appendix A and Appendix B.

Table 17. Percentage frequency of all species that significantly differed between the disturbed area and the control at the Pottery Road study site. * = non-native species.

Species	Control (% frequency)	Disturbed (% frequency)	X^2	P
Allocasuarina verticillata	0.00	100.00	40.000	<0.001
Senecio linearlifolius	0.00	90.00	32.727	<0.001
Eucalyptus globulus	0.00	75.00	24.000	<0.001
**Verbascum virgatum*	0.00	75.00	24.000	<0.001
Billardiera longiflora	0.00	65.00	19.259	<0.001
**Dactylis glomerata*	0.00	55.00	15.172	<0.001
**Rosa rubiginosa*	0.00	55.00	15.172	<0.001
Lepidosperma laterale	50.00	85.00	5.584	0.018
**Acetosella vulgaris*	80.00	40.00	6.667	0.010
Glycine clandestina	100.00	50.00	13.333	<0.001
Leptospermum scoparium	90.00	25.00	17.289	<0.001
Wahlenbergia stricta	65.00	15.00	10.417	0.001
Epacris impressa	75.00	15.00	15.545	<0.001
Brachyscome spp.	50.00	0.00	13.333	<0.001
Olearia argophylla	50.00	0.00	13.333	<0.001
Tetratheca glandulosa	50.00	0.00	13.333	<0.001
**Ulex europaeus*	50.00	0.00	13.333	<0.001
Juncus pallidus	60.00	0.00	17.143	<0.001
Lomandra longifolia	60.00	0.00	17.143	<0.001

The two dimensional ordination of quadrats from the Pottery Road study site (Figure 49) suggests that the control and disturbed areas occupy separate areas in ordination space. The diagram shows that there is only a weak relationship between the quadrats within the two individual groups. There is no evidence to suggest that a continuum currently exists between the disturbed and control quadrats at this study site.

Vectors obtained for the two dimensional solution for the Pottery Road study site are shown below in Figure 50. Numerical analysis indicates that significant vectors at the Pottery Road study site were elevation ($R = 0.964$, $P < 0.001$), and disturbance ($R = 0.964$, $P < 0.001$).

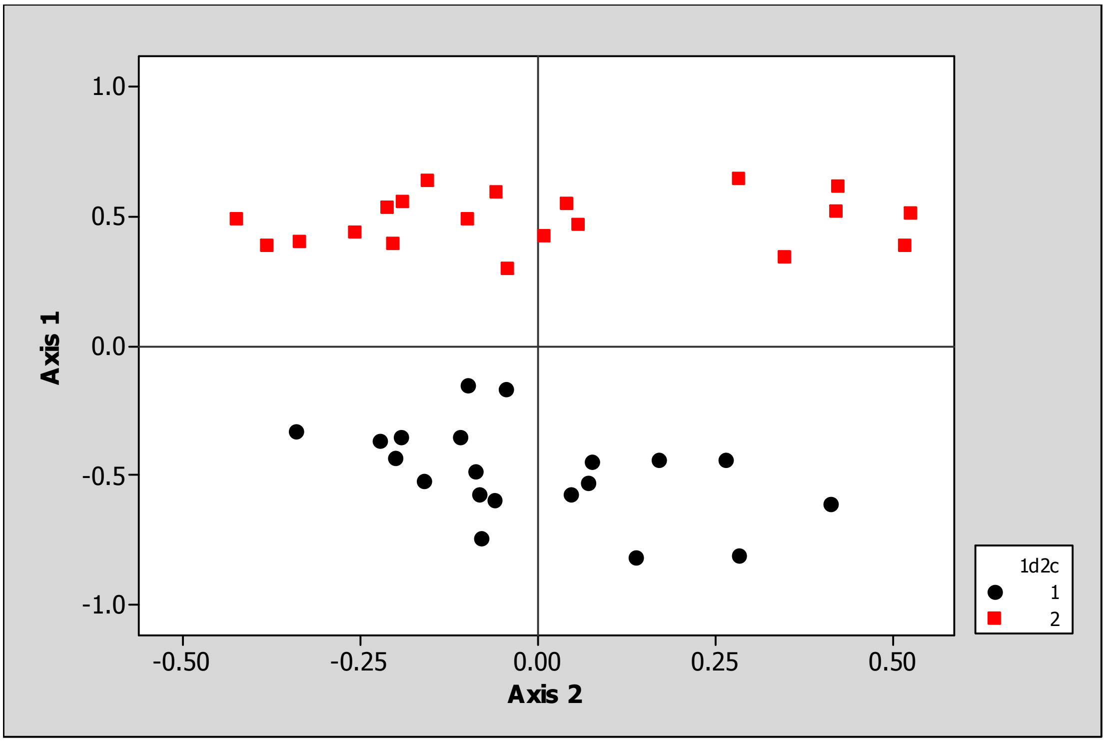

Figure 49. Ordination of quadrats (1 = disturbed, 2 = control) at the Pottery Rd study site (minimum stress = 0.216578).

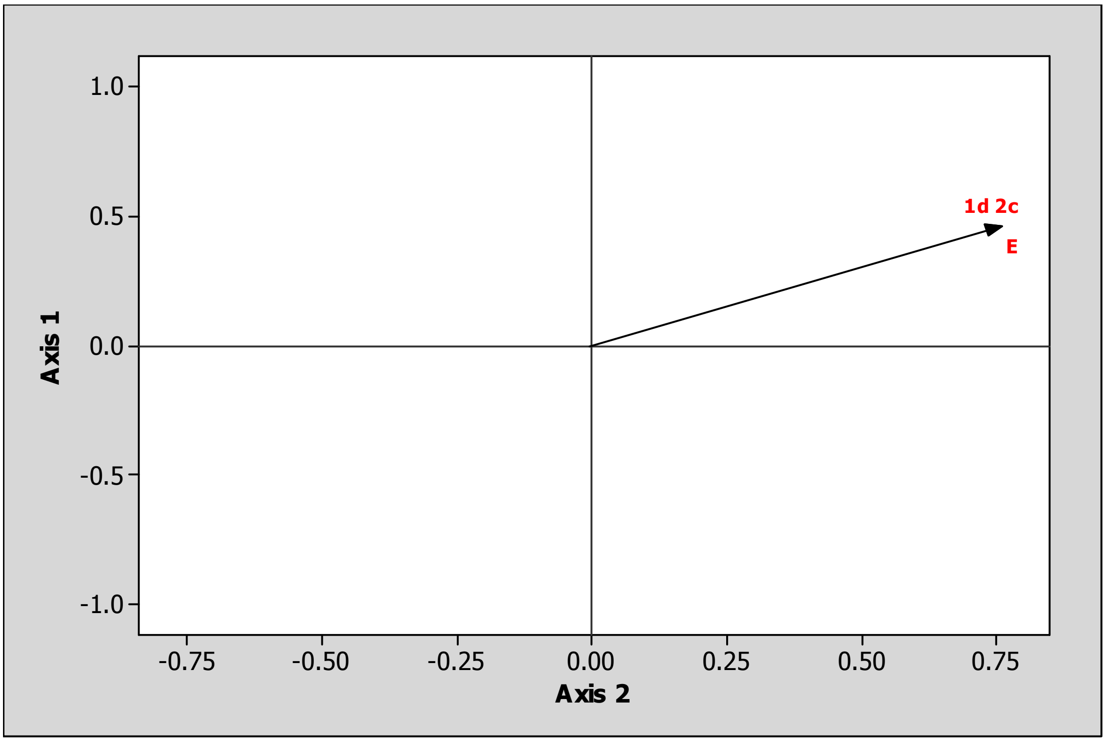

Figure 50. Significant vectors at the Pottery Rd study site. Legend: E = elevation; 1d2c = disturbance.

Soils

There were significant differences in soil pH (P = 0.005), percentage nitrogen (P = <0.001), percentage carbon (P = <0.001) and the nitrogen to carbon ratio (P = 0.029) at the Pottery Road study site (Table 18). The soil was less acidic in the disturbed area and contained more nitrogen and carbon than the control. In addition, the nitrogen to carbon ratio was also lower in the disturbed area.

Table 18. Mean values of soil analyses obtained from the Pottery Road study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	4.81 (0.064)	0.39 (0.034)	8.1 (2.5)	10.09 (0.48)	27.33 (2.2)
Control	4.49 (0.077)	0.089 (0.018)	5.51 (1.6)	6.69 (0.47)	125 (38)
T	-3.20	-7.74	-0.87	-5.07	2.60
P	0.005	<0.001	0.399	<0.001	0.029

Wyre Forest Road

A total of 32 species (29 native, two non-native) were recorded from within 80 quadrats (40 control, 40 disturbed) at the Wyre Forest Road study site (Figure 51, Figure 52). There were no species recorded that were present in all quadrats.

From the 32 species recorded, a total of 19 were present within the disturbed area and 28 occurred within the control. Six native taxa, *Acacia verticillata*, *Exocarpos strictus*, *Glycine clandestina*, *Pultenaea juniperina*, *Leptospermum scoparium* and *Xanthosia pilosa* were common within both the control and disturbed quadrats. Four taxa were confined to the disturbed area but all had relatively low frequencies.

There were two non-native taxa, *Fumaria bastardii*, and *Ilex aquifolium* common within the control area. However, these were absent from the disturbed area except for the presence of *Ilex aquifolium* within four quadrats. Further details of species distribution are provided in Appendix A and Appendix B.

Figure 51. View of *Acacia dealbata* recolonising a section of the disturbed area at the Wyre Forest Road study site.

Figure 52. General view of the control area at the Wyre Forest Road study site.

Species composition was significantly different between the disturbed and control areas (ANOSIM, R =0.7269, P < 0.001). Among the species that varied significantly in their frequency by treatment, eight taxa, including the tree, *Eucalyptus globulus*, were confined to the disturbed quadrats (Table 19). Other species confined to the disturbed quadrats, included the small shrub *Lomatia tinctoria* and the scrambler, *Billardiera longiflora*, and these were present in relatively high frequencies. Several taxa, including *Allocasuarina monilifera*, *Epacris impressa*, *Juncus pallidus*, and the non-native *Ilex aquifolium*, were concentrated within the disturbed and occurred at lower frequencies in the control (Table 19). A total of three taxa, *Acacia verticillata*, *Exocarpos strictus*, and *Leptospermum scoparium* were concentrated in the control quadrats but also occurred within the disturbed area at lower frequencies (Table 19). With the exception of *Fumaria bastardii* and *Ilex aquifolium*, all species that had significant variation, by treatment, at this site were native. There were no species recorded that were confined to the control (Table 19). See also Appendix A and B.

Table 19. Percentage frequency of all species that significantly differed between the disturbed area and the control at the Wyre Forest Road study site. * = non-native species.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	X^2	**P**
Lomatia tinctoria	0.00	80.00	53.333	<0.001
Eucalyptus globulus	0.00	70.00	43.077	<0.001
Billardiera longiflora	0.00	65.00	38.519	<0.001
**Fumaria bastardii*	0.00	57.50	32.281	<0.001
Diplarrena moraea	0.00	52.50	28.475	<0.001
Lepidosperma concavum	0.00	42.50	21.587	<0.001
Bedfordia salicina	0.00	40.00	20.000	<0.001
Indigofera australis	0.00	27.50	12.754	<0.001
Epacris impressa	12.50	97.50	58.384	<0.001
Allocasuarina monilifera	7.50	57.50	22.729	<0.001
**Ilex aquifolium*	10.00	75.00	34.578	<0.001
Eucalyptus obliqua	17.50	55.00	12.170	<0.001
Juncus pallidus	37.50	65.00	6.054	0.014
Exocarpos strictus	62.50	87.50	6.667	0.010
Leptospermum scoparium	87.50	65.00	5.591	0.018
Acacia verticillata	92.50	52.50	16.050	<0.001
Dianella tasmanica	27.50	10.00	4.021	0.045
Melaleuca spp.	37.50	7.50	10.323	0.001

The two dimensional ordination of all quadrats from the Wyre Forest Road study site is shown below in Figure 53. The diagram shows that the control and disturbed quadrats occupy discrete areas. The vegetation within the disturbed area appears to be slightly more uniform than that in the control. There is no evidence to suggest that a continuum currently exists between the two groups.

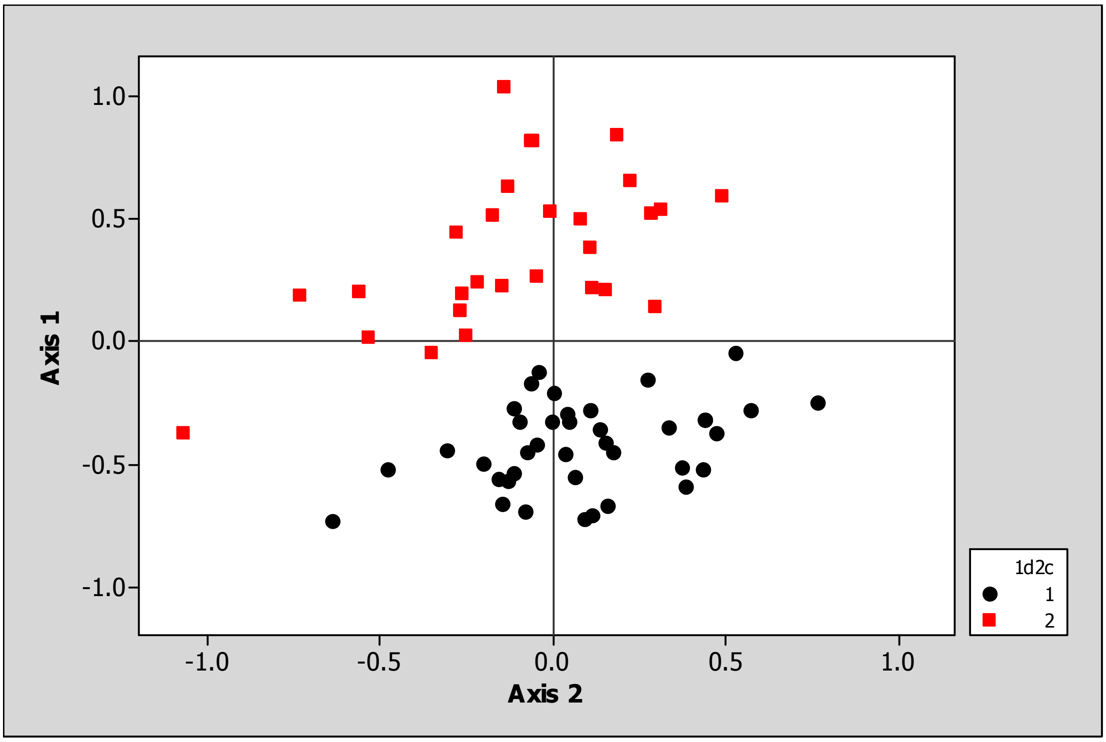

Figure 53. Ordination of quadrats (1 = disturbed, 2 = control) at the Wyre Forest Rd study site (minimum stress = 0.294215).

Vectors obtained for the two dimensional solution for the Wyre Forest Road study site are shown below in Figure 54. The elevation and disturbance vectors are in similar directions. The slope vector is in the opposite direction to elevation and disturbance and is orthogonal to the aspect vector.

The significant vectors at the Wyre Forest Road study site were aspect ($R = 0.797$, $P < 0.001$), elevation ($R = 0.882$, $P < 0.001$), slope ($R = 0.445$, $p = 0.005$), and the disturbance vector ($R = 0.925$, $P < 0.001$).

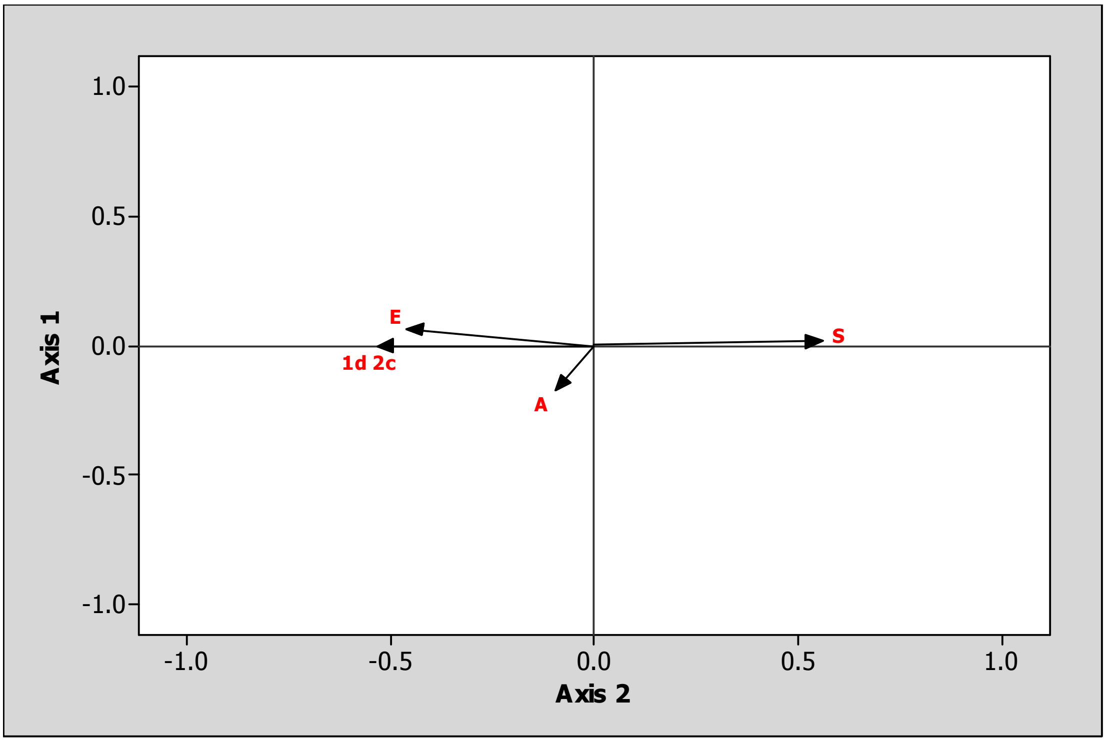

Figure 54. Significant vectors at the Wyre Forest Rd study site. Legend: A = aspect; E = elevation; S = slope; 1d2c = disturbance.

Soils

There were no significant differences in soil properties between the control and disturbed area at the Wyre Forest Road study site (Table 20).

Table 20. Mean values of soil analyses obtained from the Wyre Forest Road study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	4.32 (0.70)	0.103 (0.019)	2.88 (0.40)	3.69 (0.31)	48.9 (11)
Control	4.27 (0.052)	0.112 (0.013)	2.54 (0.23)	3.48 (0.20)	33.19 (2.7)
T	0.58	0.39	-0.73	-0.57	-1.39
P	0.572	0.703	0.48	0.577	0.196

Species distribution within dry sclerophyll ecosystems

From the 132 species (107 native, 25 non-native) recorded from within the six dry sclerophyll study sites (see Appendix A and Appendix B for details), 102 occurred in the disturbed quadrats, 99 in the control and 72 in both the disturbed and control.

The ANOSIM results (Table 9, Table 11, Table 13, Table 15, Table 17, Table 19, Table 21) indicate that significant differences exist in species composition by treatment between the disturbed and control areas at all sites investigated. Of the species that significantly differed between the disturbed area and control, a total of 39 occurred within the disturbed areas, 15 within the control and seven within both areas. There were no species recorded that differed significantly between the disturbed area and control at all study sites (Table 21).

Several species reversed their tendency between sites. These included *Acianthus* spp., *Allocasuarina monilifera*, *Austrostipa* spp., *Epacris impressa*, *Exocarpos strictus*, *Juncus pallidus*, and *Leptospermum scoparium*. There was one non-native species, *Acetosella vulgaris*, which reversed its tendency. Two native species, *Austrostipa* spp. and *Billardiera longiflora*, were more abundant within the disturbed area at three sites (Table 21). Generally, at the dry sclerophyll sites investigated, there were specific groups of species confined, but not restricted to their respective sites. Details are shown below in Table 21.

Table 21. Summary of significant differences in frequencies of taxa between disturbed and control areas. C = more abundant in control, D = more abundant in disturbed, - = absent, insignificant or not tested, * = non-native species. CB = Coles Bay, DR = Douglas Road, K = Kettering, MI = Maria Island, PR = Pottery Road, WF = Wyre Forest Road. Shaded cells indicate a reversal in tendency.

	Site					
Taxon	**CB**	**DR**	**K**	**MI**	**PR**	**WF**
Austrostipa spp.	D	D	-	D	-	-
Billardiera longiflora	-	D	-	-	D	D
Leptospermum scoparium	D	D	-	-	-	-
Leptospermum spp.	D	D	-	-	-	-
Geranium spp.	D	D	-	-	-	-
Diplarrena moraea	-	D	-	-	-	D
Senecio lineariifolius	-	D	-	-	D	-
Bursaria spinosa	-	D	-	D	-	-
Lomatia tinctoria	-	-	D	-	-	D
**Verbascum virgatum*	-	-	-	D	D	-
Eucalyptus globulus	-	-	-	-	D	D
**Agrostis capillaris*	D	-	-	-	-	-
Dillwynia sericea	D	-	-	-	-	-

Taxon	Site					
	CB	DR	K	MI	PR	WF
Oxylobium ellipticum	D	-	-	-	-	-
Themeda triandra	-	D	-	-	-	-
Dodonaea viscosa	-	D	-	-	-	-
Comesperma volubile	-	D	-	-	-	-
**Cirsium vulgare*	-	D	-	-	-	-
**Senecio vulgaris*	-	D	-	-	-	-
Clematis aristata	-	-	D	-	-	-
Astroloma humifusum	-	-	D	-	-	-
Leptospermum spp.	-	-	D	-	-	-
Pultenaea juniperina	-	-	D	-	-	-
Pultenaea daphnoides	-	-	D	-	-	-
Lepidosperma lineare	-	-	-	D	-	-
**Plantago lanceolata*	-	-	-	D	-	-
Euchiton spp.	-	-	-	D	-	-
Cotula reptans	-	-	-	D	-	-
Hydrocotyle hirta	-	-	-	D	-	-
Picris angustifolia	-	-	-	D	-	-
Lepidosperma laterale	-	-	-	-	D	-
Allocasuarina verticillata	-	-	-	-	D	-
**Dactylis glomerata*	-	-	-	-	D	-
**Rosa rubiginosa*	-	-	-	-	D	-
**Fumaria bastardii*	-	-	-	-	-	D
Lepidosperma concavum	-	-	-	-	-	D
Bedfordia salicina	-	-	-	-	-	D
Indigofera australis	-	-	-	-	-	D
**Ilex aquifolium*	-	-	-	-	-	D
Eucalyptus obliqua	-	-	-	-	-	D
Exocarpos strictus	D	C	-	C	-	D
Juncus pallidus	D	-	-	-	C	D
Allocasuarina monilifera	-	D	-	C	-	D
**Acetosella vulgaris*	-	D	-	-	C	-
Acacia verticillata	D	-	-	-	-	C
Acianthus spp.	-	-	D	C	-	-
Epacris impressa	-	-	-	-	C	D
Glycine clandestina	-	-	C	C	C	-
Lomandra longifolia	C	-	-	-	C	-
Melaleuca spp.	-	-	-	-	C	C
Oxalis perennans	C	-	-	-	-	-

Taxon	Site					
	CB	DR	K	MI	PR	WF
Callitris rhomboidea	C	-	-	-	-	-
Lycopodium deuterodensum	C	-	-	-	-	-
Banksia marginata	C	-	-	-	-	-
Stylidium graminifolium	C	-	-	-	-	-
Leptecophylla juniperina	-	C	-	-	-	-
Dillwynia glaberrima	-	C	-	-	-	-
**Centaurium erythraea*	-	-	C	-	-	-
Wahlenbergia spp.	-	-	C	-	-	-
Coprosma hirtella	-	-	C	-	-	-
Exocarpos cupressiformis	-	-	C	-	-	-
Correa reflexa	-	-	C	-	-	-
Cassinia aculeata	-	-	-	C	-	-
Pomaderris pilifera	-	-	-	C	-	-
Brachyscome spp.	-	-	-	-	C	-
Olearia argophylla	-	-	-	-	C	-
Tetratheca glandulosa	-	-	-	-	C	-
**Ulex europaeus*	-	-	-	-	C	-
Wahlenbergia stricta	-	-	-	-	C	-
Dianella tasmanica	-	-	-	-	-	C

Of the 71 species shown above in Table 21, a total of 12 are non-native. All except two, *Centaurium erythraea* and *Ulex europaeus*, were confined to the disturbed areas. The remaining non-native species were not concentrated within any particular site and tended to be mostly associated with specific sites (Table 21). As shown above in Table 21, a group of native species were associated with two or more sites. In particular, several species occurred within the disturbed areas at the Coles Bay, Douglas Road and Pottery Road sites.

The shaded cells in Table 21 indicate a particular group of species that reversed tendency between sites. One species, *Exocarpos strictus*, showed a reversal despite two areas where this occurred (Douglas Road, Wyre Forest Road) being within similar environments. The reasons for this may be related to the type of initial disturbance and time elapsed. Initial disturbance at Douglas Road occurred over 50 years ago while Wyre Forest Road is relatively more recent and more severe.

Ordination of all quadrats from the dry sclerophyll study sites is shown below in Figure 55. There is some evidence that a continuum currently exists between the sites at this level, particularly at Douglas Road, Kettering, and Wyre Forest Road (Figure 55). At all study sites, the position of the disturbed quadrats in relation to the controls is towards a north-easterly direction (Figure 55). The position of these quadrats may be related to soil fertility. For example, at the Coles Bay, Douglas Road and Pottery Road sites, nitrogen values were significantly higher within the disturbed areas. The recorded pH and carbon values were also found to be significantly higher within the disturbed areas at two (Coles Bay and Pottery Road) of these sites.

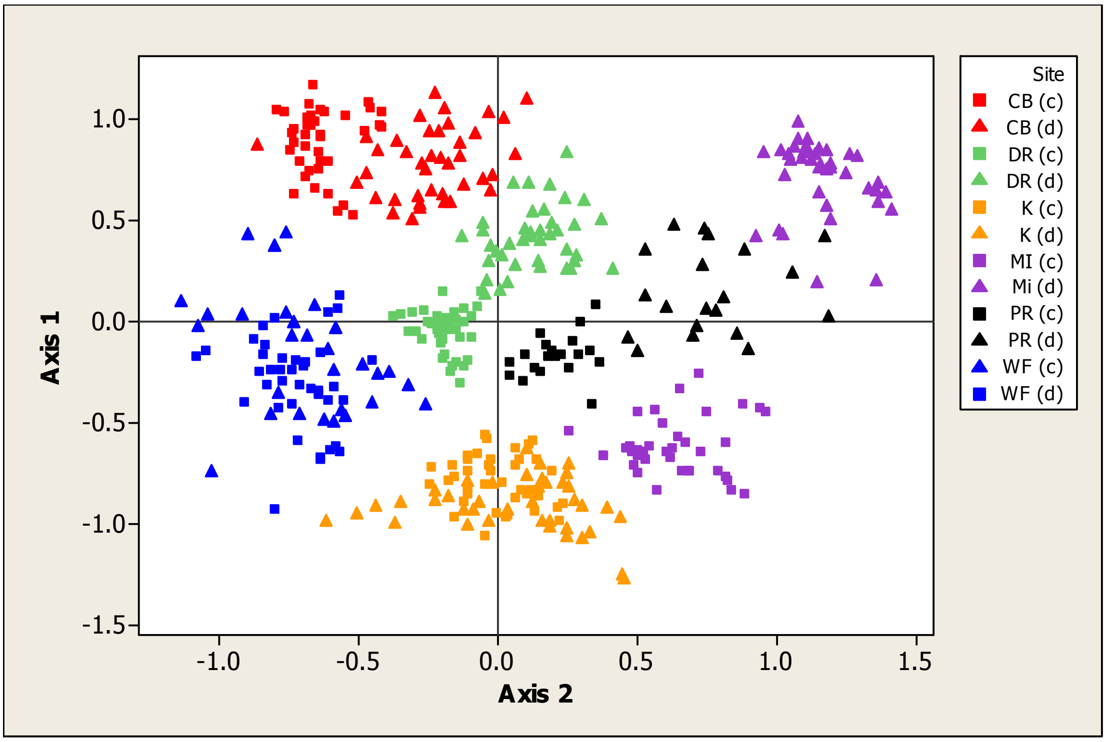

Figure 55. Ordination of all quadrats from study sites within dry sclerophyll communities. Legend: CB = Coles Bay; DR = Douglas Rd; K = Kettering; MI = Maria Island; PR = Pottery Rd; WF = Wyre Forest Rd; c = control; d = disturbed.

Soils

With the exception of phosphorus, significant differences were recorded between the disturbed and control areas with all measured soil variables (Table 22). There were no discernable differences in any measured soil property at the Maria Island study site while in contrast, four variables (pH, N, C, and N:C) were significantly different between treatments at Pottery Road (Table 22). The effects of pH were significantly different at four sites but reversed tendency between sites (Table 22).

Table 22. Significant soil properties at all dry sclerophyll study sites. Significant differences and the higher values are denoted by D (disturbed) or C (control) at each study site. A missing value indicates no significant differences. Study sites: CB = Coles Bay; DR = Douglas Road; K = Kettering; MI = Maria Island; PR = Pottery Road; WF = Wyre Forest Road

	Study site					
Property	CB	DR	K	MI	PR	WF
pH	D	-	C	-	D	C
N	D	D	-	-	D	-
P	-	-	-	-	-	-
C	D	-	-	-	D	-
N:C	-	C	-	-	C	-

Nitrogen levels were higher within the disturbed part of three of the sites (Table 14). Two of these sites, Coles Bay and Douglas Road, have similar sandy-loam soil types and may have been exposed to comparable levels of initial disturbance, encouraging the growth of nitrogen fixing species such as *Acacia verticillata*, *Allocasuarina monilifera*, *Dillwynia sericea* and *Oxylobium ellipticum*. The total carbon was found to be significantly higher within the disturbed areas at two study sites examined (Table 22). Although these two sites have contrasting soil properties, high carbon levels may be related to several different factors including field observations of relatively high amounts of organic litter incorporated into the upper soil horizons at both sites. As shown in Table 22, significant differences with the N:C ratio were recorded at two sites, Douglas Road and Pottery Road, with the higher values found within the controls at both sites.

Discussion

Fire or mechanical soil disturbance are necessary for the regeneration of many species in dry sclerophyll environments (e.g. Purdie, 1977 a,b; Mount, 1979, Gill, 1981; Ashton, 1986; Duncan, 1999 and others). While most dry sclerophyll studies have examined regeneration following wildfire, in the present study, mechanical disturbance has also been shown to be important for regeneration. Initial disturbance of all sites involved the complete removal of vegetation, ranging from superficial topsoil removal through to extensive subsoil disturbance caused through prolonged agricultural activities and the digging of trenches.

Disturbances to soil structures, particularly those from anthropogenic activities can influence soil fertility through erosion, run off and inadvertent mixing of the topsoil and subsoil horizons. Soil nutrient availability can also influence potential vegetation growth, especially nitrogen availability. In some cases, however, regenerating sites have been found to contain a high number of nitrogen fixing species and these could potentially have some influence on soil nitrogen (Nutman, 1976; MacDicken, 1994; Lindemann and Glover, 2003). Within the relatively recent disturbance at the Coles Bay study site, significant differences in nitrogen values were recorded between the disturbed area and the control. This site contained a high abundance of nitrogen fixing species from Casuarinaceae, Fabaceae and Mimosaceae were present. As the higher nitrogen value was recorded within the disturbed area, their abundance may be imparting some influence on the obtained nitrogen values.

The absence of differences in total phosphorus between the disturbed and control areas at any of the dry sclerophyll study sites may be related to the soils within these areas having low levels (<100 ppm) of available phosphorus. Previously, Lassan and Nielsen (1997) regarded phosphorus values <100 ppm as low. Within all study sites, the recorded phosphorus values were <100 ppm. Despite limitations of soil nutrient availability and therefore, potential to support vegetation, observations and analysis suggest that early succession within Tasmanian dry sclerophyll communities and the development of vegetation broadly concurs with Cole et al. (2008) in that understorey species are naturally regenerating and contain many genera from the Asteraceae, Fabaceae and Mimosaceae families. From the 71 species shown in Table 21, only 11 were significantly more abundant within the disturbed areas at more than one site. Only one of these, *Senecio lineariifolius* was a member of these families. Furthermore, only one species, *Acacia verticillata*, was found to belong to these families where a reversal in tendency was observed, suggesting that the families are ubiquitous at all stages of recovery from disturbance.

While, the present study has identified a total of 47 species that were significantly more abundant within the disturbed areas (Table 21), there are generally no patterns to the presence of species between the sites. Except for those species that were found to be significantly more abundant at more than one site and those with a reversal in tendency between disturbed and control areas, specific groups are confined to their respective sites (Table 21). The reversal in tendency of some species may indicate that the type of initial disturbance and differences in environmental conditions may be influencing their regeneration responses.

Previously, Davis et al. (1977) suggested that disturbance (fire intensity), time elapsed since disturbance, wind exposure and insolation correlated to the density, abundance and the frequency of *Acacia*, *Daviesia*, and *Dillwynia*. This study also concluded that during the initial stages of revegetation, the method (i.e. seedling establishment or vegetative regrowth) was important for determining final floristic dominance. Disturbance has been shown to increase the abundance of nitrogen-fixing species in the Fabaceae and Mimosacea (e.g. Davis et al., 1977; Cole et al., 2008), a pattern not consistently evident in the results of the present study. Initial colonising species may be replaced by non nitrogen-fixing and shade-tolerant species following the development of canopy or sub-canopy strata.

The present study found that the majority of non-native species were significantly more abundant within the disturbed areas, while two species, *Ulex europaeus* and *Acetosella vulgaris*, showed the reverse (Table 21). Their greater abundance within the controls may be partially explained by soil conditions but may also relate to their capacity to establish and persist within semi-shaded conditions. The data suggest that non-native species (except for those mentioned above) would eventually be replaced by native species. The time frames necessary for this may be relatively short and this has been broadly documented in Cole et al. (2008). However, it may be beneficial to control invasive non-native species, as in the case of *Ulex europaeus*.

In the absence of further disturbance it seems possible that disturbed dry sclerophyll ecosystems could recover naturally with a minimum abundance and frequency of non-native species. However, their potential rate of recovery appears to be correlated to the type and intensity of initial disturbance and ongoing land management practices. To illustrate this, the initial disturbance at the Maria Island site occurred a relatively long time ago and although observations at this site indicate that vegetation is extending towards the disturbed area from the adjacent control, its potential seems limited by grazing mammals. In such situations, weed control may be effective assisting the recovery of dry sclerophyll ecosystems.

Chapter 5 – Wet Sclerophyll Forest

Introduction

In Tasmania, wet sclerophyll forest types occur where the annual rainfall is between 1000 – 1500 mm. They are distinguished by the presence of dominant eucalypts in the upper stratum (Harris and Kitchener, 2005). An important component in the maintenance of wet sclerophyll forest is fire frequency. However, this can affect different parts of the forest depending on type (i.e. intensity) of fire (Wells, 1991).

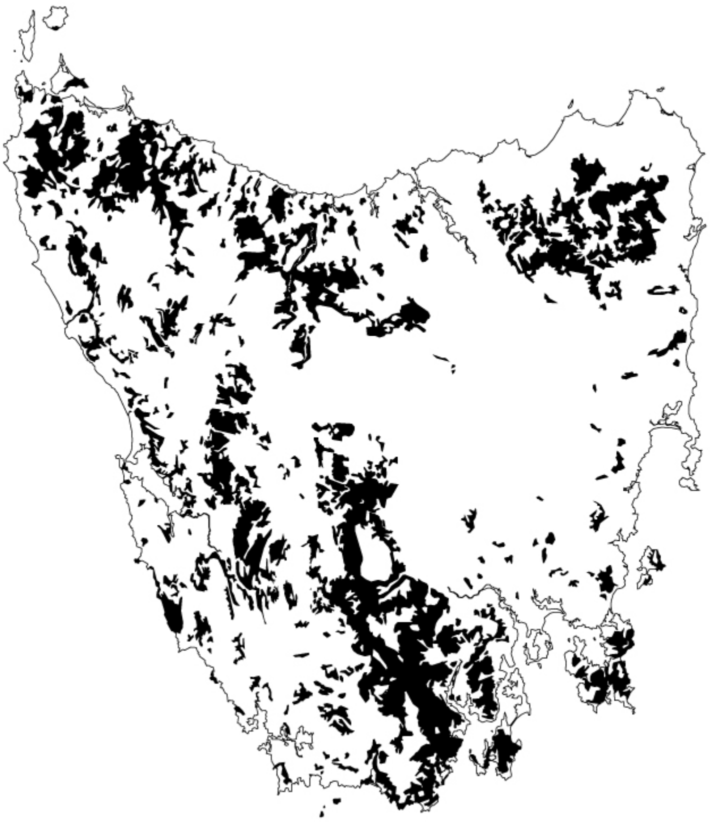

Figure 56. View of Tasmanian showing the distribution of wet sclerophyll (including mixed) forest types. Image Source: Forest Education Foundation, 2007. Source: Kirkpatrick and Dickinson (1984).

The term 'wet sclerophyll' was first defined in the Australian botanical literature by Beadle and Costin (1952) who suggested this forest type was 'peculiarly Australian' and is comprised of large eucalypts with shaft like trunks, open crowns and variable understoreys. Jackson (1981) used the term to describe forest types dominated by tall eucalypts with an understorey of broad-leaved shrubs. A wet sclerophyll community usually has a dense single understorey layer which excludes continuous regeneration of shade intolerant species, including the eucalypts (see Wells and Hickey, 1999).

Most wet sclerophyll forests are ‘tall open-forests’ which, at maturity, are at least 30 metres tall and have a projective foliage cover of between 30 and 70 % (Specht, 1970). In some areas, tall open-forest may also support an understorey of rainforest species rather than broad-leaved shrubs. In this situation they have been called ‘mixed forest’ (Gilbert, 1959). Kirkpatrick et al. (1988) used the term ‘wet eucalypt forest’ to include wet sclerophyll and mixed forest vegetation types that contain understorey vegetation comprised of either a single layer or a mixture of rainforest species and broad-leaved shrubs or ferns. Kirkpatrick et al. (1988) also noted that within a Tasmanian context, subalpine wet eucalypt forests are usually less than 30 m high. Wet sclerophyll forest and mixed forest cover approximately 993 600 ha of Tasmania (Wells and Hickey 1999) (Figure 56).

Wet sclerophyll forests generally receive higher rainfall than other forest types, with the exception of rainforest and alpine areas. Although large areas of wet sclerophyll and mixed forests have been utilised for timber harvesting operations and for the supply of raw products for the pulp and paper industry, the Southern Tasmanian bioregion has recently been described in the Australian Natural Resources Atlas (2008) as being generally in good condition. The regeneration of eucalypts in wet sclerophyll forest is generally considered dependent on the removal of understorey strata by fire (see for example, Cremer and Mount, 1965; Jackson, 1968 a,b; Ashton and Turner, 1979; Ashton, 1981; Attiwill, 1994; Hickey, 1994; Wells and Hickey, 1999). However, Gilbert (1959) proposed that fire is not essential and disturbance to promote regeneration can be achieved by other means other than the physical effects of fire.

It has been suggested that the regeneration of wet sclerophyll forest following minor impacts such as individual tree fall, will not usually occur if there has been insufficient soil disturbance (Gibbons and Lindenmayer, 2002). This is often because vigorous understorey and mid storey components will often outcompete eucalypt seedlings (Florence 1996). A study by Ough (2002) compared the floristics of natural and managed forest stands of *Eucalyptus regnans* in Victoria and showed that vegetation in sites burned by different intensities of wildfire differed significantly from clear-fell regeneration. These effects persist up to 30 years after disturbance in Tasmania (Turner and Kirkpatrick 2009).

The previous study by Ough (2002) also indicated that species composition is determined by initial floristic composition after disturbance. The sites examined in this section have all been subjected to severe disturbance regimes (i.e. mining, road construction, townships) and therefore, it might be expected that species composition within the disturbed areas could be influenced by the type of disturbance.

Aim of Chapter

This chapter reports on three anthropogenically disturbed sites (Figure 57) in wet sclerophyll areas within the Southern Ranges bioregion. Vegetation composition and soils are compared between disturbed areas and adjacent undisturbed control sites.

Methods

Three accessible sites with a known disturbance history and located within the wet sclerophyll communities in the Southern Ranges bioregion were selected. An attempt was made to select sites with different environments and original vegetation types within the bioregion.

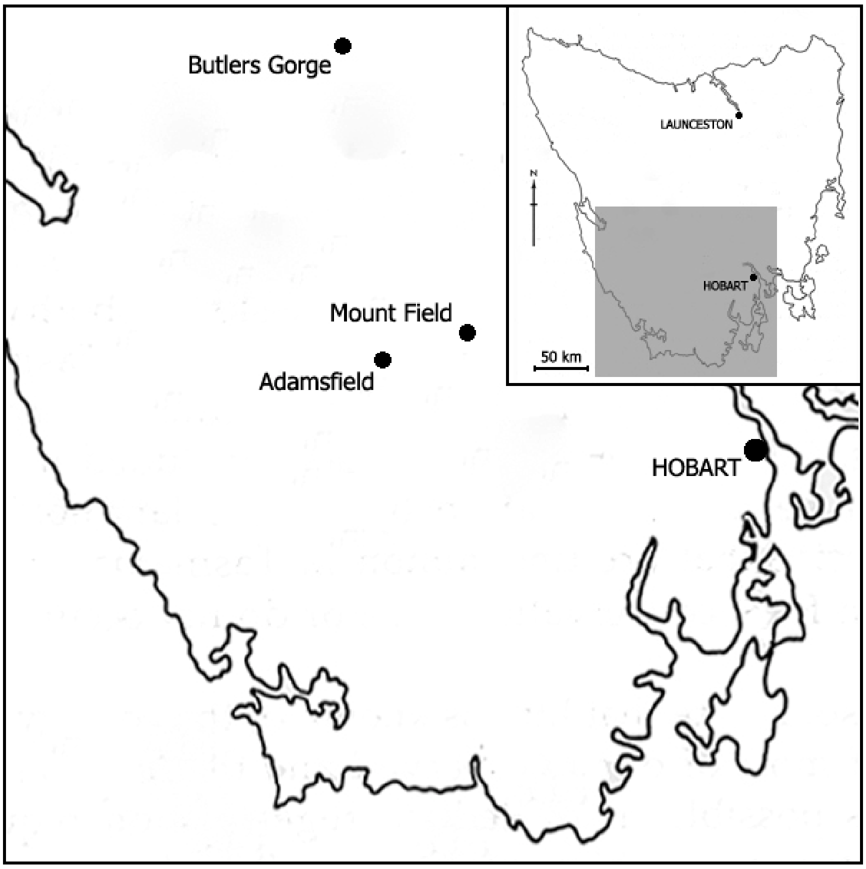

Figure 57. Locations of wet sclerophyll study sites.

Overview of Study Sites and Brief History

Adamsfield

The study site at Adamsfield is located in the south western region of Tasmania. The area was once a thriving osmiridium (more correctly, iridosmine) mining settlement (Figure 58). In 1925, it was a township of more than 1000 people. Osmiridium at the time had a market value of around £30 per ounce which, at that time was about seven times the price of gold.

Figure 58. View of a section of the mine workings at Adamsfield c. 1930s. Image taken from near the more recent 1970s operations. The township can be seen towards the centre of the image.

Initially, the mining activities involved highly labour intensive individual workings which were the initial cause of disturbance. From the late 1930s onwards, mining activities became more capital intensive with the construction of shafts, tunnels, water races and substantial amounts of infrastructure and equipment. As a result, it is likely that the level of disturbance during this period intensified. Following the outbreak of World War II, there were very few people remaining in the town and mining activities diminished until the 1960s when open cut mining was conducted for a short period. Most of the disturbances created from this operation were substantial and are still visible today (Figure 59, Figure 60).

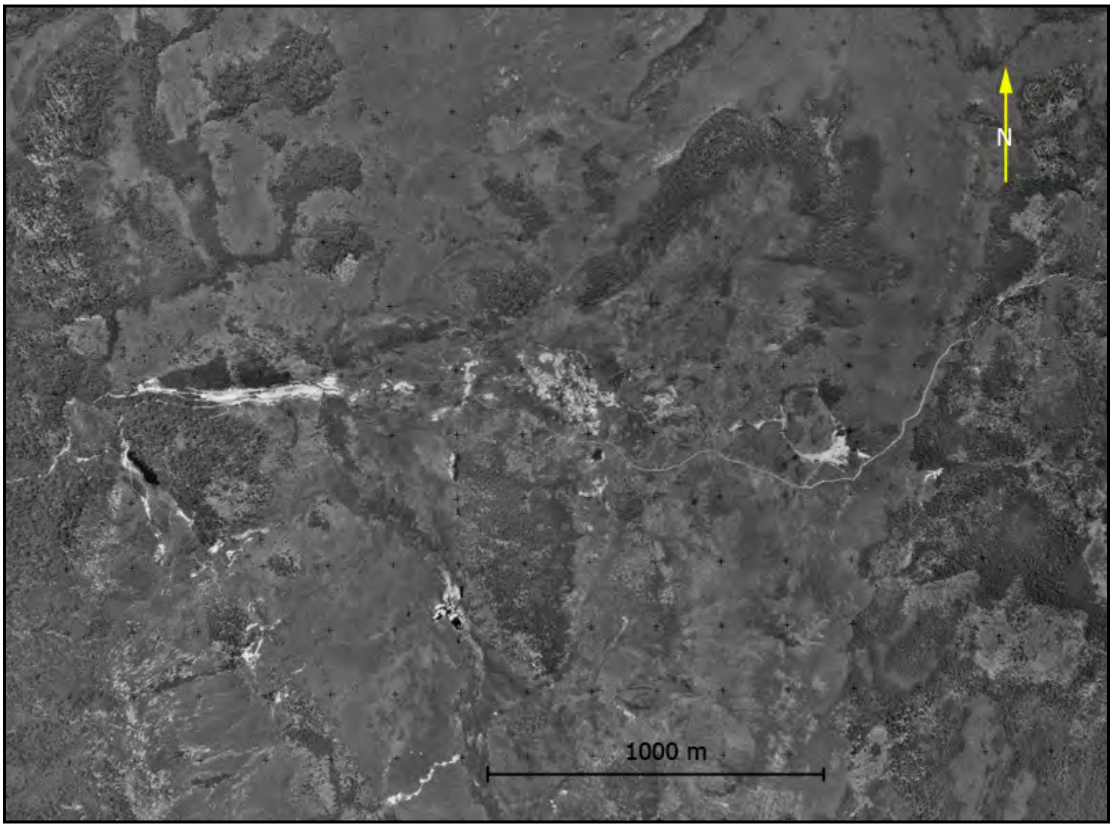

Figure 59. Aerial view of Adamsfield c. 1958. The settlement and the site of the main diggings are visible as the disturbed area in the centre of the image.

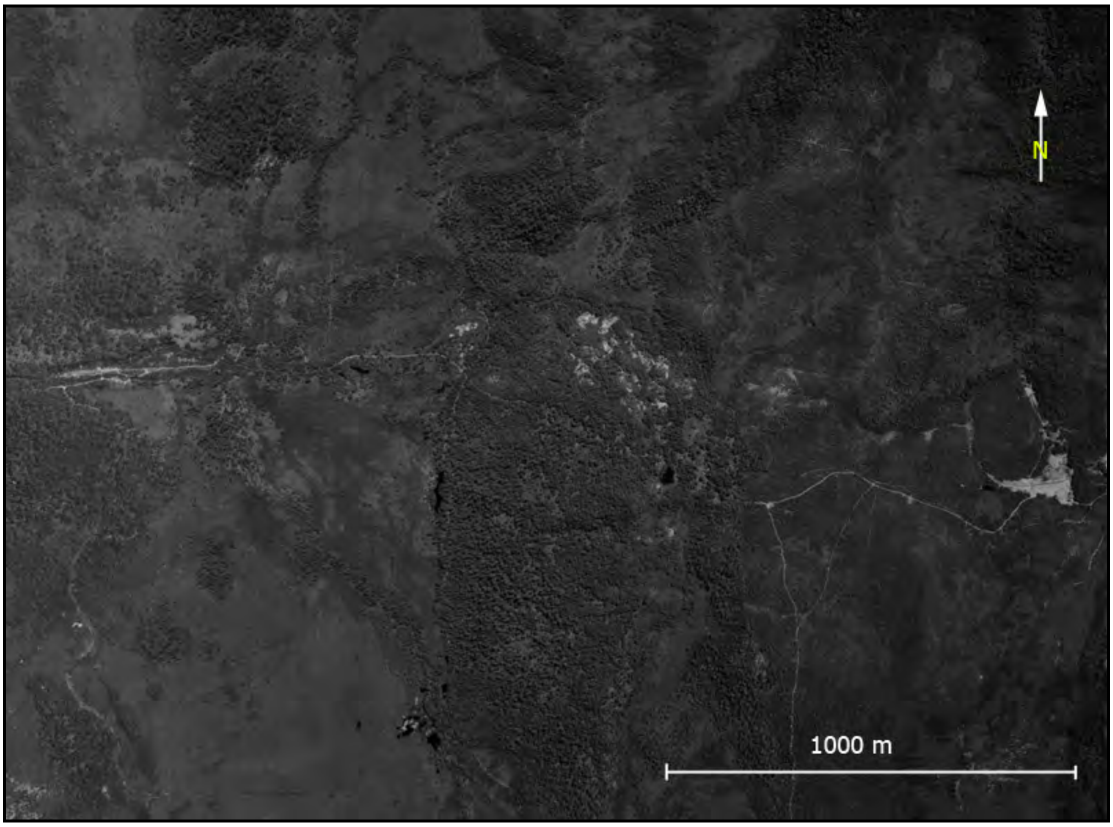

Figure 60. Aerial view of the Adamsfield township in 2002. The settlement and the site of the main diggings are visible as the disturbed area in the centre of the image.

Climate

There are no local climatic data are available for the Adamsfield area and climatic conditions were estimated by comparing data from the closest long-term weather station (operational from 1952 – 1992) located in Maydena approximately 15 km from Adamsfield. Bureau of Meteorology records indicate that mean annual rainfall at Maydena was 1212.1 mm with a mean maximum temperature of 21.6 º C in February and a mean minimum temperature of 1.3 º C in July. The environmental lapse rate determined by Nunez (1986) suggests that mean daily maximum temperature is 21.0 º C and mean minimum daily temperature is 0.7 º C. Rainfall at the Adamsfield study site, as determined by Nunez et al. (1996), is likely to be within the range of 1900 to 2099 mm per annum, with a winter maximum.

Geology

The geology of the Adamsfield region mostly consists of '…*ultramafic-mafic and ophiolite complexes emplaced during Cambrian times in the Tasman Geosyncline*' (Varne and Brown, 1978).

Except for a thin organic layer that has developed in some areas, discrete horizons in the soil profile are generally not visible in the disturbed area. The upper horizon consists of a thin layer (< 5 cm) of very fine grained grayish material. Descriptions by Isbell (2002) indicate these soils would be anthroposols and '…*result from human activities which have caused a profound modification, mixing, truncation or burial of the original soil horizons, or the creation of new soil parent material by a variety of mechanical means*'. Soils within the control area have a gradational profile with the upper horizon approximately 20 cm in depth and underlain by serpentinitic or mudstone parent material and this concurs broadly with the ferrosol description of Isbell (2002).

Butlers Gorge

The township of Butlers Gorge (Figure 61) began to be constructed in 1938. It was used to house workers involved in the construction of the Clark Dam on the upper Derwent River. The completion of the Clark Dam was delayed as World War II broke out and labour shortages became serious. During 1947, the arrival of Polish and British immigrants to Tasmania allowed the dam to be completed.

Butlers Gorge became an important part of the development of Hydro electricity generation in Tasmania. It was once known as the 'grandfather' of Hydro villages and considered to be the first true Hydro construction village. It was abandoned in 1956 and little remains today of what was once a thriving township with a post office, hospital, school, general store and hall. The only remaining visible features suggesting that a town was once located at the site are the hardened lines of the former streets and roads.

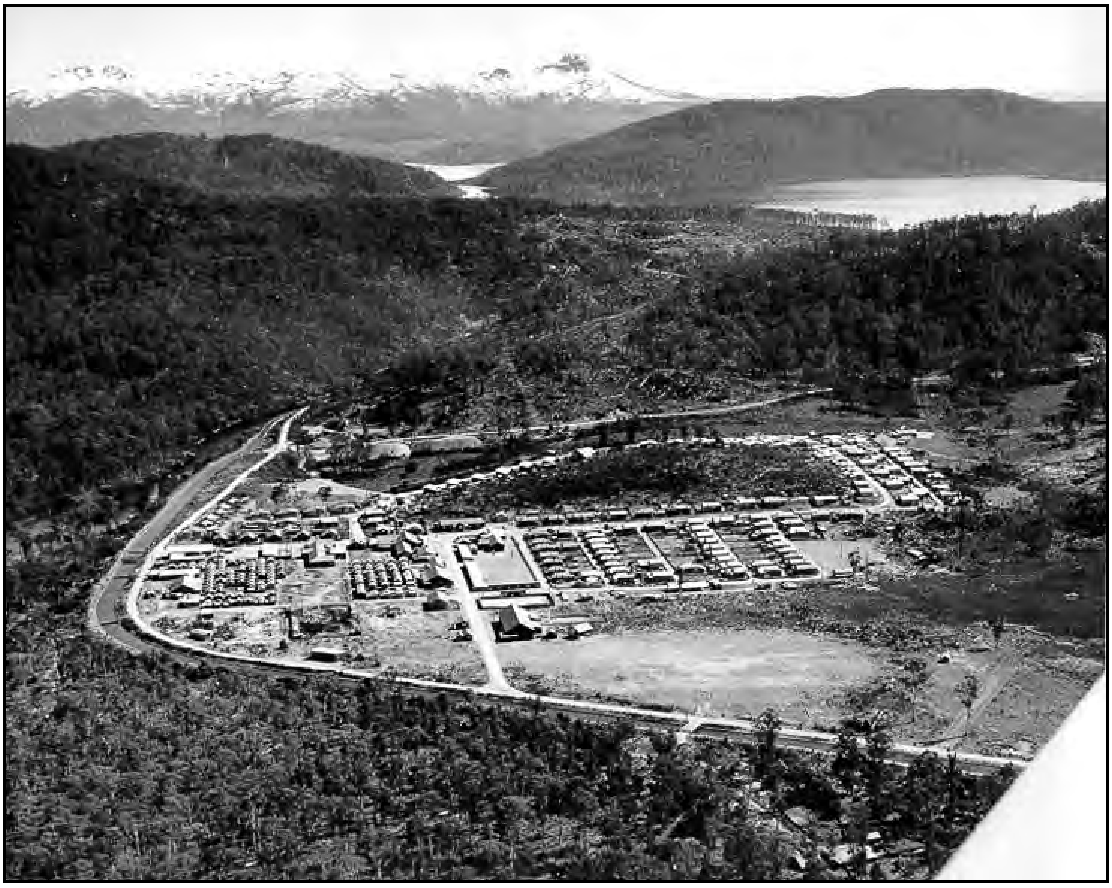

Figure 61. Oblique aerial view of the Butlers Gorge township in 1950.

Climate

Long term rainfall data were collected by The Bureau of Meteorology at Butlers Gorge from 1941 to 1998, a total of 58 years. Other data such as temperature, humidity and wind speed, were collected for slightly shorter time periods. Mean annual rainfall at Butlers Gorge was 1688 mm with a mean daily maximum temperature in the warmest months of 18.7 ° C occurring in January and February. The mean daily minimum temperature in July, the coldest month was -0.4 ºC.

Geology

The Butlers Gorge study site is located within a shallow valley adjacent to the Derwent River and appears to be part of a flood plain. The underlying parent material is weathered Jurassic dolerite. Soils within the disturbed area are anthroposols with no discrete horizons visible.

In contrast, the control area contains exposed dolerite boulders up to 1.5m across (possibly glacial erratics) and the soil profile is well horizonated. The soil type present at the site has been described in detail by Laffan and McIntosh (2005) and is gradational loam and silty loam with red subsoil. Following Isbell (2002), soils present within the control can be classified as red kurosols.

Mount Field

The Mount Field National Park is one of the oldest in Australia (in conjunction with Freycinet National Park, it was the first in Tasmania) and is approximately 75 km to the west of Hobart. Access to the ski fields was initially along a walking track from the Lake Dobson car park. During the 1960s, a road was constructed from near Lake Dobson to the ski fields. The road was constructed to facilitate easier access for vehicular traffic.

Construction of the road and the subsequent development of infrastructure created considerable erosion and disturbance in some areas. The impacts of the disturbance, in particular soil erosion and vegetation clearance, caused by the road construction are still visible today following completion of a new access road in 1963[3]. The study site is located near the ski fields within the national park and adjacent to the constructed road (Figure 62 and Figure 63).

[3]pers. comm.. Mr Frank Lakin, former plant engineer (P.W.D) was responsible for overseeing the development of the access road during 1963.

Figure 62. A section of the study site at Mt Field in 2003. The disturbance was created in 1963.

Figure 63. Oblique aerial view of the Mt Field area. The location of the study site is indicated by the yellow arrow. Image Source: Google Earth.

Climate

Some limited climatic data (rainfall only) has been recorded in close proximity to the Mount Field study site at Mount Mawson. Rainfall data are complete for three years During this period a mean annual rainfall of 2789 mm was recorded and this appears to be consistent with the rainfall estimations determined by Nunez et al. (1996). In the same period, the mean monthly rainfall was 232.4 mm. The wettest months occur between May and August. All temperature values at this site have been determined by data obtained from Maydena, the closest long term weather station, in conjunction with application of the lapse rate determined by Nunez (1986). This suggests that the mean daily maximum temperature of the warmest month is 12.7 º C and the mean daily minimum of the coldest month is -3.4 º C.

Geology and soil structure

The soils within the disturbed area and the control are yellowish brown and very stony clay loams formed on colluviums derived dolerite and similar to descriptions provided by Laffan and McIntosh (2005)

Results – Vegetation

Adamsfield

A total of 57 species (55 native, two non-native) were recorded from 80 quadrats (control = 40, disturbed = 40) at the Adamsfield study site (Figure 64, Figure 65). Of these, a total of seven, *Agastachys odorata*, *Banksia marginata*, *Bauera rubioides*, *Gahnia grandis*, *Gymnoschoenus sphaerocephalus*, *Isolepis* spp., and *Melaleuca squamea*, were common within both the control and disturbed quadrats.

From the 57 species recorded, a total of 38 species were present within the control and 32 within the disturbed area. In addition to the common species listed above, the control quadrats contained a high frequency of *Gleichenia microphylla*, *Eucalyptus delegatensis*, *E. obliqua*, *Leptospermum glaucescens*, *L. lanigerum*, *L. scoparium* and *Richea procera*. From the 32 species recorded within the disturbed area, a total of 17 were confined to the disturbed quadrats. Of the 38 species recorded in the control, 23 were confined to the control quadrats which included two non-native taxa. There were no non-native taxa recorded from the disturbed area.

Figure 64. View of recolonisation at the Adamsfield study site.

Figure 65. View of recolonisation within the former Adamsfield town site at the junction of two former main roads.

Species composition was significantly different between the control and disturbed quadrats at the Adamsfield study site (ANOSIM, R =0.9737, P < 0.001). A total of 16 species were confined to the disturbed area (Table 23), including *Allocasuarina littoralis*, *Acacia dealbata*, *Eucalyptus subcrenulata*, and *Leptospermum nitidum* in the upper strata and native small shrubs, graminoids and herbaceous plants in the lower strata.

There were 25 species concentrated in the control and these included three large trees, *Acacia melanoxylon*, *Eucalyptus delegatensis* and *E. obliqua* (Table 23). Other trees confined to the control included *Allocasuarina monilifera*, *Leptospermum lanigerum*, *L. glaucescens* and *L. scoparium* (Table 23). The remaining taxa confined to the control quadrats were native herbs, small shrubs and graminoids (Table 23). A total of four species, *Eucalyptus nitida*, *Hakea epiglottis*, *Melaleuca squamea* and *M. squarrosa* were concentrated within the disturbed quadrats but also occurred in the control quadrats but at a lower frequency (Table 23). There were two species, *Gleichenia microphylla* and *Gymnoschoenus sphaerocephalus,* that showed the reverse tendency and these were concentrated in the control quadrats but occurred within the disturbed quadrats at a lower frequency (Table 23). Further details of species distribution are presented in Appendix A.

Table 23. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Adamsfield study site.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	X^2	**P**
Leptospermum nitidum	0.00	77.50	50.612	<0.001
Eucalyptus subcrenulata	0.00	62.50	36.364	<0.001
Olearia pinifolia	0.00	57.50	32.281	<0.001
Leptecophylla juniperina	0.00	55.00	30.345	<0.001
Pteridium esculentum	0.00	50.00	26.667	<0.001
Acacia dealbata	0.00	50.00	26.667	<0.001
Baloskion tetraphyllum	0.00	47.50	24.918	<0.001
Blechnum nudum	0.00	47.50	24.918	<0.001
Stylidium graminifolium	0.00	52.50	24.475	<0.001
Coprosma nitida	0.00	45.00	23.226	<0.001
Juncus spp.	0.00	48.00	23.226	<0.001
Xyris gracilis	0.00	45.00	23.226	<0.001
Dodonaea viscosa	0.00	42.50	21.587	<0.001

Species	Control (% frequency)	Disturbed (% frequency)	X^2	P
Sprengelia incarnata	0.00	37.50	18.462	<0.001
Drymophila cyanocarpa	0.00	35.00	16.970	<0.001
Allocasuarina littoralis	0.00	27.50	12.754	<0.001
Melaleuca squamea	12.50	52.50	14.587	<0.001
Hakea epiglottis	17.50	47.50	8.205	<0.001
Eucalyptus nitida	32.50	90.00	27.860	<0.001
Melaleuca squarrosa	37.50	80.00	14.907	<0.001
Gymnoschoenus sphaerocephalus	65.00	37.50	6.054	0.014
Gleichenia microphylla	95.00	30.00	36.053	<0.001
Dillwynia glaberrima	27.50	0.00	12.754	<0.001
Monotoca glauca	30.00	0.00	14.118	<0.001
Orites diversifolia	35.00	0.00	16.970	<0.001
Callistemon viridiflorus	35.00	0.00	16.970	<0.001
Orites revoluta	37.50	0.00	18.462	<0.001
Blechnum wattsii	37.50	0.00	18.462	<0.001
Cyathodes glauca	40.00	0.00	20.000	<0.001
Histiopteris incisa	40.00	0.00	20.000	<0.001
Acacia melanoxylon	40.00	0.00	20.000	<0.001
Hibbertia prostrata	40.00	0.00	20.000	<0.001
Epacris serpyllifolia	42.50	0.00	21.587	<0.001
Drosera spp.	42.50	0.00	21.587	<0.001
Baloskion australe	47.50	0.00	24.918	<0.001
Oxylobium ellipticum	47.50	0.00	24.918	<0.001
Selaginella uliginosa	50.00	0.00	26.667	<0.001
Allocasuarina monilifera	50.00	0.00	26.667	<0.001
Eucalyptus delegatensis	52.50	0.00	28.475	<0.001
Lycopodium deuterodensum	52.50	0.00	28.475	<0.001
Leptospermum lanigerum	55.00	0.00	30.345	<0.001
Leptospermum glaucescens	57.50	0.00	32.281	<0.001
Richea scoparia	67.50	0.00	40.755	<0.001
Eucalyptus obliqua	72.50	0.00	45.490	<0.001
Leptospermum scoparium	72.50	0.00	45.490	<0.001
Monotoca elliptica	72.50	0.00	45.490	<0.001
Acacia mucronata	75.00	0.00	48.000	<0.001

The disturbed and control areas occupy two discrete groups in ordination space (Figure 66). The diagram indicates that the vegetation is more uniform within each group rather than between them. There is no evidence of a continuum between the two individual groups at this study site.

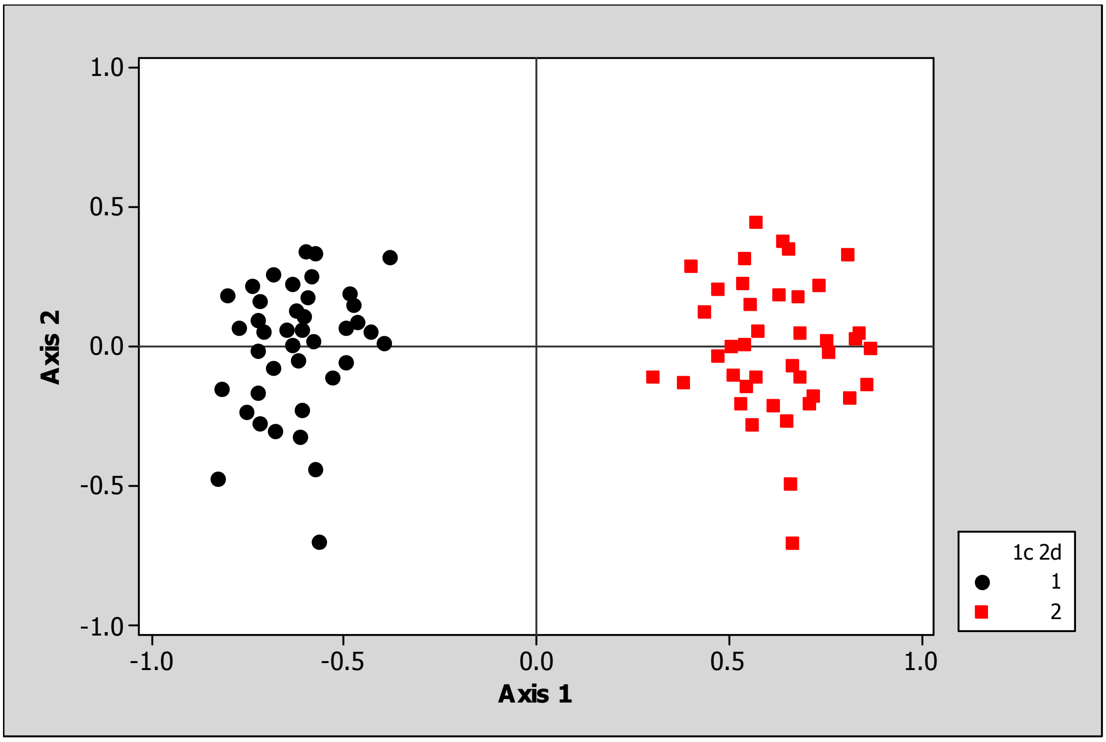

Figure 66. Two dimensional ordination of quadrats (1 = disturbed, 2 = control) from the Adamsfield study site (minimum stress = 0.192977).

Vectors obtained for the two dimensional solution for the Adamsfield study site are shown below in Figure 67. Litter cover and aspect were in the same direction. Disturbance, slope and rock cover were in similar directions but opposite to litter and aspect. Elevation and bare ground were in similar directions and orthogonal to the disturbance vector.

Significant vectors for the Adamsfield study site were aspect ($R = 0.849$, $P < 0.001$), bare ground ($R = 0.799$, $P < 0.001$), elevation ($R = 0.728$, $P < 0.001$), litter cover ($R = 0.816$, $P < 0.001$), rock cover ($R = 0.573$, $P < 0.001$), slope ($R = 0.3064$, $p = 0.023$) and disturbed quadrats ($R = 0.953$, $P < 0.001$).

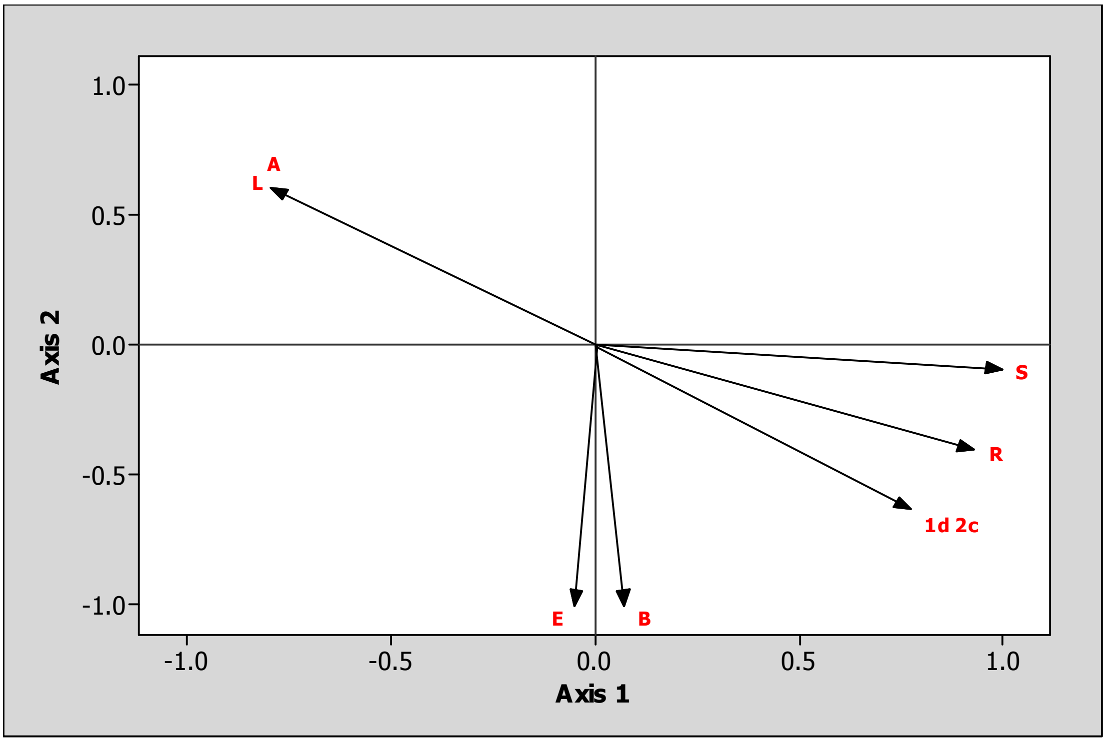

Figure 67. Vector fitting from the Adamsfield study site. Legend: A = aspect, B = bare ground, E = elevation, L = litter cover, R = rock cover, S = Slope, 1d2c = disturbed/control.

Soils

Soil pH (P = <L0.001), nitrogen (P = 0.007) and phosphorus (P = 0.012) differ between the disturbed area and the control, with pH having higher values in the disturbed area while N and P have higher values in the control (Table 24).

Table 24. Mean values of soil analyses obtained from the Adamsfield study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	4.06 (0.062)	0.067 (0.039)	2.621 (0.76)	2.41 (1.7)	35.97 (7.2)
Control	3.49 (0.052)	0.206 (0.012)	5.101 (0.34)	5.23 (0.19)	25.72 (14)
T	7.02	-3.40	-2.97	-1.61	1.64
P	<0.001	0.007	0.012	0.141	0.126

Butlers Gorge

A total of 54 species (51 native, three non-native) were recorded within 80 quadrats (control = 40, disturbed = 40) at the Butlers Gorge study site (Figure 68, Figure 69). Two taxa, *Bauera rubioides* and *Isolepis* spp. were common in the control and disturbed areas. However, none were present in all quadrats.

Figure 68. General view of secondary succession (recolonisation) of a disturbed area at the Butlers Gorge study site. A section of the control area can be see towards the rear of the image.

Figure 69. View of recent recolonising shrubby vegetation at the Butlers Gorge study site. Undisturbed (remnant) vegetation can be seen towards the rear of the image.

From the 52 species recorded, 40 were confined to the disturbed area and seven were confined to the control. There were no species recorded that were present within all disturbed or control quadrats. A total of 13 native species were recorded within the control quadrats at the Butlers Gorge study site and from these a total of seven were confined to the control.

Species composition was significantly different between the control and disturbed areas (ANOSIM, R =0.991, P < 0.001). A total of 15 species were confined to the disturbed quadrats (Table 25). Among the species that significantly varied in their frequency by treatment, the tree, *Eucalyptus delegatensis* was confined to the control area and was present at a relatively high frequency as were *Carex gaudichaudiana*, *Leptecophylla juniperina* and *Lomatia polymorpha* (Table 25). One non-native taxon, *Genista monspessulana*, was present within the control at a relatively high frequency and was absent from the disturbed area (Table 25). A total of four taxa (two native, two non-native) were concentrated within the disturbed area (Table 25). Further details of species distribution are presented in Appendix A and Appendix B.

Table 25. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Butlers Gorge study site. * = non-native species.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	X^2	**P**
Eucalyptus delegatensis	0.00	80.00	53.333	<0.001
Carex gaudichaudiana	0.00	80.00	53.333	<0.001
Leptecophylla juniperina	0.00	77.50	50.612	<0.001
Lomatia polymorpha	0.00	77.50	50.612	<0.001
Eucalyptus coccifera	0.00	75.00	48.000	<0.001
Epacris serpyllifolia	0.00	70.00	43.077	<0.001
**Genista monspessulana*	0.00	67.50	40.755	<0.001
Austrodanthonia caespitosa	0.00	57.50	32.281	<0.001
Agastachys odorata	0.00	52.50	28.475	<0.001
Dianella tasmanica	0.00	45.00	23.266	<0.001
Monotoca elliptica	0.00	42.50	21.587	<0.001
Hakea lissosperma	0.00	32.50	15.222	<0.001
Pentachondra involucrata	0.00	32.50	15.522	<0.001
Banksia marginata	5.00	35.00	11.250	0.001
Drimys lanceolata	15.00	45.00	8.571	0.003
Acaena novae-zelandiae	100.00	65.00	16.970	<0.001
Lepidosperma filiforme	25.00	0.00	11.429	0.001

Species	Control (% frequency)	Disturbed (% frequency)	X^2	P
Gymnoschoenus sphaerocephalus	27.50	0.00	12.754	<0.001
Bauera rubioides	27.50	0.00	12.754	<0.001
Rubus gunnii	30.00	0.00	14.118	<0.001
Picris angustifolia	35.00	0.00	16.970	<0.001
Oxylobium ellipticum	37.50	0.00	18.462	<0.001
Richea scoparia	40.00	0.00	20.000	<0.001
Gonocarpus serpyllifolius	42.50	0.00	21.587	<0.001
Leptospermum lanigerum	47.50	0.00	24.918	<0.001
**Holcus lanatus*	52.50	0.00	28.475	<0.001
Gonocarpus montanus	60.00	0.00	34.286	<0.001
Hakea microcarpa	70.00	0.00	43.077	<0.001
Pultenaea juniperina	85.00	0.00	59.130	<0.001
Baloskion australe	100.00	0.00	80.000	<0.001
**Sonchus asper*	100.00	0.00	80.000	<0.001
**Centaurium erythraea*	100.00	0.00	80.000	<0.001
Juncus spp.	100.00	0.00	80.000	<0.001

Ordination of the quadrats from the Butlers Gorge study site is shown in Figure 70. The ordination diagram indicates that the control and disturbed groups occupy discrete areas in ordination space. The ordination diagram (Figure 70) indicates that there is a closer relationship within the individual groups rather than between them. There is no evidence that a continuum exists between the two groups.

All environmental variables measured at the Butlers Gorge study site had significant vectors (Figure 71). These were aspect ($R = 0.990$, $P < 0.001$), bare ground ($R = 0.388$, $p = 0.001$), elevation ($R = 0.403$, $P < 0.001$), litter cover ($R = 0.649$, $P < 0.001$), rock cover ($R = 0.364$, $P = 0.004$), slope ($R = 0.959$, $P < 0.001$) and disturbed quadrats ($R = 0.991$, $P < 0.001$).

The variables of aspect, litter cover, and slope were almost similar in their direction. The disturbance vector was opposite in direction to these, and bare ground, elevation and rock cover were independent of the disturbance vector.

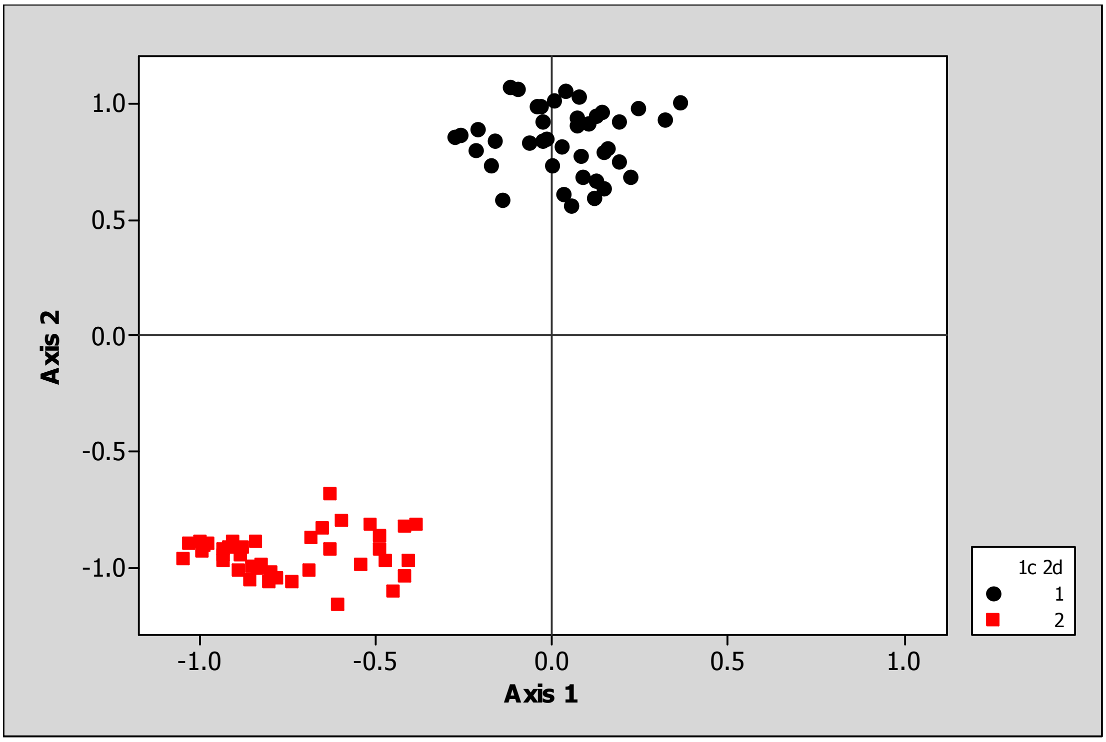

Figure 70. Ordination of all quadrats (1 = disturbed, 2 = control) from the Butlers Gorge study site (minimum stress = 0.000450).

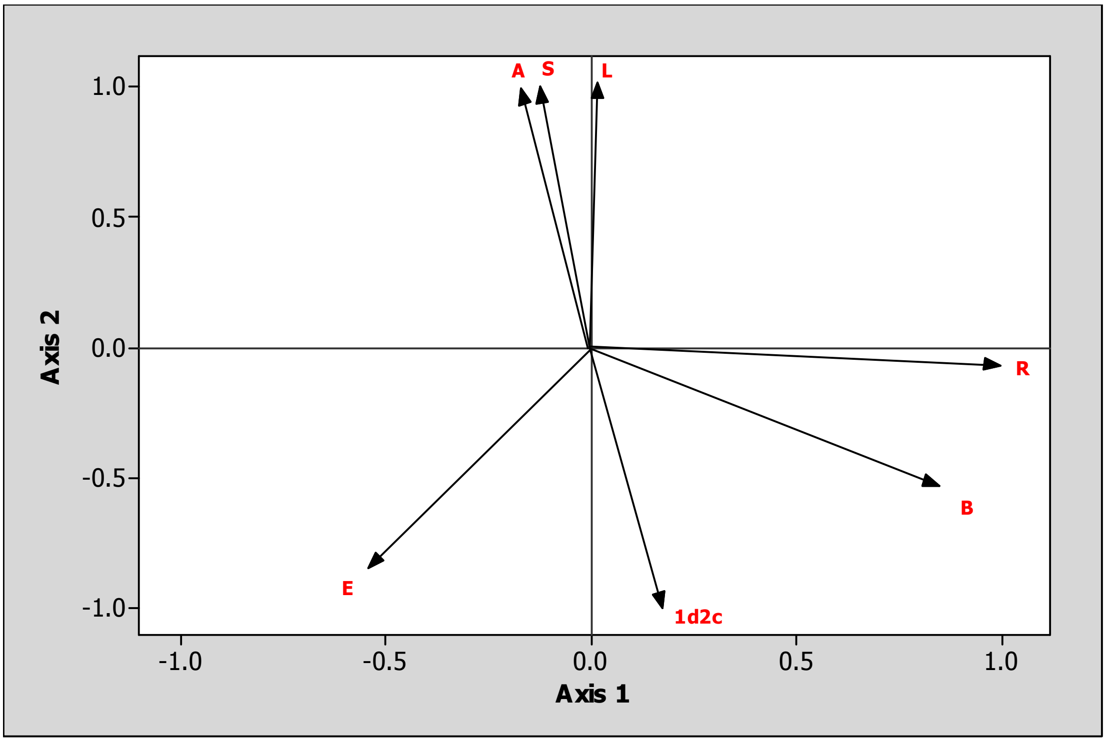

Figure 71. Vector fitting from the Butlers Gorge study site. A = aspect, B = bare ground, E = elevation, L = litter cover, R = rock cover, S = Slope, 1d2c = disturbed/control.

Soils

Soil nitrogen (P = <0.001) and carbon (P = 0.011) were significantly higher in the disturbed areas than in the control area (Table 26). There were no other significant differences in the soil properties measured at the Butlers Gorge study site.

Table 26. Mean values of soil analyses obtained from the Butlers Gorge study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	4.52 (0.70)	0.278 (0.034)	5.52 (0.75)	8.34 (1.7)	37.55 (9.6)
Control	4.52 (0.70)	0.088 (0.011)	5.19 (0.75)	2.94 (0.31)	39.39 (6.8)
T	0.00	-5.27	-0.32	-3.21	0.16
P	1.00	<0.001	0.753	0.011	0.878

Mount Field

A total of 38 species (34 native, four non-native) were recorded from within 40 quadrats (disturbed = 20, control = 20) at the Mount Field study site (Figure 72, Figure 73). Four native species, *Acaena novae-zelandiae*, *Eucalyptus coccifera*, *Gaultheria hispida* and *Ozothamnus rodwayi*, were common within both the control and disturbed quadrats.

From the 38 species recorded at the Mt Field study site, a total of 30 were present within the control quadrats and nine were observed only in the control quadrats. Of these, 25 species were recorded only from within the disturbed quadrats. Two taxa, *Ozothamnus rodwayi* and *Eucalyptus coccifera* occurred within all control quadrats. Two non-native taxa, *Centaurium erythraea*, and *Sonchus asper* were both confined to the disturbed area while, *Cirsium vulgare* (non-native) was present within both the disturbed area and control.

In addition to the above, the disturbed quadrats contained an additional five species, *Dichondra repens*, *Eucalyptus coccifera*, *Ewartia catipes*, *Poa gunnii* and *Geranium potentilloides* with a high frequency. Two species, *Eucalyptus coccifera* and *Poa gunnii* occurred within all quadrats in the control area. Further details of species distribution are provided in Appendix A and Appendix B.

Figure 72. A section of the control area at the Mt Field study site.

Figure 73. Interface between the control and disturbed areas at the Mt Field study site.

Species composition was significantly different between the control and disturbed areas (ANOSIM, R = 0.5676, P < 0.001). Among the species that significantly varied in their frequency by treatment (Table 27), three species, *Olearia phlogopappa*, *Plantago tasmanica* and *Rubus gunnianus* were confined to the disturbed quadrats (Table 27). A total of six taxa were present within both the control and disturbed quadrats (Table 27). Of these, the native grass, *Poa gunnii*, was recorded from all control quadrats and was also present within the disturbed area at a lower frequency than the control (Table 27).

One taxon, *Olearia ledifolia*, was confined to the control while *Ewartia catipes*, was concentrated in the control quadrats but occurred within the disturbed area. Four taxa, *Blechnum penna-marina*, *Tasmannia lanceolata*, *Eucalyptus coccifera* and *Orites revoluta* were concentrated in the disturbed quadrats and these also occurred within the control (Table 27). The tree, *Eucalyptus coccifera* had a high frequency within the control (Table 27). Further details of species distribution are presented in Appendix A and Appendix B.

Table 27. Percentage frequency of all significant species at the Mt Field study site (ordered by frequency in the disturbed column).

Species	**Control (% frequency)**	**Disturbed (% frequency)**	X^2	**P**
Plantago tasmanica	0.00	60.00	17.143	<0.001
Rubus gunnianus	0.00	50.00	13.333	<0.001
Olearia phlogopappa	0.00	15.00	15.172	<0.001
Orites revoluta	20.00	75.00	12.130	<0.001
Tasmannia lanceolata	20.00	65.00	8.286	0.004
Blechnum penna-marina	20.00	60.00	6.667	0.010
Eucalyptus coccifera	80.00	100.00	4.444	0.035
Ewartia catipes	95.00	35.00	15.824	<0.001
Poa gunnii	100.00	45.00	15.172	<0.001
Olearia ledifolia	50.00	0.00	13.333	<0.001

The control and disturbed quadrats occupy slightly different areas in ordination space (Figure 74). The ordination diagram indicates less heterogeneity within the control quadrats compared to the disturbed quadrats.

Significant vectors (Figure 75) were bare ground (R = 0.8751, P < 0.001), slope (R = 0.8486, P < 0.001), and aspect (R = 0.6968, P < 0.001).

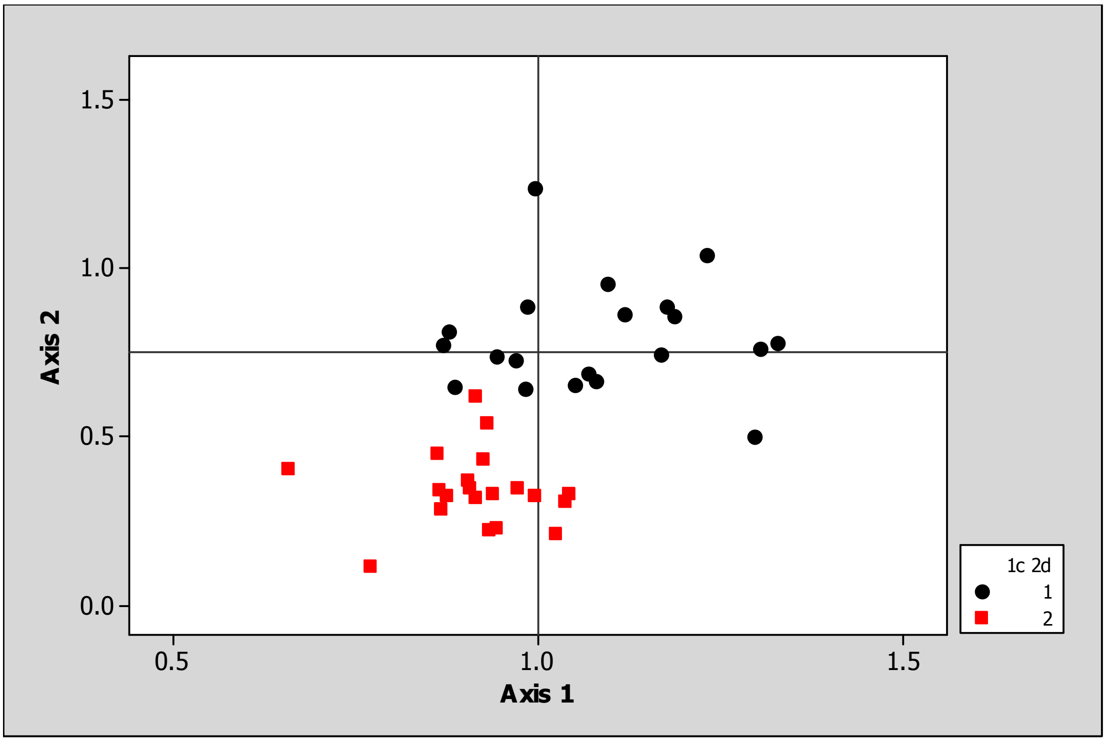

Figure 74. Ordination of quadrats (1 = disturbed, 2 = control) from the Mount Field study site (minimum stress = 0.233455).

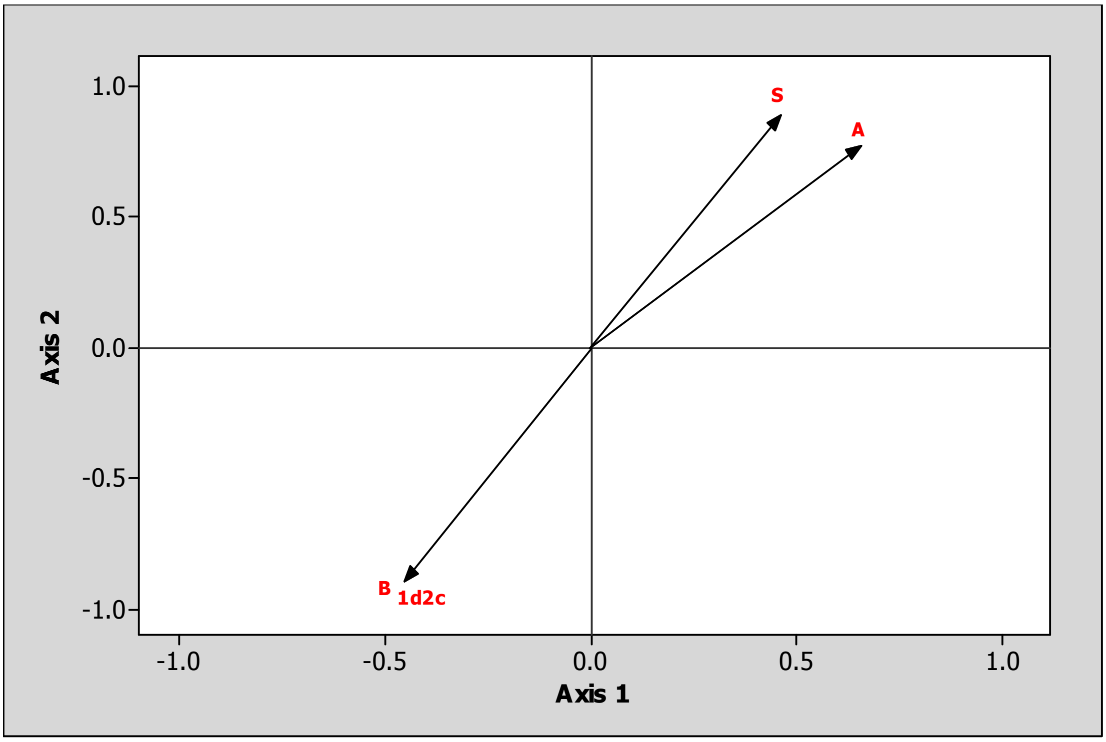

Figure 75. Vector fitting from the Mount Field study site. Legend: A = aspect, B = bare ground, L = litter cover, R = rock cover, S = Slope, 1d2c = disturbed/control.

Soils

The soil within the control site is more acidic (P = <0.001), contains a greater percentage of total nitrogen (P = <0.001), a greater amount of carbon (P = <0.001) and the N:C ratio (P = 0.019) is higher compared to the disturbed area (Table 28).

Table 28. Mean values of soil analyses obtained from the Mount Field study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

	Mean Values of Soil Properties				
	pH	**N**	**P**	**C**	**N:C**
Disturbed	5.37 (0.070)	0.13 (0.016)	6.95 (1.5)	1.92 (0.55)	15.1 (4.3)
Control	4.48 (0.090)	0.33 (0.034)	3.53 (0.53)	9.07 (0.82)	27.9 (1.7)
T	-7.78	5.27	-2.17	7.27	2.74
P	<0.001	<0.001	0.053	<0.001	0.019

Species distribution within wet sclerophyll ecosystems

From the 114 species recorded within the wet sclerophyll study sites (see Appendix A and Appendix B), none occurred within both the disturbed and control quadrats at all sites. Only one species, *Banksia marginata*, was recorded within the disturbed quadrats at all sites.

The ANOSIM results (Table 23, Table 25, Table 27, Table 29) indicate that significant differences exist in species composition by treatment between the disturbed and control areas at all sites investigated. Of the 65 species that differed significantly between the disturbed and control areas, a total of 22 were present only within the disturbed areas and 40 were present only within the control areas. There was a total of six species recorded that reversed tendency between sites and these ranged from small herbaceous plants to large forest trees (Table 29). Only two species, *Eucalyptus coccifera* and *Tasmannia lanceolata* were recorded as significantly more abundant within the disturbed area at two sites (Table 29).

No species were recorded that were present within all sites examined (Table 29). A total of four non-native species were recorded as significantly more abundant at one site only (Butlers Gorge). However, only one species, *Genista monspessulana*, was significantly more abundant within the disturbed area at this site (Table 29).

Table 29. Summary of significant differences in frequencies of taxa between disturbed and control areas. C = more abundant in control, D = more abundant in disturbed, - = absent, insignificant or not tested, * = non-native species. A = Adamsfield, BG = Butlers Gorge, MF = Mount Field. Shaded cells indicate a reversal in tendency.

	Site		
Taxon	**A**	**BG**	**MF**
Eucalyptus coccifera	-	D	D
Drimys lanceolata	-	D	D
Dodonaea viscosa	D	-	-
Sprengelia incarnata	D	-	-
Drymophila cyanocarpa	D	-	-
Allocasuarina littoralis	D	-	-
Melaleuca squamea	D	-	-
Hakea epiglottis	D	-	-
Melaleuca squarrosa	D	-	-
Carex gaudichaudiana	-	D	-
Leptecophylla juniperina	-	D	-
Lomatia polymorpha	-	D	-
**Genista monspessulana*	-	D	-
Austrodanthonia caespitosa	-	D	-
Agastachys odorata	-	D	-
Dianella tasmanica	-	D	-
Hakea lissosperma	-	D	-
Pentachondra involucrata	-	D	-
Banksia marginata	-	D	-
Plantago tasmanica	-	-	D
Olearia phlogopappa	-	-	D
Blechnum penna-marina	-	-	D
Orites revoluta	C	-	D
Epacris serpyllifolia	C	D	-
Eucalyptus delegatensis	C	D	-
Monotoca elliptica	C	D	-
Rubus gunnianus	-	C	D
Baloskion australe	C	C	-
Oxylobium ellipticum	C	C	-
Leptospermum lanigerum	C	C	-
Richea scoparia	C	C	-
Gymnoschoenus sphaerocephalus	C	C	-
Gleichenia microphylla	C	-	-
Dillwynia glaberrima	C	-	-

	Site		
Taxon	**A**	**BG**	**MF**
Monotoca glauca	C	-	-
Orites diversifolia	C	-	-
Callistemon viridiflorus	C	-	-
Blechnum wattsii	C	-	-
Cyathodes glauca	C	-	-
Histiopteris incisa	C	-	-
Acacia melanoxylon	C	-	-
Hibbertia prostrata	C	-	-
Drosera spp.	C	-	-
Selaginella uliginosa	C	-	-
Allocasuarina monilifera	C	-	-
Lycopodium deuterodensum	C	-	-
Leptospermum glaucescens	C	-	-
Eucalyptus obliqua	C	-	-
Leptospermum scoparium	C	-	-
Acacia mucronata	C	-	-
Acaena novae-zelandiae	-	C	-
Lepidosperma filiforme	-	C	-
Bauera rubioides	-	C	-
Picris angustifolia	-	C	-
Gonocarpus serpyllifolia	-	C	-
**Holcus lanata*	-	C	-
Gonocarpus montanus	-	C	-
Hakea microcarpa	-	C	-
Pultenaea juniperina	-	C	-
**Sonchus asper*	-	C	-
**Centaurium erythraea*	-	C	-
Juncus spp.	-	C	-
Ewartia catipes	-	-	C
Poa gunnii	-	-	C
Olearia ledifolia	-	-	C

Of the 65 species shown above in Table 29, only four were non-native and these were all restricted to the Butlers Gorge study site. Three of these were significantly more abundant within the control while one non-native species, *Genista monspessulana*, reversed this tendency and was found to be significantly more abundant within the disturbed area (Table 29).

The ordination of all wet sclerophyll sites shown below in Figure 76, indicates that disturbance has produced a similar directional response at all sites examined. The explanations for this may be related to environmental conditions and the intensity of initial disturbance. There is no observable trend in measured soil properties within or between the sites thus, differences in soil properties may only partially explain the directional response of the ordination.

The ordination diagram (Figure 76) indicates that distance between the disturbed and control areas at Adamsfield and Butlers Gorge are greater than Mt Field. It may be plausible that similarities with mean maximum temperatures of the warmest months at Adamsfield and Butlers Gorge could be having some influence on growth patterns. The quadrats at the Mt Field site appear to be more heterogeneous than the other two sites (Figure 76). The directional response of the disturbed quadrats may be partially explained by a combination of the initial disturbance intensity and environmental conditions rather than by soil properties and other edaphic factors.

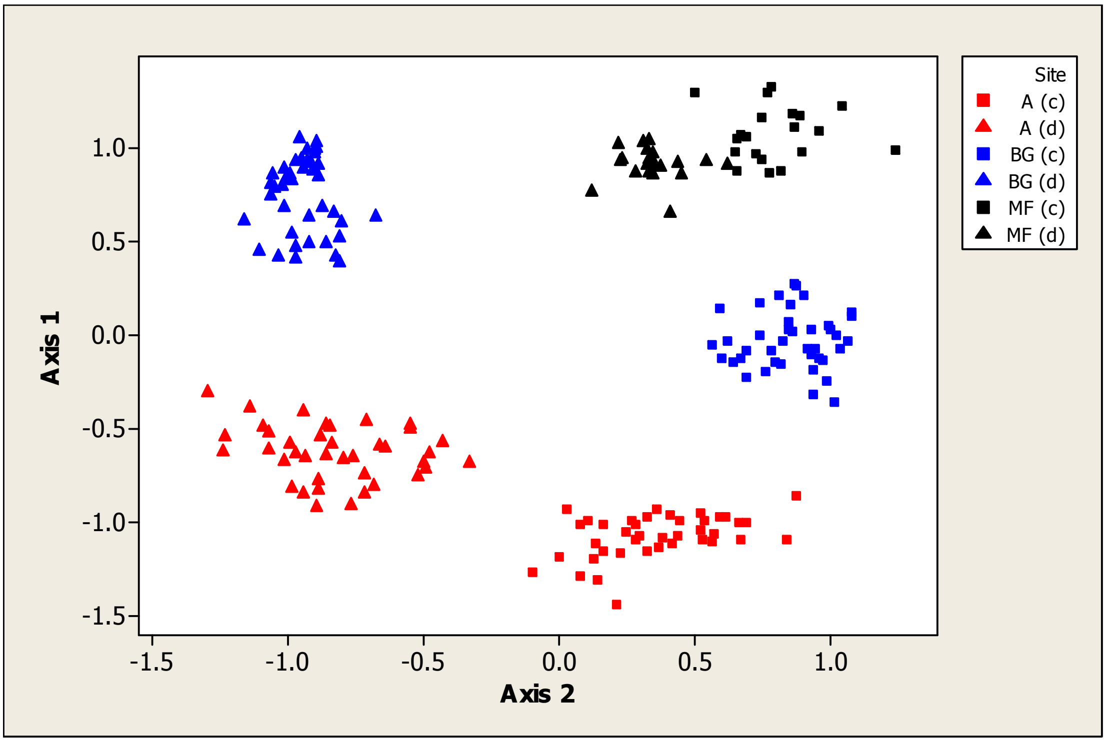

Figure 76. Ordination of all quadrats within wet sclerophyll study sites. Site: A = Adamsfield; BG = Butlers Gorge; MF = Mount Field; c = control; d = disturbed.

Soils

Soil analyses from the three wet sclerophyll study sites have indicated that there are significant differences in all measured soil properties however, these are inconsistent between the sites. The mean soil pH was found to be significantly higher within the disturbed areas at the Adamsfield and Mount Field sites (Table 30). At these two sites, there is evidence of extensive topsoil and subsoil mixing from associated mining and construction activities and thus, the surface pH may be related to the nature of the underlying geology and parent material.

Nitrogen was significantly different between the disturbed area and controls at all wet sclerophyll sites investigated (Table 30). However, it reversed tendency between sites with higher values recorded within the controls at Adamsfield and Mount Field and within the disturbed area at Butlers Gorge (Table 30).

Observations within the disturbed areas at Adamsfield and Mount Field found that there is little organic matter incorporated into the upper horizons. Thus it might be reasonable to suggest that biological activity is suppressed and therefore, nitrogen levels may be influenced by this. Nitrogen and carbon was found to be higher in the disturbance at the Butlers Gorge site (Table 30) and this may be a result of fertiliser applications, but could also result from the nature of the colonising vegetation and its impact on the soils. The higher nitrogen and carbon values at Butlers Gorge could be related to the establishment of grassy shrubland vegetation on mostly intact soils. In contrast, it is reasonable to suggest that soils at the Adamsfield and Mt Field were typically removed during mining and construction activities.

Table 30. Significant soil properties at all wet sclerophyll study sites. Significant differences and the higher values are denoted by D (disturbed) or C (control) at each study site. A missing value indicates no significant differences. Study sites: A = Adamsfield; BG = Butlers Gorge; MF = Mount Field.

	Study site		
Property	A	BG	MF
pH	D	-	D
N	C	D	C
P	C	-	-
C	-	D	C
N:C	-	-	D

Discussion

Soil disturbance within wet sclerophyll communities often enhances conditions for the growth of weed species. However, these tend to be excluded once a canopy and other layers have formed and reduced the availability of light. Previously, Wells and Hickey (1999) have suggested that severe disturbance, such as wildfire, is generally a requirement in wet sclerophyll forests for their regeneration, others including Gilbert (1959), Cremer and Mount (1965), Ashton and Turner (1979), Ashton (1981) and Attiwill (1994) have argued that regeneration can be facilitated by the removal of understorey vegetation through clearance or logging and thus, soil disturbance. Results from the soil analyses indicate that differences within and between the sites are generally inconsistent and this could reflect greater variation in the chemical properties of the C horizons rather than undisturbed top soils. Additionally, it may also relate to differences in the soil-forming characteristics of the litter from early colonising species within and between the individual sites examined. For example, where leguminous species are highly abundant in early the regeneration phases after disturbance, but not present within the control, it could be assumed that differences in nitrogen would be very dissimilar to where the reverse prevailed.

At the Adamsfield site, soils are derived from regolith formed on ultramafic rock types. These rocks tend to be rich in calcium, potassium, chromium, and nickel and therefore, soils contain levels of these elements that are toxic to many plants (e.g. Brown et al., 1986; Gibson et al., 1992; Read et al., 1995; Proctor, 2003; Burge and Barker, 2010; Pillon et al., 2010). As a result, these soils typically support distinctive groups of vegetation. At Adamsfield, soil pH was significantly higher within the disturbed area (Table 24). This could be a result of extensive soil mixing caused from alluvial mining techniques. However, soil disturbance appears to have facilitated regeneration, yet field observations indicate that the rate of recovery is slower than that observed in other similar sites. Robinson et al. (1996) argued that ‘serpentine scrub’ produces acidic litter but accumulation within disturbed areas is likely to be less than forested areas. Therefore, any potential acidifying effect from litter decomposition might be minimal. As lower pH values were recorded from the control, the present study is in accord with Robinson et al. (1996) in this regard.

Disturbed quadrats within the Adamsfield study site contained a high frequency of two *Melaleuca* species and two eucalypt species, *E. nitida* and *E. subcrenulata* and these appear to be early colonisers of disturbance. An additional two eucalypts, *E. delegatensis* and *E. obliqua* were recorded from the control at this site but these were absent from the disturbed area. The distribution of these species is unusual in that they persist in discrete areas at this study site and while it seems likely they may be colonising species, it might be reasonable to assume that the disturbed and control were in different environments. Further investigation of their distribution within this area may be beneficial as it does not appear to have been documented elsewhere within a Tasmanian context.

The present study concurs with Gilbert (1959), Cremer and Mount (1965), Ashton and Turner (1979), Ashton (1981) and Attiwill (1994) in that wet sclerophyll forests have capacity to regenerate following disturbance other than wildfire. However, it is known that eucalypts (a common element of wet sclerophyll communities) differ in their response to disturbance (i.e. Ashton, 1981; Read and Hill, 1988; Neyland and Hickey, 1990). A fundamental component to facilitate regeneration however is that soil disturbance must occur and this is supported in the present study. To illustrate this, species found to be significantly more abundant within the disturbed areas, were absent from the controls (Table 29), indicating that initial colonisers recorded in the present study form a discrete group of species that appear to be eventually replaced through succession.

There are several well known colonising species of disturbed areas within the wet sclerophyll forests of Tasmania and other parts of Australia and these have been well documented in the literature (e.g. Gynn and Richards, 1985; Johnston and Johnston, 2004). One of these species, *Acaena novae-zelandiae* had a high frequency at two of the disturbed sites, Butlers Gorge and Mt Field. The nutrient status of soils at these two sites reversed tendency, particularly with nitrogen and carbon values (Table 30). Although, the relatively high frequency of *Acaena novae-zelandiae* may be related to light conditions rather than soil properties, it might also indicate wider environmental tolerance with respect to soil nitrogen levels for this species. One eucalypt species, *Eucalyptus coccifera*, was present within almost 50 % of all quadrats in the disturbed area at Mt Field which consists of a disturbed roadside. Previously Wells and Hickey

(1999) indicated that regeneration of eucalypts is possible along roadsides where the topsoil has been removed in close proximity to a mature forest and in the absence of fire.This has also been described in other comparisons of disturbed wet sclerophyll sites that are adjacent to the availability of a seed source (e.g. Floyd, 1966; Duckett, 1990; Wells, 1991).

Many wet sclerophyll forests within Tasmania and other parts Australia have been noted as being even aged as a result of regeneration following forest fire, or they may consist of two or three age classes which have been created by less sever ground fires (Attiwill et al., 1998). Accordingly, the concept of fire within wet sclerophyll and other forest types in Australia has received considerable attention within the current literature. However, natural regeneration following other types of disturbance within wet sclerophyll ecosystems has received considerably less attention and most studies appear to be focussed on disturbance following logging and other timber harvesting activities, reflecting the economic value of wet sclerophyll forests. In view of this, the present study has shown that wet sclerophyll species (and communities) have the capacity to recolonise bare ground following severe disturbance caused from mining activities, road construction and the development of infrastructure in the absence of wildfire, often considered essential to facilitate regeneration. Accordingly, this is an important for consideration by land management agencies if natural regeneration rather than active management is preferred.

Chapter 6 – Western Tasmanian Communities

Introduction

The western region of Tasmania is dominated by Pre-Cambrian and Cambrian aged rock types that support a range of soil types including oligotrophic acid peat soils (Resource Planning and Development Commission, 2006). Large areas of western Tasmania have been subjected to several glaciations during the past two million years (Australian Natural Resources Atlas, 2007). These repeated glacial/interglacial cycles have influenced the current distribution of rainforest vegetation as well as other vegetation types (Jordan et al. 1991; Colhoun, 1996, 2000; Kirkpatrick and Fowler, 1998; Reid et al. 1999; Fletcher and Thomas, 2007).

Western Tasmania receives some of the highest annual rainfalls in Australia, with parts of it receiving in excess of 3500 mm per annum. While rainfall is generally heaviest during the winter period, it is not strongly seasonal (Williams, 1974). As a result of the high rainfall, rainforest is potentially the dominant vegetation type in lowland western Tasmania. It is usually dominated by *Nothofagus cunninghamii*, although other tree species, such as *Atherosperma moschatum*, *Eucryphia lucida*, *Phyllocladus aspleniifolius*, *Athrotaxis selaginoides* and *Lagarostrobos franklinii,* can also be codominant or dominant. However, despite the potential dominance of rainforest, the vegetation of lowland western Tasmania consists of a mosaic of rainforest, buttongrass moorlands, *Leptospermum/Melaleuca* scrub and *Eucalyptus nitida* scrub and forest (Jackson, 1999; ANRA, 2008). An overview of the vegetation communities in the western Tasmanian bioregion that were included in the present project is given below.

Rainforest

Many Tasmanian rainforest species are recognised as having considerable economic value. For example, the endemic conifers *Athrotaxis selaginoides* and *Lagarostrobos franklinii* are highly valued for their timber products particularly within the boat building industry. Demand for these products in conjunction with widespread fires, has led to a 32 percent loss of *A. selaginoides* forest during the last 100 years (Brown 1983, Harris et al., 1995). The responses of western Tasmanian rainforest and alpine vegetation to fire have been described by Jackson (1968a,b), Kirkpatrick (1977), Bowman and Jackson (1981), Brown and Podger (1982), Jarman et al. (1982), Jarman and Brown (1983), Kirkpatrick and Dickinson (1984) and Read (1999). In some cases, fire can cause local extinction of the more fire-sensitive rainforest species, such as *A. selaginoides*, *L. franklinii* and *Nothofagus gunnii*.

In Tasmania, rainforest can occur from near sea level to the climatic treeline. Jackson (1983) suggested that a minimum annual rainfall of 800 mm is required for the development of rainforest. At this lower rainfall limit, rainforest is restricted to river gullies and south east facing slopes protected from wind and fire (Read, 1999). In areas where rainfall exceeds 1200 mm, rainforest can develop on a wide range of soils and topographic situations. In those areas where rainfall exceeds 2000 mm per annum, and where the summer rainfall exceeds 50 mm per month, soil type and topographic situation do not restrict rainforest development (Jackson, 1983). However, the growth rates of rainforest trees within Tasmania are slow compared to other co-occurring species such as eucalypts and wet sclerophyll understorey species which can overtop the developing rainforest trees in post-disturbance regeneration, forming a mixed forest (Gilbert, 1959; Jackson, 1968a; Hickey, 1994).

The canopy composition of pure rainforest can vary along elevation and edaphic gradients (Gilbert 1959; Jackson 1968, 1983; Kirkpatrick 1977, 1984; Jarman et al.1991, 1994). Species such as *Nothofagus cunninghamii* dominate lowland rainforests that occur on fertile, well-drained soils where they form a tall closed-forest with a low diversity of woody species (Read, 1995). As soil quality declines (i.e. lower fertility and /or poorer drainage), species such as *Eucryphia lucida* and *Phyllocladus aspleniifolius* become more common and the diversity of woody species increases (Read, 1995). However, it is understood that the processes of secondary succession in rainforest communities can take decades to centuries (e.g. Chambers et al., 1977; Mount, 1979; Ashton, 1981; Bowman and Jackson, 1981, McMahon, 1987; Attiwill, 1994; Woodgate et al., 1994).

Mixed Forest

Up to 20% of forests in Tasmania are mixed forest (Hickey and Savva, 1992).The structure of mixed forests varies from tall open-forests, dominated by eucalypts that can exceed 90 m in height, with a closed rainforest understorey to short forests in the sub-alpine zone with open montane rainforest understoreys (Wells and Hickey, 1999). A continuum between mixed forests and rainforest may exist along a gradient of increasing time since fire (Wells and Hickey, 1999).

Wells and Hickey (1999) suggested that within Tasmania, many mixed forest types have similarities with rainforest in terms of the vascular and non-vascular species composition of understorey and can therefore be ascribed to the rainforest groups of Jarman et al. (1994). In addition, Wells and Hickey (1999) have also indicated that dominant eucalypts tend to be associated with particular groups of rainforest (Table 31). The Tasmanian mixed forest communities are diverse in their structure and Wells and Hickey (1999) suggested that on oligotrophic soils of the western region, the species *Eucalyptus nitida* can be reduced in height. In contrast, on sites with higher fertility and rainfall, the dominant eucalypt species, *Eucalyptus obliqua* and *E. regnans*, can attain greater heights (Wells and Hickey, 1999).

Table 31. Affinity between rainforest groups and dominant eucalypts within mixed forests as indicated by Gilbert (1959), Jarman et al. (1994), Duncan (1985) and Kirkpatrick et al. (1988).

Rainforest Group	**Dominant overstorey eucalypts**
Callidendrous	*E. brookeriana, E. dalrympleana, E. delegatensis, E. obliqua, E. regnans*
Thamnic	*E. brookeriana, E. delegatensis, E. johnstonii, E. nitida, E. obliqua, E. subcrenulata*
Implicate	*E. nitida*
Open montane	*E. coccifera, E. gunnii, E. subcrenulata, E. urnigera*

Ecological Processes

Many ecological processes within Tasmanian rainforest and associated mixed forest communities are not well understood. Ecological drift (Jackson, 1968) has been used to explain development of soil and vegetation in relation to fire frequency. However, it has been suggested by Mount (1979) that the Jacksonian model is problematic because it assumes that changes in vegetation and soil structure can occur through chance differences in the intervals between successive fires (see Jackson and Brown, 1999). Mount (1979) argued that the physical environment (parent material, soil, topography and drainage) exerts control on vegetation development and that fire frequency is not a chance event as postulated by Jackson (1968). The Mount model describes processes where the type of plant community will have an inherent burning frequency related to the time taken following fire to reach a flammable condition. In this model it is believed that vegetation can burn once this stage is reached, with ignition being controlled by lightning and embers from other fires (Mount, 1979).

Recovery from disturbance other than fire

Read and Hill (1988) showed that the establishment of some Tasmanian rainforest species was related to the size of canopy gaps. However, establishment is also limited by the availability of propagules where a gap in the canopy has been formed (i.e. Grubb, 1977). It is possible that the range of rainforest communities can be extended within other forests by land slips (Cullen, 1991). Read and Hill (1983) have shown that tracts of rainforest previously cleared for agricultural use and abandoned, or grazed at low stocking rates for at least 30 years, are regenerating. This study showed that the main species recolonising were *Tasmannia lanceolata* (a bird-dispersed species) while *Atherosperma moschatum* and *Nothofagus cunninghamii* were slowly establishing from the forest edge.

In other studies, Harle et al (2002) investigated human impacts in western Tasmania and found that metal contaminants from mining operations could be transported by wind and therefore, affect regeneration capacity of native vegetation. Although Harle et al. (2002) suggested that there has been minimal impact to rainforest, historically mining activities and forestry operations have had significant ecological impacts through topsoil loss, erosion and changes in fire frequency. These may profoundly influence the rates of recovery. Calais and Kirkpatrick (1983) showed that areas scraped by logging machinery differed in their abundance and composition of regenerating rainforest species from those where material was piled. Read and Hill (1985) suggested that initial floristic composition of a disturbed area is an important indicator of the eventual species composition in the absence of wildfire. This study found that the less shade tolerant species, *Nothofagus cunninghamii* and *Eucryphia lucida* in association with *Atherosperma moschatum*, have capacity to continuously regenerate in canopy gaps, both vegetatively and by seedling establishment.

Dawson (1996) investigated the recolonisation of native vegetation on a heavily disturbed area of western Tasmania and considered the effects of nutrient availability on growth rates of several species. This study, conducted on abandoned mining land found that low soil pH was limiting potential growth rates and natural recolonisation rates, largely through its influence on heavy metal toxicity. Mining activities are an extreme case of disturbance. For example, where sulphide bearing rocks are extracted, if appropriate mitigation measures are not adopted, acidification of soils and high levels of toxicity may result. Accordingly, this can influence nutrient availability (Bradshaw and Chadwick, 1980).

Other similar studies have demonstrated that where extreme land degradation has occurred through mining activities, mineral toxicity can limit the potential for establishment of seedlings (i.e. Athar and Ahmad, 2002; Schützendübel and Polle, 2004; Zhao et al. 2006). Within the western region of Tasmania higher rainfall than most other areas is a regular occurrence and this may lead to loss of topsoil through erosion particularly where disturbance or vegetation removal has occurred.

Aim of Chapter

This chapter investigates the nature of secondary succession on anthropogenically disturbed sites in the western Tasmanian rainforest and wet eucalypt forest (*sensu* Kirkpatrick et al., 1988). Comparisons between the type of initial disturbance and the regeneration potential of vegetation and soil properties following disturbance are examined.

Methods

Study Site Selection

A total of six accessible sites with a known disturbance history and located within the rainforest were selected (Figure 77). An attempt was made to select sites with different environments and original vegetation types.

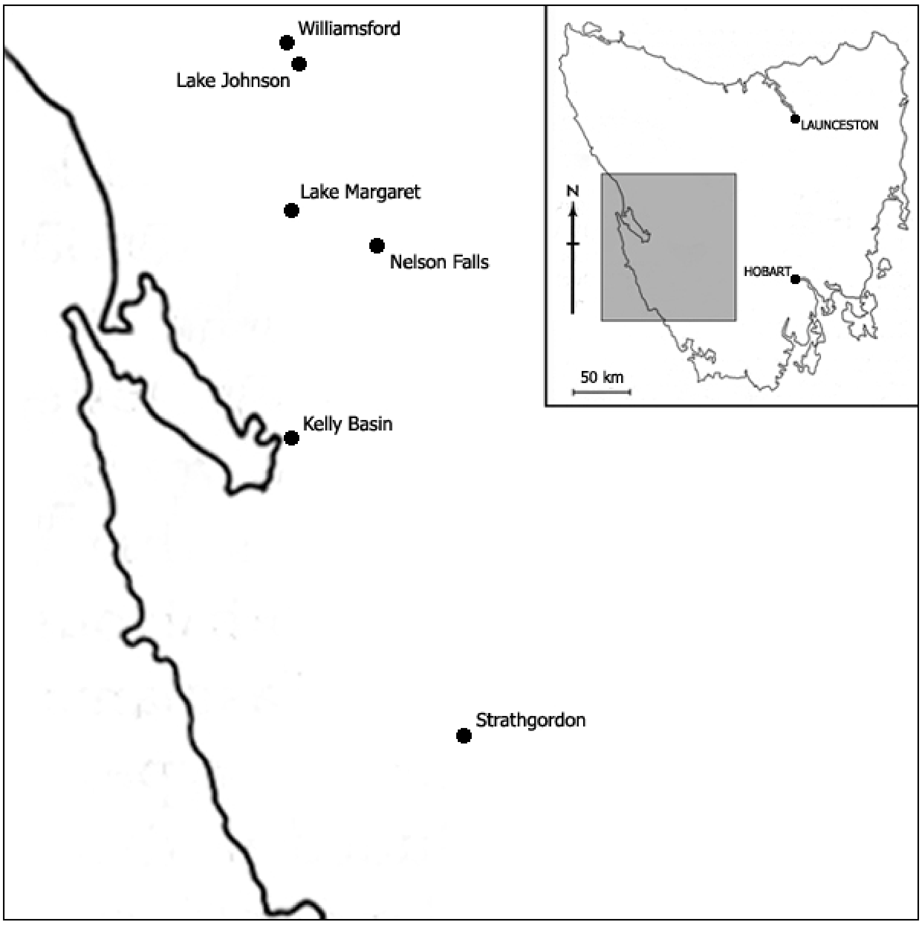

Figure 77. Map of Tasmania showing the location of all Western Tasmanian study sites.

Overview of Study Sites and Brief History

Kelly Basin

In the late 1800s, the port town of East Pillinger was established by the North Mount Lyell Copper Company on the shores of Macquarie Harbour in Kelly Basin (Figure 77). James Crotty formed the North Mount Lyell Copper Company in 1897. After formation of the company, Crotty initiated the construction of infrastructure which included a mine at the township of Linda, smelters at Crotty, a small settlement at the nearby location of Darwin, industrial facilities at the township of East Pillinger and a small gauge railway linking them. By 1898, the North Mount Lyell Copper Company had employed hundreds of men to construct the infrastructure which included three wooden wharves, a brick kiln, sawmill, ore crushing plant, railway terminus and shipping facility, workers huts, mess hall, and office buildings. A further small town, established adjacent to the port town at West Pillinger by the government of the day, included a police station, hotel and several stores (Figure 78).

Figure 78. The government-established town of West Pillinger is visible at the front of the image. The settlement at East Pillinger is visible towards the rear and left of the image. (Image source: State Library of Tasmania, W.L. Crowther Collection, ca. 1890. ADRI AUTAS001125298398).

The vision for development of the township at Kelly Basin and for the North Mount Lyell Copper Company was lost following the death of James Crotty in 1898 and The North Mount Lyell Copper Company merged with the Mount Lyell Company. As a result of the merger, most of the infrastructure at Kelly Basin was not required and was either removed to be utilised elsewhere or abandoned. In 1903, Strahan was selected as a preferred port over West Pillinger.

After the mining company left the township, some residents remained making a living by harvesting timber, firewood, sawmilling, and servicing the occasional ship or train. The railway remained open until 1925, mainly for the transportation of fire wood and timber to the mines. In the following year, the rail section between Kelly Basin and the township of Darwin was dismantled. Following its removal and the cessation of rail services, only two families, one shop and a hotel remained open. The last permanent residents left the township in 1943. Today, there is little evidence left of the townships that were established at Kelly Basin and remaining buildings are collapsing into the regenerating forest (National Parks and Wildlife Service, 2006).

All disturbed quadrats for the Kelly Basin study site are located in the settlement of East Pillinger (Figure 78).The control quadrats are approximately 1 km from East Pillinger. The vegetation of the control sites varies from wet eucalypt forest to rainforest. Historical evidence indicates that the majority of original vegetation at Kelly Basin was removed to facilitate construction activities (see Figure 79).

It is evident from historical records that a large proportion of the topsoil at the site was removed for construction purposes or subjected to erosion after exposure. Mapping from the Department of Primary Industries and Water (TASVEG 1.3) has identified *Leptospermum lanigerum – Melaleuca squarrosa* swamp forest and *Eucalyptus nitida* over rainforest as the major vegetation communities within the general area. However, vegetation adjacent to the study site is *Acacia melanoxylon* swamp forest.

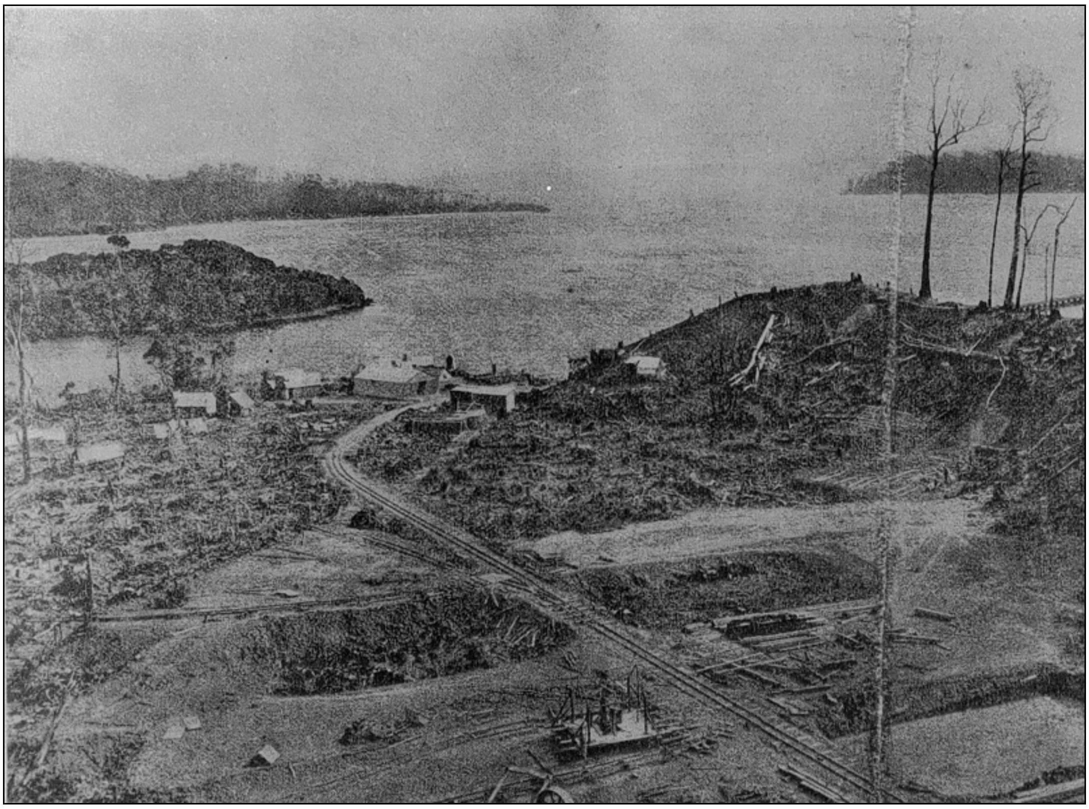

Figure 79. View of Pillinger during construction circa 1898. Image Source: Queenstown Information Centre and Galley Museum, Queenstown Tasmania.

Climate

No local climatic data are available for Kelly Basin. Climatic conditions were initially extrapolated by estimating an environmental gradient between Kelly Basin and the closest long-term weather station (operational from 1971 – 1991) located in Strahan approximately 25 km from Kelly Basin. Both sites have similarities in elevation (7 m) and aspect. However, rainfall may be much higher at Kelly Basin than Strahan (Nunez et al., 1996).

Bureau of Meteorology records indicate that mean annual rainfall at Strahan is 1658.5 mm. The station had a mean daily maximum temperature of 21.5 º C in February and a mean daily minimum temperature of 4.8º C in July. Rainfall at the Kelly Basin study site, as suggested by the rainfall modeling of Nunez et al. (1996), is likely to be within the range of 1900 to 2099 mm per annum with the wettest months being from June to August and the driest occur from January to March.

Geology and soils

The main geological sequences within the Kelly Basin area consist of Quaternary - Tertiary age sediments that are dominantly non-marine sequences of gravel, sand, silt, clay and regolith and related pyroclastic rocks (Tasmania Geological Survey, Mineral Resources of Tasmania, 2009).

Soils present within the control area are generally shallow and gradational clay loams. The upper horizon is fine grained material with incorporated organic matter and the B horizon is a brownish clay loam. The uppermost mineral horizon can be overlain by organic material up to 20 cm deep. The soils present within the area generally concur with the tenosol groups of Isbell (2002).

Lake Johnston

Lake Johnston is located in a glacial cirque about 8 km south of Rosebery and directly to the south of Mount Read. It is located within the boundaries of the ~138 ha Lake Johnston Nature Reserve (Figure 80). The reserve was declared primarily because it contains poorly-reserved rainforest communities of high conservation value. Anker et al. (2001) have shown that the Mount Read area contains some of the best examples of sub-alpine rainforest communities in Tasmania. The reserve is also considered important for nature conservation because it contains the rare and restricted *Orites milliganii*, at least seven species of the Tasmanian endemic conifers, one of the largest patches of the endemic deciduous beech, *Nothofagus gunnii* and two separate but genetically identical patches of subalpine Huon pine (*Lagarostrobos franklinii*) believed to have been derived from plants that have been present on the site for over 10 000 years (Shapcott et al. 1995; Barton and Colhoun, 1998)

The disturbance at the study site near Lake Johnston is the result of a geological survey line constructed in 1992/93. This line is approximately 2m wide and was cut through a *Nothofagus gunnii* dominated community at approximately 1000 m in elevation. The control quadrats were placed immediately adjacent to the transect line.

Figure 80. View of the Lake Johnston Nature Reserve. The study site is located to the left of the image. Source: DPIWE, 2001. Lake Johnston Nature Reserve Site Development Plan – 2001, p.1.

Climate

Climatic data from the Mount Read automatic weather station, located at 1120 m has been collected since 1996. These data indicate that Mount Read and its environs receive annual precipitation that can exceed 4000 mm per annum with an average of

3839 mm. The wettest period is from May to July when rainfall exceeds 350 mm per month, while the driest months are January and February, typically receiving less than 200 mm each.

Data from the Bureau of Meteorology indicates that the mean daily maximum temperature at Mount Read is 8.8º C. February is generally the warmest month with a mean daily maximum of 14.3º C. The annual average mean daily minimum temperature is 2.9º C with the coldest month being August which has a mean daily minimum of 0.2º C. Because of the cool conditions and a short growing season, growth rates could be expected to be slow in comparison to other areas within western Tasmania.

Geology and soils

The Mount Read area is composed of Cambrian metamorphosed rocks. Generally, these are mafic-ultramafic rocks with high levels of mineralization and are recognised widely as the 'Mount Read Volcanics' geological sequence. As a result of the high mineralization, the soil types that develop also tend to reflect this characteristic and this can profoundly affect plant growth rates.

Kirkpatrick and Dickinson (1984) found that in recently burned areas, a combination of prolonged exposure, heavy precipitation, strong winds and the frequent formation of needle ice was a cause of soil instability, even on gentle slopes. Little opportunity exists for biological fixation through higher plants within the Mt Read area as leguminous shrubs and herbs are virtually absent (Kirkpatrick and Dickinson, 1984). Other taxa that are known to be nitrogen fixers and identified by Carr et al. (1980) are also mainly absent or have low cover values.

The surface soils have lower pH values than those recorded from other alpine areas in Tasmania (Kirkpatrick and Dickinson, 1984). The soils are ferrosols (Isbell, 2002). The soil horizons are not well defined but the shallow (<5cm depth) uppermost horizon consists of a shallow (<5 cm depth) fine grained loam material with included small rocks up to 5 cm across. The B horizon consists of a fine grained dark yellow clay-loam.

Lake Margaret

Early in 1912, Maltese migrants to Tasmania began construction of a wooden tramway towards the site for the proposed Lake Margaret power station. Following construction of the tramway, a site was cleared for the power station and for the development of associated infrastructure on the banks of the Yolande River near the foothills of Mt Sedgwick and approximately 6 km north of the township of Queenstown on the west coast of Tasmania. The power station, which generated electricity for the Mt Lyell Company, commenced operation in 1914.

During the construction phase of the Lake Margaret hydro-electric development, a small township was built to provide accommodation and facilities for workers (Figure 81). A 'fire break' was maintained around the township during the early years of operation as a means to prevent damage from frequent bushfires. The break was reduced in width after Hydro Tasmania bought the power station in 1985 and because of reductions in labour, maintenance of the break ceased completely in 2001.

The disturbance at the Lake Margaret study site is located on an east-facing slope towards the western side of the township. All disturbed quadrats are located within the most recently cleared vegetation zone shown in Figure 81. All control quadrats are located in an undisturbed area with similar environmental characteristics.

Climate

The Bureau of Meteorology has recorded long-term rainfall data since 1945 at Lake Margaret. The mean annual rainfall is 2949 mm per annum. The wettest months are July and August when rainfall usually exceeds 300 mm. Temperature data are not recorded at the Lake Margaret weather station.

Mean temperatures (minimum and maximum) are extrapolated from values at the nearby Queenstown (7XS) weather station using the environmental lapse rate of Nunez (1986). The mean daily maximum temperature of the warmest month, January, would be expected to be approximately 15.0 ºC and the mean daily minimum for the coldest month in July is expected to be 4.2 ºC.

Geology and soils

The rocks at the Lake Margaret study site are Early Cambrian in age. Layered peridotite, serpentinite and other highly mineralised associated rock types predominate (Mineral Resources of Tasmania, 2009).

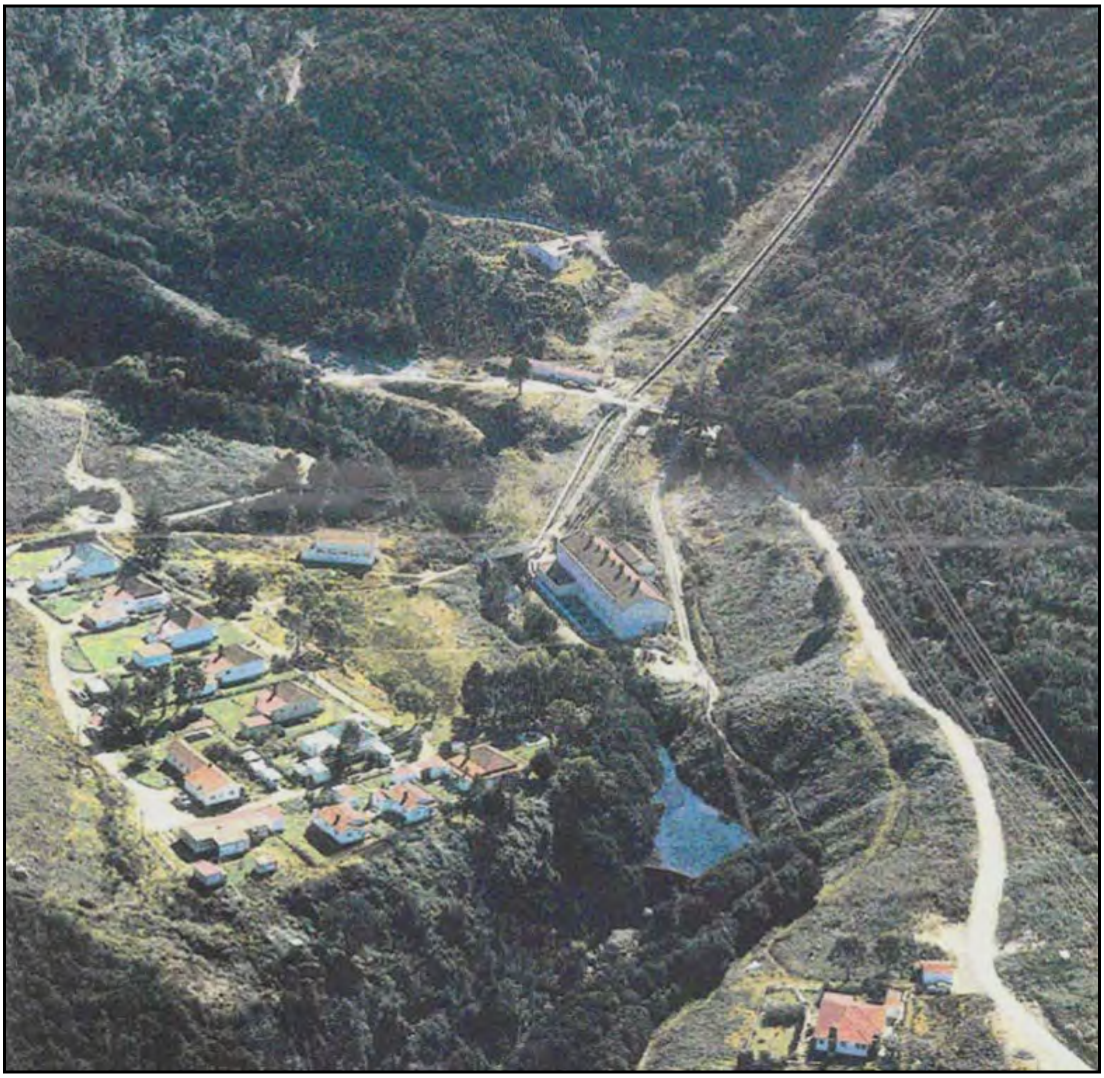

Figure 81. The Lake Margaret village in 1985. The study site is visible as the cleared area immediately to the left of the houses. Source: Lake Margaret Collection.

Soils in the control area are shallow, sandy and acidic with a layer of incorporated humus and other organic matter up to 10 cm deep. Clay-loam soils on Cambrian-Ordovician rock types also occur. Soils within the disturbed area are eroded and some mixing of the horizons has occurred. They are shallow and rocky but contain incorporated organic matter and are up to 10 cm depth. The soil types concur with the descriptions for the ferrosol group as defined by Isbell (2002).

Nelson Falls

The Nelson Falls study site is approximately 20 km east of the mining town of Queenstown in a small clearance adjacent to the Lyell Highway and is the site of a former dairy and pig farm. Stones which appear to be part of foundations for small buildings and other infrastructure are still visible at the site (Figure 82).

Figure 82. The study site at Nelson Falls is visible on the right of the image (ca. 1940). The remains of infrastructure are visible on the right towards the lower edge of the image. Image source: Queenstown Information Centre and Galley Museum, Queenstown Tasmania.

The study area at Nelson Falls today mostly consists of a lawn which appears to be maintained through the action of native marsupial grazing. Recently, there have been some limited attempts at rehabilitation of the site by staff of the Tasmanian National Parks and Wildlife Service mainly involved weed control within the adjacent areas and along the nearby roadsides. Some large non-native Monterey Cypress trees (*Cupressus macrocarpus*) were removed from the study site in 2001.

The location of all disturbed quadrats at the Nelson Falls study site is within the previously cleared area adjacent to the former house site. All control quadrats are located within the adjacent forest. The rainforest has occasional emergent eucalypts to 30 m high. The least disturbed vegetation within the area consists of rainforest. Smaller patches of wet sclerophyll forest are also present.

The ground cover of the control area is dominated by a dense layer of *Blechnum nudum*. In contrast, the wet scrub community contains *Acacia melanoxylon* as the dominant species with *Melaleuca squarrosa* and *Leptospermum nitidum* present in the lower stratum.

Climate

There are no local climate data available for the Nelson Falls study site. The study site is located approximately 40 km east of Queenstown. Rainfall data has been estimated from the maps of Nunez et al. (1996). The location of the two closest weather stations is at Queenstown and another at Lake St Clair. A weather station commenced operation at Queenstown in 1964 and ceased in 1995 (total of 31 years). This is considered to be a reliable source of data.

The maps in Nunez et al. (1996) suggest that rainfall at the Nelson Falls study site is likely to be within the range of 2500 – 2699 mm per annum. The wettest months are likely to be July and August with January and February being the driest months of the year. Applying the environmental lapse rate of Nunez (1986), and utilising data from the Queenstown weather station, the mean daily maximum temperature of the warmest month, January is expected to be approximately 14.3 ºC and the mean daily minimum in July would be approximately 4.3 ºC.

Geology and soils

Mapping by Mineral Resources of Tasmania (1: 250 000 scale) suggests that the area is underlain by the Arthur Metamorphic Complex and consists of chloritic schist with minor phyllite, dolomite and amphibolite with elements of garnetiferous quartzite. Soils within the control are typically dark shallow loams that contain a high percentage of incorporated organic matter and are similar to the ferrosols described by Isbell (2002). In contrast, the soils within the disturbed area contain a greater percentage of clay.

Strathgordon

Strathgordon is the site of a former HEC (Hydro Electric Commission) construction village located in southwest Tasmania near the foothills of the Twelvetrees Range (Figure 83). The approximate elevation of the Strathgordon is 360 m. The name 'Strathgordon' was officially gazetted in 1968 and the village established in 1969 to house workers on the Gordon River Stage 1 Hydro-electric Scheme. During the peak period of construction activities at Strathgordon, the permanent population reached almost 2500.

Figure 83. A view of part of the Strathgordon township (*ca.* 1970s). The study site, indicated by the arrow, is located near the transition in vegetation structure towards the rear of the image. Source: Aurora Energy.

The undisturbed vegetation communities within the region and surrounding the study site consist of a mosaic of rainforest and wet sclerophyll communities and occasional patches of buttongrass moorland. All control quadrats are located within the adjacent forest. Vegetation within the control consists of an emergent layer of *Eucalyptus nitida* with an understorey of *Acacia mucronata*, *Bauera rubioides*, *Gahnia grandis*, *Leptospermum glaucescens* and *Nothofagus cunninghamii*. The area chosen for the disturbed quadrats at the Strathgordon study site is located entirely within the area previously utilised for housing, buildings and infrastructure. Removal of buildings and infrastructure occurred during 1982-83.

Climate

Climatic data have been collected at Strathgordon by the Bureau of Meteorology since 1968, representing a total of 40 years. However, temperature data have been collected for only 26 years. Strathgordon receives a mean annual rainfall of 2566 mm with the two wettest months being August and September when the mean monthly rainfall typically exceeds 270 mm. The mean daily maximum temperature of the warmest months, December to February is 14º C and the mean daily minimum is of the coldest months, June to August, is 6.3º C.

Geology and soils

The main geological sequence at the Strathgordon study site has been mapped by Mineral Resources of Tasmania (1: 250 000) as a pale-weathering, thin bedded laminated quartz siltstone with subordinate interbedded fissile shale.

The soils are generally shallow light coloured loams that are derived from the underlying quartzitic parent material. The soil within the disturbed quadrats typically contains very little incorporated organic matter and has been subjected to extensive erosion and compaction from the operation of heavy machinery and associated construction activities.

In contrast, the control area contains a thick layer of accumulated organic material on the surface. Below the organic layer, the soils are generally light coloured and fine grained in the A horizon changing to material having a gravelly clay texture in the lower horizons. The soil type is consistent for the ferrosol group of soils described by Isbell (2002).

Williamsford

During 1891, the prospectors Concliffe and Will were following the Ring River in search of gold. They subsequently pegged the first mining leases on the steep slopes of the Mount Read massif. Commercial mining operations commenced in 1894.

Following the commencement of mining, a small settlement was established on the nearby slopes of Mt Hamilton. The settlement was located at approximately 1000 m elevation but was abandoned in the late 1890s because of its poor climate. Another township was established at a lower elevation at Williamsford (Figure 84).

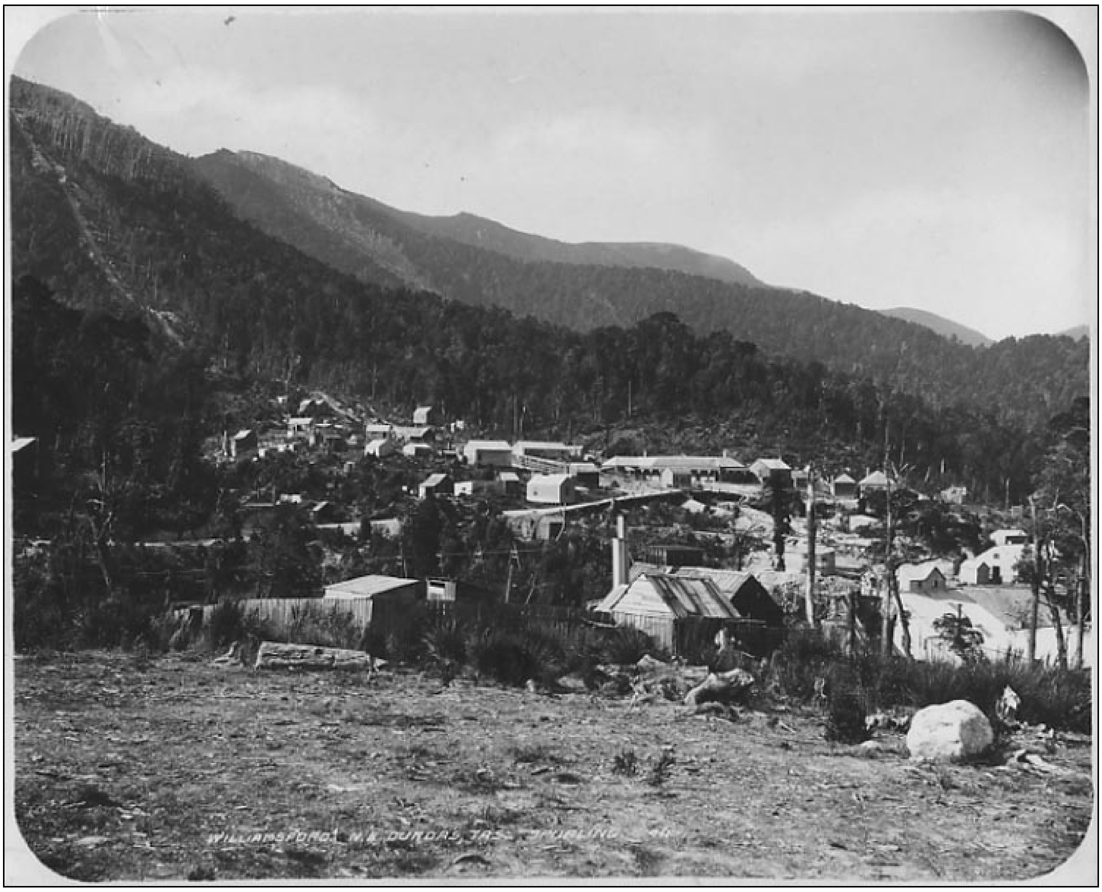

Figure 84. Williamsford township in 1900. The old haulage line is visible on the left of the image. Source: Spurling Photo, Archives Office of Tasmania.

Williamsford housed employees and others involved in the daily operations of the Hercules mine and associated infrastructure. Mining operations at Hercules occurred on a continuous basis from 1891 to 1986. The mine was re-opened to facilitate an additional small operation from 1996 to 1999. Following cessation of the mining activities in 1986, the township of Williamsford was closed and remaining residents were relocated to the nearby town of Rosebery.

The undisturbed vegetation surrounding the former township of Williamsford consists mostly of mixed forest with patches of dry sclerophyll communities present. Vegetation in the control is a dense low-growing forest to 15 m and is a mosaic of communities dominated by *Acacia melanoxylon*, *Eucalyptus nitida*, *Nothofagus* *cunninghamii* and *Leptospermum scoparium* in the upper stratum and *Acacia mucronata*, *Atherosperma moschatum Eucryphia lucida* and *Gahnia grandis* in the lower strata. All control quadrats are located less than 1 km from the disturbance. The disturbed quadrats at the Williamsford study site are located within the former township amongst housing and infrastructure. After abandonment of Williamsford in 1986 and removal of most of the infrastructure, driveways, drains and foundations for dwellings and other buildings that were present on site are still visible.

Climate

Long term climatic data are not available for the Williamsford study site and values have been extrapolated by applying the environmental lapse rate determined by Nunez (1986) from long-term data collected at Rosebery, 6 km to the north. Climatic records from Rosebery were collected between 1979 and 1993, a total of 14 years. Temperature data were collected for 10 years. Rosebery receives an average of 1952 mm of rainfall per annum. The mean daily maximum temperature of the warmest months between December to March is 16.4 º C. The mean daily minimum temperature of the coldest months from June to August is 6.6º C. The differences in elevation between the Rosebery weather station (165 m) and Williamsford (370 m) is 205 m. The environmental lapse rate of Nunez (1986) suggests temperatures at Williamsford are likely to be 15º C for the mean daily maximum temperature of the warmest moths and 5.2 º C for the mean daily minimum temperature of the coldest months. It is expected that the warmest and coldest months would be similar to Rosebery.

Geology and Soils

The main geological sequence occurring at Williamsford, has been mapped by Mineral Resources of Tasmania as a sequence of felsic to intermediate calc-alkaline (Central Volcanic Complex) and correlates. Layered peridotite, serpentinite and other associated rock types also occur in close proximity and these may have had some influence on the soil types. The soils at Williamsford are variable but are mostly shallow and light coloured loams. The control area contains a thick surface layer of organic material and is ferrosol in the classification of Isbell (2002). Soils within the disturbed area have been subjected to mixing and contain very little organic material.

High volumes of incorporated rock fragments up to 3 cm across are present. These are anthroposols in the classification of Isbell (2002).

Results

Vegetation

Kelly Basin

A total of 39 species (38 native, one non-native) were recorded within 80 quadrats (disturbed = 40, control = 40) at the Kelly Basin study site (Figure 85, Figure 86). *Acacia melanoxylon*, *Melaleuca ericifolia*, *Blechnum nudum*, *Blechnum wattsii*, *Coprosma nitida* and *Dicksonia antarctica* were common in both the control and disturbed quadrats.

From the 39 species recorded at the Kelly Basin study site, 31 were present within the disturbed quadrats and 28 were present within the control. Of these, a total of 12 were present only within the disturbed quadrats. One non-native taxa, *Zantedeschia aethiopica*, was present within three disturbed quadrats only and was absent within the control. Further details of species distribution are provided in Appendix A.

Figure 85. Typical view of dense understorey vegetation at the Kelly Basin control.

Figure 86. Typical view of understorey vegetation at the Kelly Basin disturbed area.

Species composition was significantly different between the control and disturbed quadrats (ANOSIM, R =0.7192, P = <0.001). Among the species that varied significantly in their frequency by treatment, the sedge, *Gahnia grandis* was confined to the disturbed quadrats and *Microsorum diversifolium* was confined to the control quadrats (Table 32). The tree, *Nothofagus cunninghamii*, occurred within all quadrats in the control area but was almost absent from the disturbed quadrats (Table 32).

There were six taxa, *Anopterus glandulosus*, *Atherosperma moschatum*, *Dicksonia antarctica*, *Eucryphia lucida*, *Hymenophyllum flabellatum*, and *Polystichum proliferum* concentrated within the control quadrats and these also occurred within the disturbed quadrats at a lower frequency (Table 32). Of these, *Eucryphia lucida*, was present only at a low frequency in the disturbed quadrats.

Three taxa, *Blechnum nudum*, *Coprosma nitida*, and *Melaleuca ericifolia* were concentrated within the disturbed quadrats and these also occurred within the control at a lower frequency (Table 32). All species that significantly varied in their frequency by treatment were native. Further details of species distribution are presented in Appendix A and Appendix B.

Table 32. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Kelly Basin study site.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	X^2	**P**
Gahnia grandis	0.00	40.00	20.000	<0.001
Melaleuca ericifolia	22.50	57.50	10.208	0.001
Coprosma nitida	40.00	82.50	15.221	<0.001
Blechnum nudum	42.50	80.00	11.850	0.001
Dicksonia antarctica	92.50	62.50	10.323	0.001
Pomaderris apetala	32.50	12.50	4.588	0.032
Polystichum proliferum	80.00	20.00	28.800	<0.001
Anopterus glandulosus	42.50	10.00	10.912	0.001
Clematis aristata	25.00	5.00	6.275	0.012
Histiopteris incisa	35.00	5.00	11.250	0.001
Atherosperma moschatum	87.50	10.00	48.080	<0.001
Hymenophyllum flabellatum	75.00	5.00	40.833	<0.001
Nothofagus cunninghamii	100.00	5.00	72.381	<0.001
Eucryphia lucida	70.00	2.50	39.432	<0.001
Microsorum diversifolium	30.00	0.00	14.118	<0.001

Results from the two dimensional ordination (Figure 87) indicate that the control and disturbed areas are separated into two discrete groups. The ordination indicates that a closer relationship exists within groups rather than between them.

The ordination diagram (Figure 87) shows that the disturbed quadrats occupy a larger area in ordination space suggesting the presence of a weaker similarity between quadrats within this group.

Vectors obtained from the two dimensional solution at the Kelly Basin study site are shown below in Figure 88. The significant vectors were bare ground ($R = 0.0691$, $P = <0.001$), rock cover ($R = 0.4351$, $P = <0.001$) and litter cover ($R = 0.3216$, $P = <0.001$). The disturbance vector was orthogonal to bare ground.

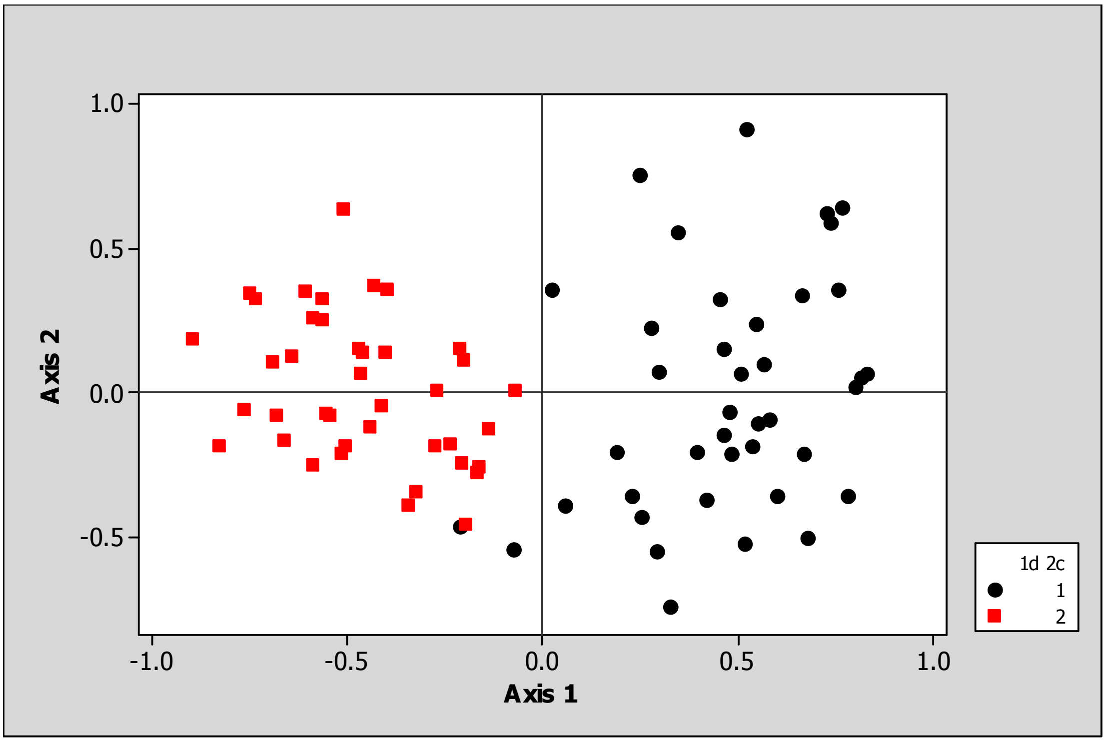

Figure 87. Two dimensional ordination of all quadrats (1 = disturbed, 2 = control) at the Kelly Basin study site (minimum stress = 0.209).

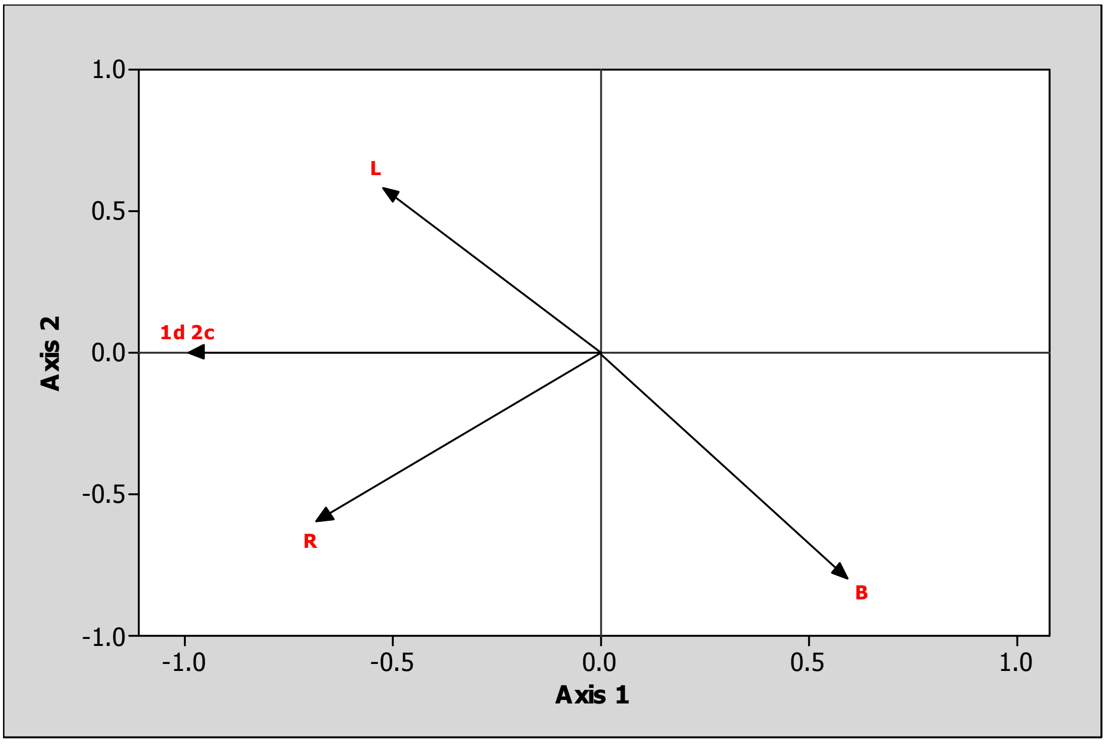

Figure 88. Vector fitting obtained for the Kelly Basin study site. B = bare ground; L = litter; R = rock cover; S = slope; 1d2c = disturbed/control.

Soils

Soil pH was the only soil property that differed significantly (P = 0.047) between the disturbed area and control at the Kelly Basin study site (Table 33). The soil was more acidic within the control (undisturbed) area than the disturbed.

Table 33. Mean values of soil analyses obtained from the Kelly Basin study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	4.12 (0.033)	0.269 (0.036)	8.9 (1.9)	9.16 (0.9)	34.05 (6.1)
Control	4.04 (0.016)	0.282 (0.062)	4.7 (0.76)	8.13 (1.1)	28.8 (5.3)
T	-2.19	0.18	-1.99	0.74	-0.29
P	0.047	0.858	0.073	0.472	0.772

Lake Johnston

Vegetation

A total of 24 species (24 native, 0 non-native) were recorded from within 80 quadrats (disturbed = 40, control = 40) at the Lake Johnston study site (Figure 89 and Figure 90). Two taxa, *Astelia alpina* and *Bellendena montana* were common within both the control and disturbed quadrats. Two other taxa, *Diselma archeri* and *Richea scoparia* are also common within both areas but at a lower frequency.

From the 24 species recorded, a total of 21 were present within the disturbed area and 18 were present within the control. Of the total species recorded from this site, seven occurred only within the disturbed area and three occurred only within the control quadrats

The disturbed quadrats contained a high frequency of the species *Astelia alpina*, *Bellendena montana*, *Carpha alpina*, *Dichelachne* sp., *Tasmannia lanceolata* and *Trochocarpa gunnii*. In contrast, the control quadrats contained a high frequency of *Astelia alpina*, *Diselma archeri*, *Nothofagus gunnii* and *Richea scoparia*.

Figure 89. Typical view of the study site at Lake Johnston

Figure 90. View of the Lake Johnston study site showing recolonisation

Species composition varied significantly between the control and disturbed quadrats (ANOSIM, R =0.8684, P = <0.001). Among the species that differed significantly, by their treatment, three taxa, *Carpha alpina*, *Senecio pectinatus*, and *Trochocarpa gunnii*, were confined to the control quadrats (Table 34). One species, *Nothofagus gunnii*, was present in all control quadrats but also occurred at a lower frequency within the disturbed area (Table 34).

Three species, *Athrotaxis selaginoides*, *Diselma archeri*, and *Richea scoparia*, were concentrated within the control quadrats but also occurred within the disturbed area at a lower frequency (Table 34). Six taxa showed the reverse tendency and were concentrated in the disturbed area while also occurring within the control at lower frequencies (Table 34). Further details of species distribution are provided in Appendix A and Appendix B.

Table 34. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Lake Johnston study site.

Species	Control (% frequency)	Disturbed (% frequency)	X^2	P
Carpha alpina	0.00	97.50	76.098	<0.001
Trochocarpa gunnii	0.00	60.00	34.286	<0.001
Senecio pectinatus	0.00	25.00	11.429	0.001
Dichelachne spp.	5.00	82.50	48.813	<0.001
Anemone crassifolia	5.00	50.00	20.313	<0.001
Helichrysum milliganii	7.50	40.00	11.655	0.001
Tasmannia lanceolata	25.00	75.00	20.000	<0.001
Athrotaxis selaginoides	37.50	7.50	10.323	0.001
Richea scoparia	45.00	17.50	7.040	0.008
Bellendena montana	50.00	75.00	5.333	0.021
Astelia alpina	62.50	95.00	12.624	<0.001
Diselma archeri	85.00	42.50	15.632	<0.001
Nothofagus gunnii	100.00	7.50	68.837	<0.001

The disturbed and control quadrats occupy discrete areas in ordination space (Figure 91). The diagram indicates that a closer relationship exists within the groups rather than between them. The variables, bare ground (R = 0.4349, P = 0.004) and litter cover (R = 0.3716, P = 0.017) had significant vectors in ordination space (Figure 92).

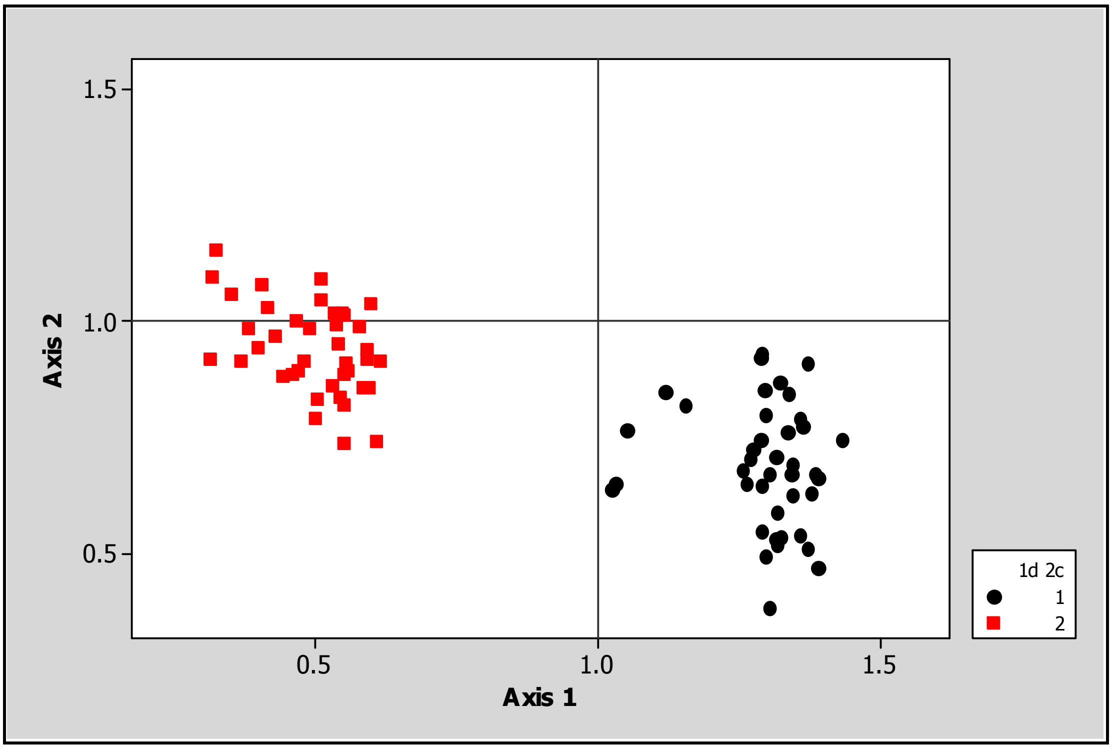

Figure 91. Two dimensional ordination of all quadrats (1 = disturbed, 2 = control) at the Lake Johnston study site (minimum stress = 0.275927).

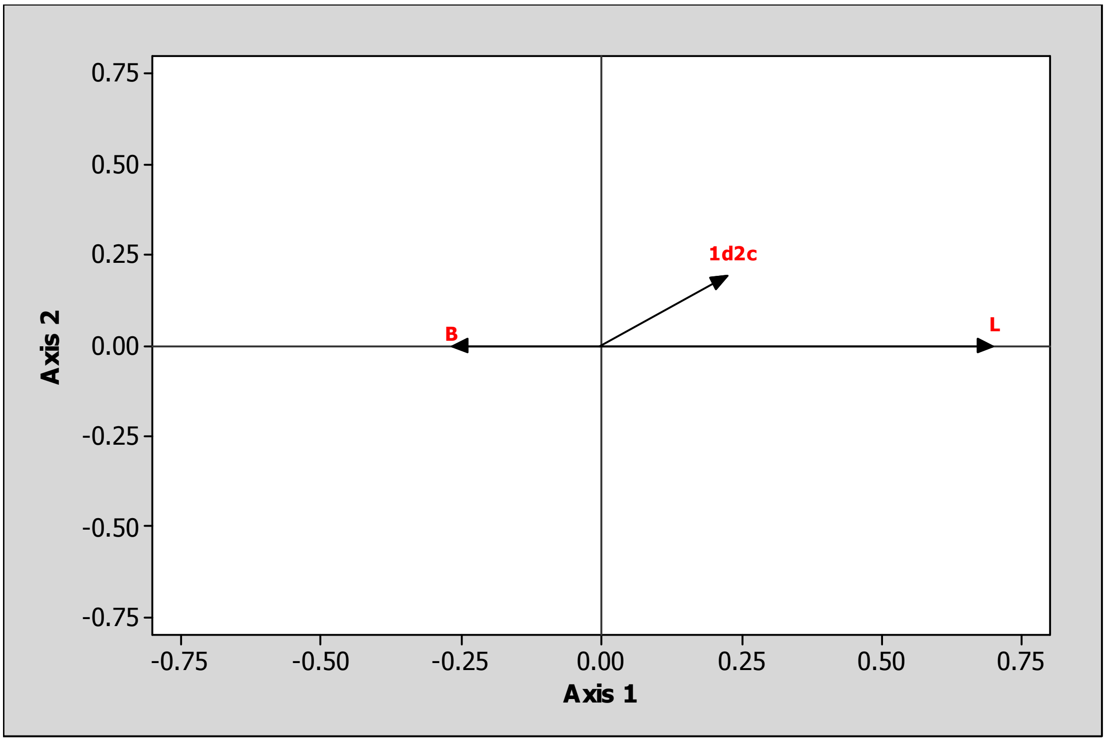

Figure 92. Significant vectors at the Lake Johnston study site Legend: B = bare ground; L = litter cover, 1d2c = disturbance

Soils

There were significant differences in available phosphorus (P = <0.001) and total carbon (P = 0.038) between the control and disturbed areas at the Lake Johnston study site with the values being higher within the control (Table 35).

Table 35. Mean values of soil analyses obtained from the Lake Johnson study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

	Mean Values of Soil Properties				
	pH	**N**	**P**	**C**	**N:C**
Disturbed	3.69 (0.21)	0.094 (0.18)	2.4 (0.31)	3.69 (0.87)	66.7 (12)
Control	3.59 (0.43)	0.152 (0.16)	5.3 (0.54)	8.49 (0.36)	55.8 (11)
T	-2.28	2.46	4.58	2.36	-0.86
P	0.40	0.25	<0.001	0.038	0.404

Lake Margaret

Vegetation

A total of 55 species (46 native, nine non-native) were recorded from within 80 quadrats (disturbed = 40, control = 40) at the Lake Margaret study site (Figure 93 and Figure 94). Two taxa, *Blechnum wattsii* and *Monotoca glauca* were common within both the disturbed area and the control. One taxon, *Gahnia grandis* was also common within both areas but had a lower frequency.

From the total 55 species recorded, 31 were significantly different in their occurrence between the disturbed and control areas (Table 36). Species that occurred within the disturbed area at relatively high frequencies included the widespread tree *Acacia melanoxylon* and understorey plants including *Baloskion tetraphyllum*, *Blechnum wattsii*, *Melaleuca squarrosa*, *Pteridium esculentum* and *Sprengelia incarnata*.

A total of nine non-native species recorded at this site, *Acer* spp., *Digitalis purpurea*, *Cotoneaster franchetii*, *Holcus lanatus*, *Ilex aquifolium*, *Narcissus pseudonarcissus*, *Rubus fruticosus*, *Salix alba* and *Vinca major* were all confined to the disturbed area. In contrast to the disturbed area, the control quadrats contained a high frequency of *Anopterus glandulosus*, *Bauera rubioides*, *Eucalyptus nitida*, *Monotoca elliptica*, *Leptospermum nitidum*, and *Phebalium squameum*.

Figure 93. View of the previously disturbed area at the Lake Margaret study site. This area is at an early stage of succession - indicated by the presence of immature forest.

Figure 94. Typical view of understorey vegetation within the control area at Lake Margaret

Species composition was significantly different between he control and disturbed quadrats (ANOSIM, R =0.9747, P = <0.001). Among the species that significantly varied in their frequency by treatment, a total of 20 were confined to the disturbed quadrats (Table 36). As discussed above, these included the tree, *Acacia melanoxylon* and several other small trees and large shrubs. The tree-fern, *Dicksonia antarctica* and the endemic *Gaultheria hispida* also occurred only within the disturbed quadrats.

Several non-native species, including *Cotoneaster franchetii*, *Digitalis purpurea*, and *Rubus fruticosus* were confined to the disturbed quadrats. Four taxa were confined to the control quadrats (Table 36). One species, *Leptospermum nitidum*, occurred within all control quadrats (Table 36). Six taxa were concentrated within the control but occurred in the disturbed area at lower frequencies (Table 36). Two taxa, *Leptecophylla juniperina* and *Pteridium esculentum*, showed the reverse pattern and were concentrated in the disturbed and occurred within the control at lower frequency (Table 36). Further details of species distribution are presented in Appendix A and Appendix B.

Table 36. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Lake Margaret study site. * = non-native species.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	**X^2**	**P**
Baloskion australe	0.00	77.50	50.612	<0.001
Melaleuca squarrosa	0.00	70.00	43.077	<0.001
Acacia melanoxylon	0.00	67.50	40.755	<0.001
Juncus spp.	0.00	60.00	34.286	<0.001
Gaultheria hispida	0.00	60.00	34.286	<0.001
Pomaderris apetala	0.00	50.00	26.667	<0.001
Sprengelia incarnata	0.00	47.50	24.918	<0.001
Dicksonia antarctica	0.00	45.00	23.226	<0.001
**Rubus fruticosus*	0.00	45.00	23.226	<0.001
Acaena novae-zelandiae	0.00	42.50	21.587	<0.001
**Cotoneaster franchetii*	0.00	42.50	21.587	<0.001
**Acer* spp.	0.00	40.00	20.000	<0.001
Gleichenia microphylla	0.00	37.50	18.462	<0.001
Baloskion tetraphyllum	0.00	37.50	18.462	<0.001
Clematis aristata	0.00	35.00	16.970	<0.001
Polystichum proliferum	0.00	32.50	15.522	<0.001
**Digitalis purpurea*	0.00	32.50	15.522	<0.001

Species	Control (% frequency)	Disturbed (% frequency)	X^2	P
Leptospermum scoparium	0.00	30.00	14.118	<0.001
Acacia stricta	0.00	30.00	14.118	<0.001
Epacris impressa	0.00	27.50	12.754	<0.001
Richea pandanifolia	5.00	20.00	4.114	0.043
Pteridium esculentum	10.00	80.00	39.596	<0.001
Leptecophylla juniperina	15.00	50.00	11.186	0.001
Bauera rubioides	72.50	45.00	6.241	0.012
Monotoca elliptica	82.50	62.50	4.013	0.045
Anopterus glandulosus	85.00	15.00	39.200	<0.001
Eucalyptus nitida	92.50	30.00	32.916	<0.001
Leptospermum nitidum	100.00	0.00	80.00	<0.001
Drymophila cyanocarpa	70.00	0.00	43.077	<0.001
Phebalium squameum	67.50	0.00	40.755	<0.001
Telopea truncata	55.00	0.00	30.345	<0.001

The quadrats from the Lake Margaret study site separated into two discrete groups in ordination space (Figure 95). The diagram indicates that closer relationships exist within the groups rather than between them and the quadrats are more heterogeneous in the control. There is no evidence of a continuum between the disturbed area and control.

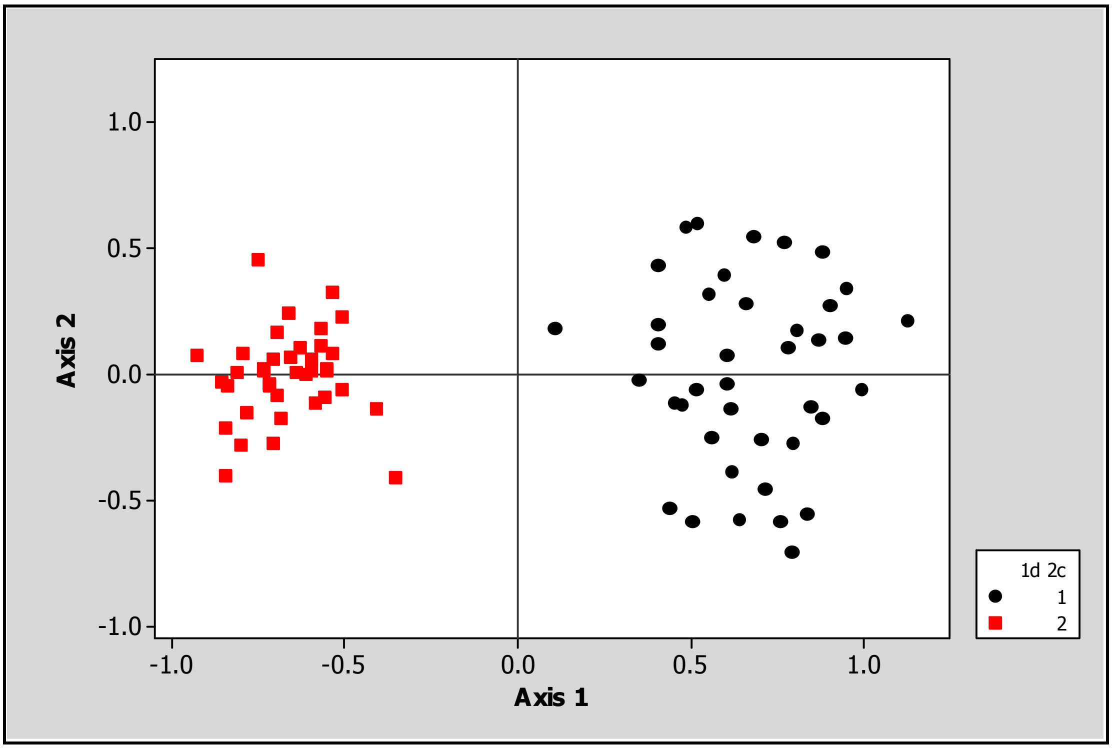

Figure 95. Two dimensional ordination of all quadrats (1 = disturbed, 2 = control) at the Lake Margaret study site (minimum stress = 0.213055).

Vectors obtained from the two dimensional solution at the Lake Margaret study site are shown in Figure 96. The significant vectors were aspect (R = 0. 8736, P = <0.001) bare ground (R = 0.5646, P = <0.001), elevation (R = 0.9115, P = <0.001), litter cover (R = 0.5067, P = <0.001), and slope (R = 0.8752, P = <0.001).

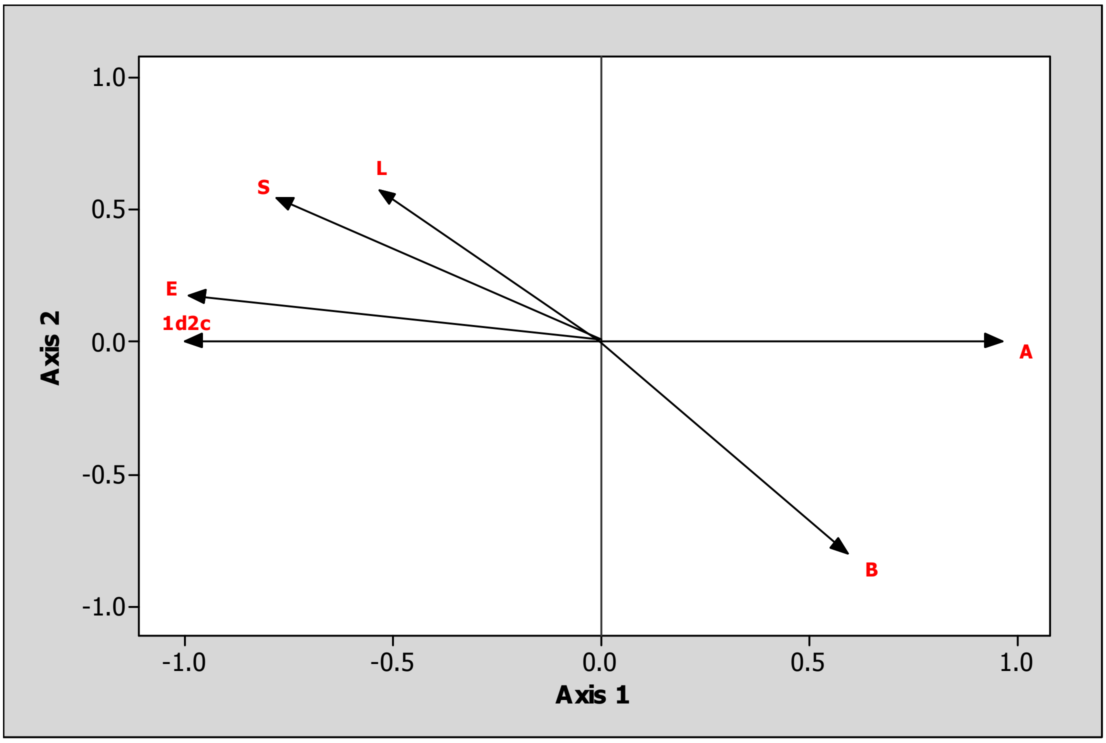

Figure 96. Vectors obtained for the Lake Margaret study site. Legend: A = aspect; B = bare ground; E = elevation; L = litter cover; S = slope; 1d2c = disturbance

Soils

There were significant differences in soil pH (P = <0.001), percentage nitrogen (P = <0.001) and total carbon (P = <0.001) between the disturbed area and control at the Lake Margaret study site (Table 37).

The soil was more acidic in the control and contained a higher percentage of nitrogen and carbon compared to the disturbed area. Phosphorus and the nitrogen to carbon ratio had minimal differences at this study site.

Table 37. Mean values of soil analyses obtained from the Lake Margaret study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

	Mean Values of Soil Properties				
	pH	**N**	**P**	**C**	**N:C**
Disturbed	4.43 (0.079)	0.304 (0.031)	10.3 (2.0)	9.6 (0.43)	31.6 (2.9)
Control	3.47 (0.14)	0.934 (0.11)	7.8 (0.62)	22.4 (1.1)	23.4 (3.0)
T	-6.14	5.63	-1.18	11.24	-0.159
P	<0.001	<0.001	0.265	<0.001	0.130

Nelson Falls

Vegetation

A total of 44 species (38 native, 6 non-native) were recorded from within 80 quadrats (disturbed = 40, control = 40) at the Nelson Falls study site (Figure 97, Figure 98). There were no species recorded that occurred in high frequencies in the disturbed and control quadrats at this study site.

From the 44 species recorded, a total of 16 occurred within the disturbed quadrats and 37 were present within the control. Of these, 29 species occurred only within the control quadrats. There was no species recorded that was present within all control quadrats. However, two taxa, *Blechnum nudum* and *Leptospermum nitidum* were recorded within almost all of the control quadrats.

The disturbed quadrats contained a high frequency of *Acaena novae-zelandiae*, *Juncus pallidus*, *Lycopodiella diffusa* and *Oxylobium ellipticum*. Two non-native taxa, *Aira caryophyllea* and *Anthoxanthum odoratum* also had a high frequency within the disturbed quadrats with *A. caryophyllea* being present within all disturbed quadrats. A total of seven non-native taxa were recorded at the Nelson Falls site. One taxon, *Ilex aquifolium*, was confined to the control area.

Figure 97. Typical view of the disturbed area at the Nelson Falls study site

Figure 98. View of the transition between control and disturbed areas at Nelson Falls.

Species composition was significantly different between the control and disturbed areas at the Nelson Falls study site (ANOSIM, R =0.9969, P = <0.001). Among the species that significantly varied in their frequency by treatment, a total of six were confined to the disturbed quadrats (Table 38). Of these, there was one non-native species, *Aira caryophyllea*, present in all quadrats and another, *Anthoxanthum odoratum*, also had a relatively high frequency (Table 38).

A total of 22 species were confined to the control quadrats and these included the large trees, *Acacia melanoxylon*, *Atherosperma moschatum*, *Leptospermum nitidum*, and *Nothofagus cunninghamii* (Table 38). The ferns, *Blechnum nudum* and *Blechnum wattsii* were also present within the control quadrats at a high frequency. Four taxa, *Acaena novae-zelandiae*, *Geranium potentilloides*, *Juncus pallidus*, and *Oxalis perennans* were concentrated within the disturbed quadrats but also occurred within the control (Table 38). The non-native bramble, *Rubus fruticosus*, showed the reverse pattern and was concentrated within the disturbed area (Table 38). Further details of species distribution are presented in Appendix A and Appendix B.

Table 38. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Nelson Falls study site. * = non-native species.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	X^2	**P**
**Aira caryophyllea*	0.00	100.00	80.000	<0.001
Lycopodiella diffusa	0.00	95.00	72.381	<0.001
**Anthoxanthum odoratum*	0.00	52.50	28.475	<0.001
Oxylobium ellipticum	0.00	47.50	24.918	<0.001
Carex gaudichaudiana	0.00	37.50	18.462	<0.001
Baloskion tetraphyllum	0.00	27.50	12.754	<0.001
Geranium potentilloides	7.50	25.00	4.501	0.034
Oxalis perennans	10.00	35.00	7.168	0.007
Juncus pallidus	17.50	55.00	12.170	<0.001
Acaena novae-zelandiae	22.50	57.50	10.208	0.001
Clematis aristata	25.00	0.00	11.429	0.001
Phebalium squameum	27.50	0.00	12.754	<0.001
Eucryphia lucida	30.00	0.00	14.118	<0.001
Polystichum proliferum	30.00	0.00	14.118	<0.001
Atherosperma moschatum	32.50	0.00	15.522	<0.001
Pomaderris elliptica	32.50	0.00	15.522	<0.001

Species	Control (% frequency)	Disturbed (% frequency)	X^2	P
Acradenia frankliniae	32.50	0.00	15.522	<0.001
Muehlenbeckia gunnii	35.00	0.00	16.970	<0.001
Coprosma nitida	35.00	0.00	16.970	<0.001
Anopterus glandulosus	37.50	0.00	18.462	<0.001
Bauera rubioides	40.00	0.00	20.000	<0.001
Dicksonia antarctica	42.50	0.00	21.587	<0.001
Acacia melanoxylon	52.50	0.00	28.475	<0.001
Leptospermum scoparium	57.50	0.00	32.281	<0.001
Blechnum wattsii	67.50	0.00	40.755	<0.001
Monotoca elliptica	67.50	0.00	40.755	<0.001
Nothofagus cunninghamii	70.00	0.00	43.077	<0.001
Melaleuca squarrosa	72.50	0.00	45.490	<0.001
Gahnia grandis	72.50	0.00	45.490	<0.001
Baloskion australe	75.00	0.00	48.000	<0.001
Blechnum nudum	92.50	0.00	68.837	<0.001
Leptospermum nitidum	92.50	0.00	68.837	<0.001

The quadrats from the Nelson Falls study site separated into two discrete groups in two dimensional ordination space (Figure 99). The diagram indicates that a closer relationship exists within the groups rather than between them and the quadrats were more heterogeneous within the control area (Figure 99).

Significant vectors obtained from the two-dimensional solution for the Nelson Falls study site are shown below in Figure 100. The significant vectors were bare ground (R = 0.4603, P = 0.004), disturbed quadrats (R = 0.9938, P = <0.001) and litter cover (R = 0.7188, P = <0.001).

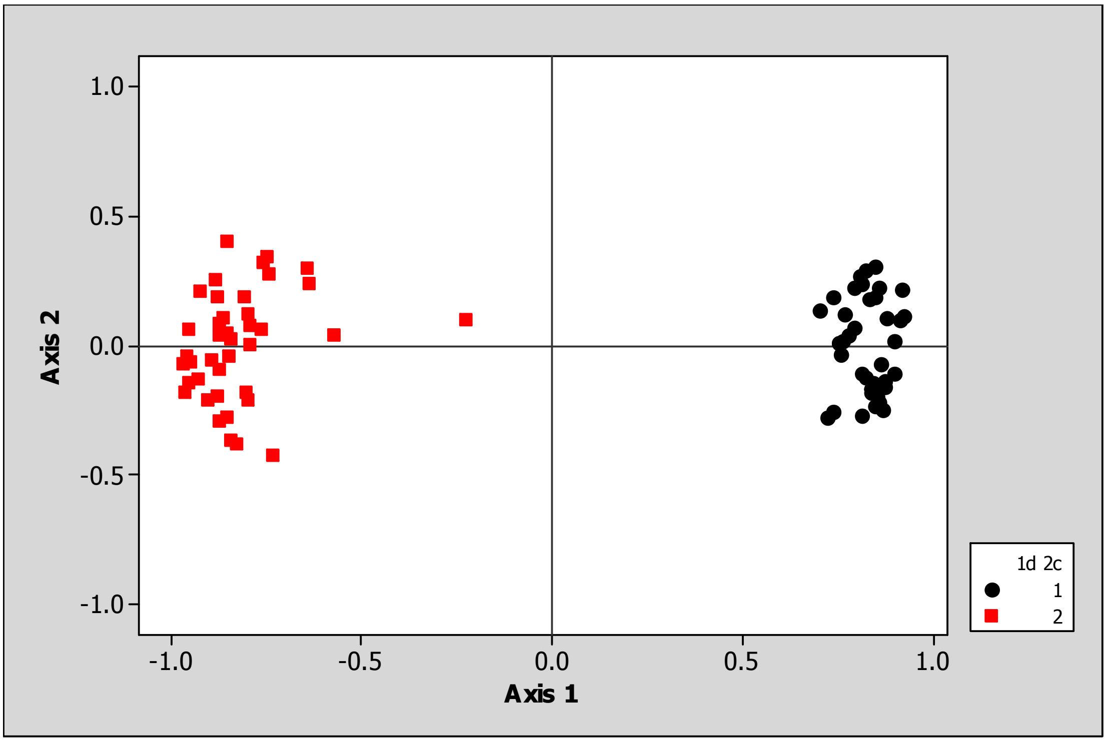

Figure 99. Two dimensional ordination of all quadrats (1 = disturbed, 2 = control) at the Nelson Falls study site (minimum stress = 0.120551).

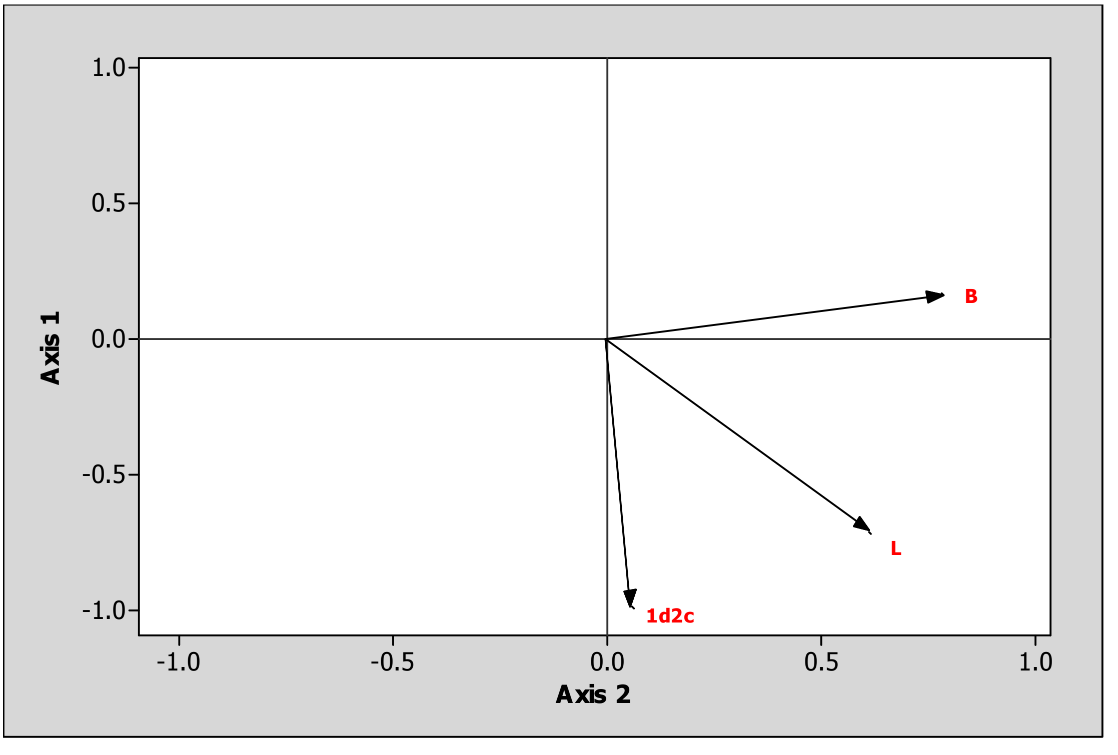

Figure 100. Significant vectors at the Nelson Falls study site Legend: B = bare ground; L = litter cover; 1d2c = disturbance.

Soils

There were significant differences in soil pH (P = 0.002), percentage nitrogen (P = <001), total phosphorus (P = <0.001), and the N:C ratio (P = 0.01) between the disturbed area and the control at the Nelson Falls study site (Table 39).

The phosphorus level was almost five times higher within the disturbed area. The soil within the disturbed area was more acidic and contained less nitrogen than the control. The nitrogen to carbon ratio was significantly higher within the disturbed area.

Table 39. Mean values of soil analyses obtained from the Nelson Falls study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	4.18 (0.07)	0.269 (0.07)	20.7 (0.035)	9.44 (5.9)	35.09 (0.47)
Control	4.66 (0.01)	0.333 (0.051)	4.4 (0.72)	8.71 (1.7)	26.1 (5.6)
T	3.85	-44.47	5.57	-1.95	3.26
P	0.002	<0.001	<0.001	0.08	0.01

Strathgordon

Vegetation

A total of 74 species (67 native, seven non-native) were recorded from within 80 quadrats (disturbed = 40, control = 40) at the Strathgordon site (Figure 101 and Figure 102). Four species, *Acacia mucronata*, *Gahnia grandis*, *Gleichenia microphylla*, and *Leptospermum glaucescens*, were common within both the disturbed quadrats and control. *Eucalyptus nitida* was common to both areas but had a higher frequency in the control quadrats.

From the 74 species recorded at this study site, a total of 37 occurred within the control and 51 within the disturbed area. Of these, 37 were confined to the disturbed quadrats and 23 were confined to the control. A total of seven non-native taxa, *Centaurium erythraea*, *Dactylis glomerata*, *Erica lusitanica*, *Holcus lanatus*, *Lotus corniculatus*, *Rorippa nasturtium-aquaticum* and *Sonchus asper*, were confined to the disturbed quadrats. Further details of species distribution are provided in Appendix A and Appendix B.

Figure 101. General view of disturbed area at the Strathgordon study site.

Figure 102. View of soil compaction at the Strathgordon study site. The image shows the location of a former residential site – most likely a residential driveway

Species composition was significantly different between the control and disturbed areas (ANOSIM, R =0.9683, P = <0.001). Among the species that varied significantly in their frequency by treatment, a total of 19 were confined to the disturbed quadrats and 14 confined to the control (Table 40).

Several small herbaceous taxa and graminoids were concentrated within the disturbed quadrats and these were absent from the control (Table 40). A total of eight native taxa, including *Acacia mucronata*, *Comesperma volubile*, *Eucryphia lucida*, *Gahnia grandis*, *Gleichenia microphylla*, *Gymnoschoenus sphaerocephalus*, *Nothofagus cunninghamii* and *Leptospermum glaucescens*, were concentrated in the control quadrats but these were also present within the disturbed quadrats at lower frequencies (Table 40). One taxon, *Acacia melanoxylon*, showed the reverse and was concentrated within the disturbed quadrats but occurred within the control quadrats at a lower frequency (Table 40). All Non-native species were concentrated within the disturbed quadrats (Table 40). Further details of species distribution are presented in Appendix A and Appendix B.

Table 40. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Strathgordon study site. * = non-native species.

Species	**Control**	**Disturbed**	**X^2**	**P**
**Centaurium erythraea*	0.00	82.50	56.170	<0.001
Acacia dealbata	0.00	62.50	36.364	<0.001
Juncus kraussii	0.00	62.50	36.364	<0.001
Acianthus caudatus	0.00	60.00	34.286	<0.001
Oxalis perennans	0.00	50.00	26.667	<0.001
**Sonchus asper*	0.00	50.00	26.667	<0.001
Pteridium esculentum	0.00	47.50	24.918	<0.001
Blechnum nudum	0.00	45.00	23.226	<0.001
Acacia myrtifolia	0.00	45.00	23.226	<0.001
Poa spp.	0.00	45.00	23.226	<0.001
Acaena novae-zelandiae	0.00	37.50	18.462	<0.001
Acacia verticillata	0.00	37.50	18.462	<0.001
Geranium potentilloides	0.00	35.00	16.970	<0.001
**Holcus lanata*	0.00	35.00	16.970	<0.001
Hypericum graminifolium	0.00	35.00	16.970	<0.001
Hydrocotyle hirta	0.00	30.00	14.118	<0.001
Juncus pallidus	0.00	30.00	14.118	<0.001
Eucalyptus obliqua	0.00	27.50	12.754	<0.001
Pomaderris elliptica	0.00	20.00	11.429	0.001
Acacia melanoxylon	35.00	47.50	1.289	<0.001

Species	Control	Disturbed	X^2	P
Gahnia grandis	92.50	67.50	7.812	0.005
Leptospermum glaucescens	90.00	57.50	10.912	0.001
Eucryphia lucida	50.00	27.50	4.266	0.039
Acacia mucronata	90.00	35.00	25.813	<0.001
Comesperma volubile	52.50	12.50	14.587	<0.001
Gymnoschoenus	37.50	5.00	12.624	<0.001
Atherosperma moschatum	27.50	0.00	12.754	<0.001
Leptecophylla juniperina	30.00	0.00	14.118	<0.001
Isolepis nodosa	32.50	0.00	15.522	<0.001
Baloskion australe	35.00	0.00	16.970	<0.001
Agastachys odorata	40.00	0.00	20.000	<0.001
Blechnum wattsii	40.00	0.00	20.000	<0.001
Leptocarpus tenax	40.00	0.00	20.000	<0.001
Cenarrhenes nitida	42.50	0.00	21.587	<0.001
Melaleuca squamea	42.50	0.00	21.587	<0.001
Banksia marginata	45.00	0.00	23.226	<0.001
Histiopteris incisa	45.00	0.00	23.226	<0.001
Melaleuca squarrosa	60.00	0.00	34.286	<0.001
Drosera pygmaea	62.50	0.00	36.364	<0.001
Hypolaena fastigiata	67.50	0.00	40.755	<0.001

The quadrats from the Strathgordon study site separated into two discrete groups in ordination space (Figure 103). The diagram indicates that a closer relationship exists within the two groups rather than between them.

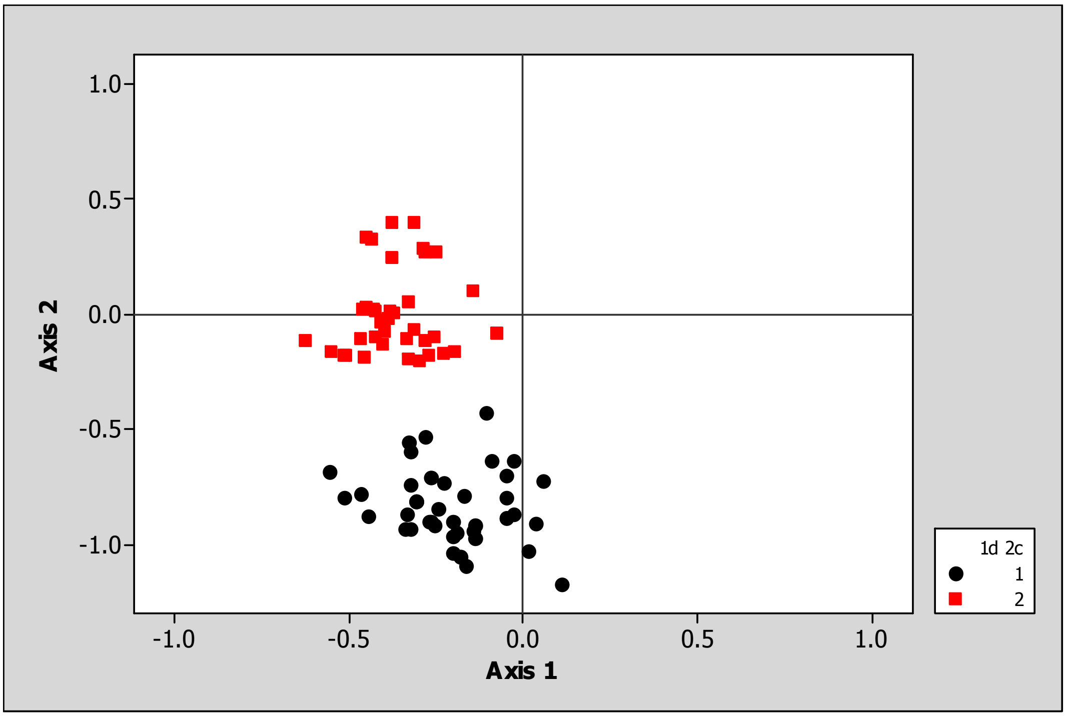

Figure 103. Two dimensional ordination of all quadrats (1 = disturbed, 2 = control) at the Strathgordon study site (minimum stress = 0.106277).

The variables 1d2c (R = 0.9678, P = <0.001), aspect (P = 0.000, R = 0.7647); bare ground (R = 0.4120, P = <0.001); rock cover (R = 0.7255, P = <0.001); litter cover (R = 0.7196, P = <0.001); and elevation (R = 0.9539, P = <0.001) had significant vectors in ordination space (Figure 104).

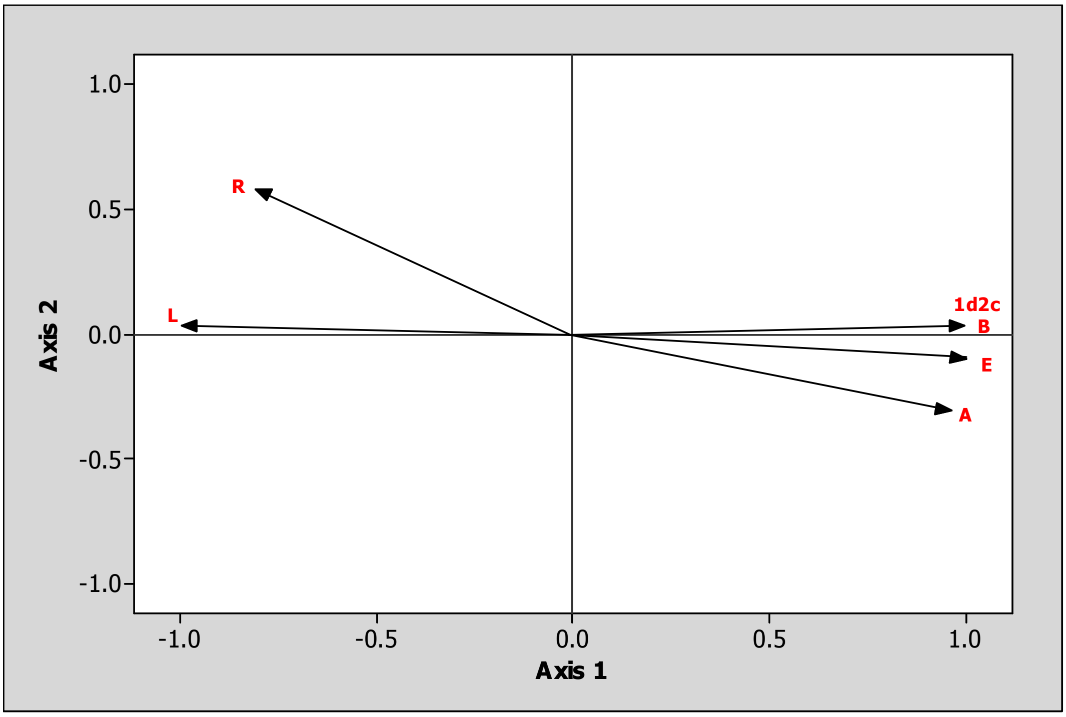

Figure 104. Significant vectors (P < 0.05) at the Strathgordon study site. Legend: A = aspect; B = bare ground; E = elevation; L = litter cover; S = slope; 1d2c = disturbance.

Soils

There were significant differences in soil pH (P = 0.012), percentage nitrogen (P = 0.012) and the nitrogen to carbon ratio (P = 0.002) between the disturbed area and control at the Strathgordon study site (Table 41).

The soil was more acidic within the control and contained higher levels of nitrogen compared to the disturbed area. The nitrogen to carbon ratio was also significantly higher within the control area at this study site.

Table 41. Mean values of soil analyses obtained from the Strathgordon study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	4.35 (0.12)	0.086 (0.012)	3.2 (0.022)	1.46 (0.53)	18.6 (0.27)
Control	3.96 (0.054)	0.126 (0.054)	3.7 (0.023)	5.63 (0.59)	21.6 (0.98)
T	-2.97	-2.97	1.26	0.07	4.12
P	0.012	0.012	0.224	0.495	0.002

Williamsford

Vegetation

A total of 53 species (44 native, nine non-native) were recorded from within 80 quadrats (disturbed = 40, control = 40) at the Williamsford study site (Figure 105 and Figure 106). Four taxa, *Dicksonia antarctica*, *Gahnia grandis*, *Leptospermum scoparium* and *Polystichum proliferum* were common within both the control and disturbed quadrats.

From the 53 species recorded from the Williamsford study site, 34 occurred within the disturbed quadrats and 36 within the control. *Blechnum wattsii* was also common to both areas but had a lower frequency. Of the 53 species recorded, 16 occurred only within the disturbed quadrats and 18 occurred only within the control.

The disturbed quadrats (Figure 105) contained high frequencies of *Austrodanthonia caespitosa*, *Dicksonia antarctica*, *Juncus* spp., *Leptospermum scoparium*, *Oxalis perennans*, and *Pteridium esculentum*. The nine non-native taxa recorded were confined to the disturbed quadrats. One of these, *Dactylis glomerata* was present within all disturbed quadrats. Further details of species distribution are provided in Appendix A and Appendix B.

Figure 105. Typical view of disturbance at the Williamsford study site

Figure 106. Typical view of the control area (left) adjacent to a developed car parking area at the Williamsford study site.

Species composition was significantly different between the control and disturbed areas (ANOSIM, R =0.9132, P = <0.001). Among the species that significantly varied in their frequency by treatment, 11 were confined to the disturbed quadrats (Table 42). Of these, six were non-native and one *Dactylis glomerata*, was present in all quadrats (Table 42). Several large trees including *Acacia melanoxylon*, *Eucalyptus nitida*, *Leptospermum nitidum* and *Phyllocladus aspleniifolius* were confined to the control (Table 42). One native taxon, *Atherosperma moschatum* was present at a relatively high frequency within the disturbed quadrats but also occurred in the control at a lower frequency (Table 42). Further details of species distribution are presented in Appendix A and Appendix B.

Table 42. Percentage frequency of all species that were significantly different in their occurrence in disturbed and control quadrats at the Williamsford study site. * = non-native species.

Species	**Control (% frequency)**	**Disturbed (% frequency)**	**X^2**	**P**
**Dactylis glomerata*	0.00	100.00	80.000	<0.001
**Crocosmia X crocosmifolia*	0.00	97.50	76.098	<0.001
**Pinus radiata*	0.00	90.00	65.455	<0.001
**Cytisus scoparius*	0.00	82.50	56.170	<0.001
Austrodanthonia caespitosa	0.00	82.50	56.170	<0.001
Oxalis perennans	0.00	82.50	56.170	<0.001
Pteridium esculentum	0.00	70.00	43.077	<0.001
**Sonchus asper*	0.00	45.00	23.226	<0.001
Epacris lanuginosa	0.00	45.00	23.226	<0.001
Poa spp.	0.00	45.00	21.587	<0.001
**Rubus fruticosus*	0.00	30.00	14.118	<0.001
Tasmannia lanceolata	5.00	22.50	5.156	0.023
Leptospermum glaucescens	17.50	42.50	5.952	0.015
Atherosperma moschatum	62.50	97.50	15.313	<0.001
Nothofagus cunninghamii	77.50	35.00	14.679	<0.001
Gleichenia microphylla	75.00	30.00	16.241	<0.001
Eucryphia lucida	80.00	27.50	22.175	<0.001
Blechnum nudum	22.50	5.00	5.165	0.023
Juncus spp.	100.00	15.00	59.130	<0.001
Phyllocladus aspleniifolius	25.00	0.00	11.429	0.001
Eucalyptus nitida	27.50	0.00	12.574	<0.001
Trochocarpa gunnii	27.50	0.00	12.574	<0.001
Leptospermum nitidum	27.50	0.00	12.574	<0.001
Cenarrhenes nitida	35.00	0.00	16.970	<0.001
Acacia melanoxylon	40.00	0.00	20.00	<0.001
Acacia mucronata	42.50	0.00	21.587	<0.001

Quadrats from the Williamsford study site separated into two discrete groups in the two dimensional ordination (Figure 107). The diagram indicates that a closer relationship exists within the two groups rather than between them (Figure 107).

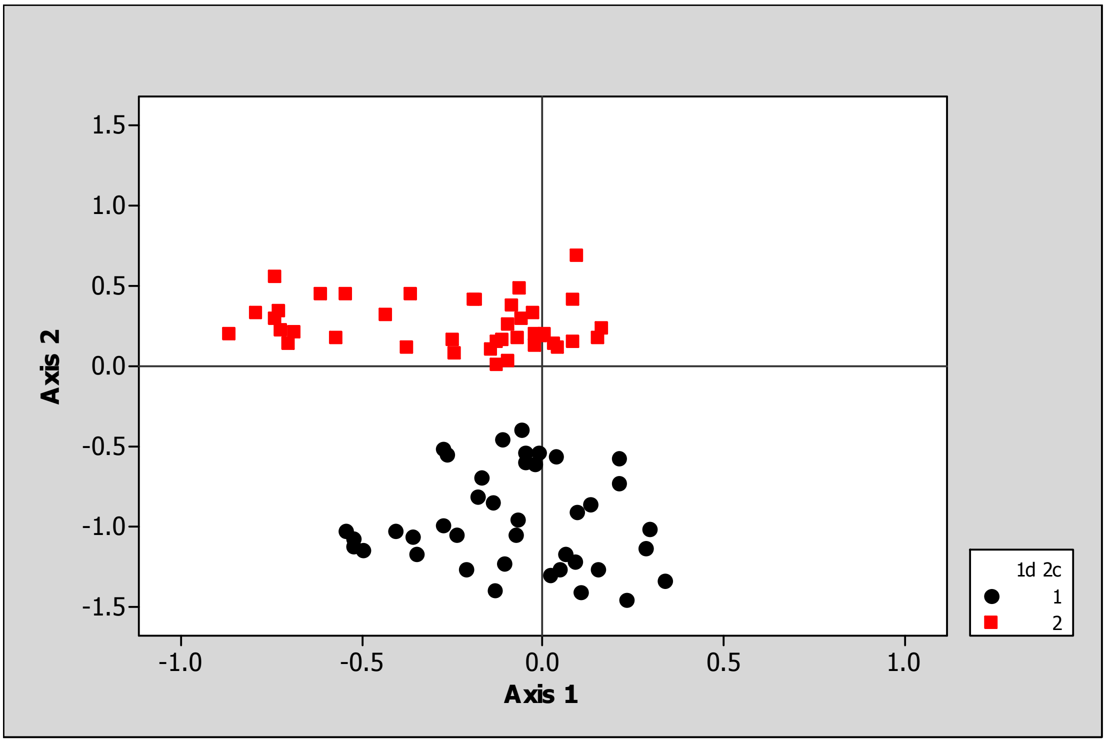

Figure 107. Two dimensional ordination of all quadrats (1 = disturbed, 2 = control) at the Williamsford study site (minimum stress = 0.232119).

Significant vectors for the Williamsford study site are shown below in (Figure 108). The significant vectors were bare ground (R = 0.3963, P = 0.001); rock cover (R = 0.3090, P = 0.021); slope (R = 0.7464, P = <0.001); aspect (R = 0.3364, P = 0.010); elevation (R = 0.9511, P = <0.001); and disturbance (R = 0.9610, P = <0.001).

The vectors for disturbed quadrats and slope were in the opposite direction to those for elevation, bare ground and rock cover. Aspect was independent of the other vectors at this site (Figure 108).

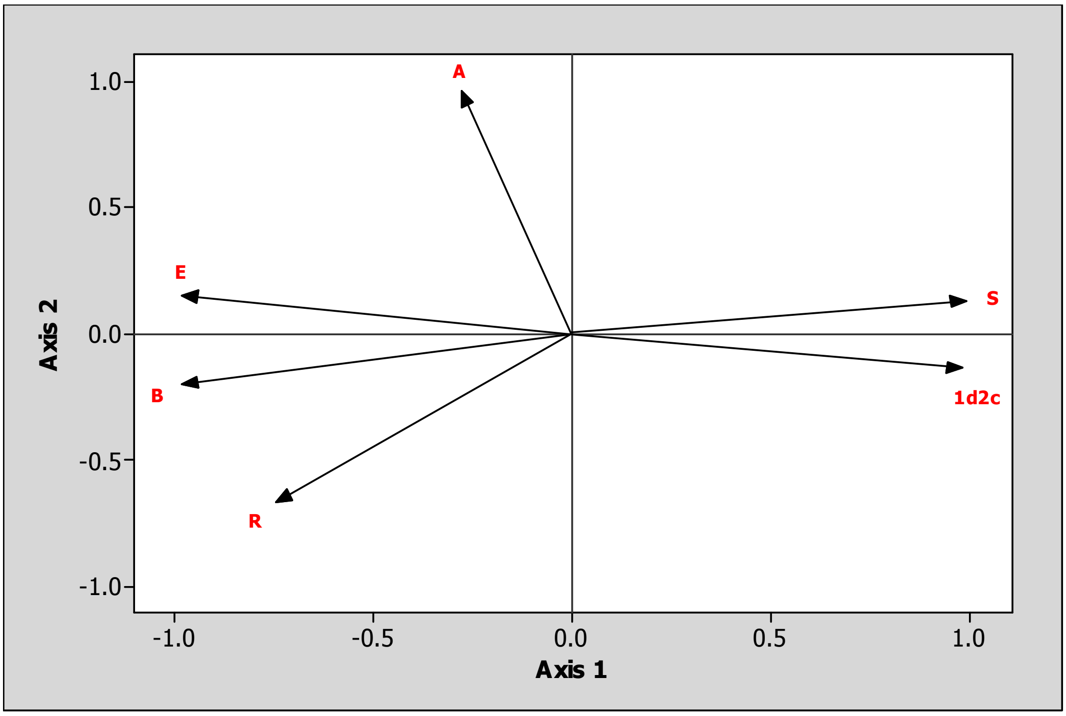

Figure 108. Significant vectors at the Williamsford study site. Legend: A = aspect; B = bare ground; E = elevation; L = litter cover; R = rock cover; S = slope; 1d2c = disturbance.

Soils

There were significant differences with all measured soil properties (Table 43). Soils within the disturbed area were more acidic (P = <0.001) and contained significantly greater levels of nitrogen (P = <0.001), phosphorus (P = 0.008) and carbon (P = 0.001). The nitrogen to carbon ratio (P = <0.001) was slightly lower within the disturbed area.

Table 43. Mean values of soil analyses obtained from the Williamsford study site. DF = 18, n = 10 disturbed, 10 control. Standard error is shown in brackets.

Mean Values of Soil Properties

	pH	N	P	C	N:C
Disturbed	3.78 (0.076)	0.409 (0.043)	16.3 (4.7)	10.3 (0.77)	25.2 (3.0)
Control	4.53 (0.065)	0.363 (0.065)	5.0 (0.059)	9.58 (1.0)	26.4 (1.7)
T	7.51	52.79	-3.42	-4.11	-4.65
P	<.001	<0.001	0.008	0.001	<.001

Species distribution within rainforest ecosystems

A total of 155 species (121 native, 34 non-native) were recorded from the six rainforest study sites examined (see Appendix A and Appendix B). Of the total species recorded, 41 occurred only in the disturbed quadrats, 102 within both the control and disturbed quadrats and 11 occurred only within the control quadrats.

The ANOSIM results (Table 32, Table 34, Table 36, Table 38, Table 40, Table 42, Table 44) indicate that significant differences exist in species composition by treatment between the disturbed and control areas at all sites investigated. A total of 97 species (85 native, 12 non-native) significantly differed between the disturbed and control areas. From these, 48 were present only within the disturbed areas and 28 were present only within the control areas (Table 44). A total of 16 species were recorded from within both the disturbed and control areas. There were no species recorded that differed significantly between the disturbed and control areas that were recorded at all sites. Generally, there is no observable pattern to the distribution of species.

While there were several species recorded within three sites, two native species, *Acacia melanoxylon* and *Blechnum nudum*, were significantly different in abundance between the disturbed and control areas at four sites. At three sites, *Acacia melanoxylon* was significantly more abundant within the control. The greater abundance found within the disturbed area at Lake Margaret may be related to frequent ongoing disturbance that occurred at the site. It is known that *Acacia melanoxylon* can exist as soil-stored seed for long periods and is a colonising species of disturbed areas. Accordingly, it may be postulated that following the cessation of disturbance, conditions were favourable to the germination and establishment of *Acacia melanoxylon*.A group of species differ significantly between control and disturbed within several sites (Table 44). Most of these species have significant differences at more than one site and are consistent in their response. In addition, many of these species are persistently more abundant within the disturbed areas (Table 44) and have been the focus of many studies on regeneration in disturbed areas of western Tasmania. As a result, many of these are considered to be initial colonisers of disturbed areas in western Tasmania. These include *Acacia dealbata* (Gilbert, 1959; Cunningham and Cremer, 1965; Forestry Commission 1991; Jordan et al., 1992), *Histiopteris incisa*, *Pteridium esculentum* (Cremer and Mount, 1965), *Acacia melanoxylon* (Hickey, 1982), *Tasmannia lanceolata* (Read and Hill, 1988), *Gahnia grandis* (Williamson, 1990; Hickey, 1994), *Atherosperma moschatum* and

Eucryphia lucida (Neyland and Hickey, 1990; Hickey and Wilkinson, 1999). In addition to the species considered above that are significantly more abundant within the disturbed areas, a number of the species recorded from the rainforest sites were more abundant within the controls (Table 44).

The reversal in tendency with some species may be a result of different stages of succession. It is likely that, at least some of the controls have not reached a final stage of succession (or climax community) and therefore, this may partially explain why differences exist in species abundance between and within the sites. Although Hickey (1994), indicated that rainforests of Tasmania exhibit structural and floristic diversity, it has been suggested that these communities can be considered to be in a disclimax state as a result of previous disturbance history, with particular reference to fire (e.g. Jackson, 1968, 1983; Brown and Podger, 1982; Read and Hill, 1983; Hill and Read, 1984). It is conceivable that vegetation within the disturbed areas and controls at the rainforest sites examined are most likely in transitional through different seral stages or they may be at alternative stable conditions (Jackson, 1968; Beisner et al., 2003; Schröder et al., 2005).

Table 44. Summary of significant differences in frequencies of taxa between disturbed and control areas. C = more abundant in control, D = more abundant in disturbed, - = absent, insignificant or not tested, * = non-native species. KB = Kelly Basin, LJ = Lake Johnston, LM = Lake Margaret, NF = Nelson Falls, S = Strathgordon, W = Williamsford. Shaded cells indicate a reversal in tendency.

	Site					
Taxon	**KB**	**LJ**	**LM**	**NF**	**S**	**W**
Acaena novae-zelandiae	-	-	D	D	D	-
Pteridium esculentum	-	-	D	-	D	D
Oxalis perennans	-	-	-	D	D	D
Tasmannia lanceolata	-	D	-	-	-	D
Baloskion tetraphyllum	-	-	D	D	-	-
**Sonchus asper*	-	-	-	-	D	D
Poa spp.	-	-	-	-	D	D
Geranium potentilloides	-	-	-	D	D	-
Juncus pallidus	-	-	-	D	D	-
**Rubus fruticosus*	-	-	D	-	-	D
Melaleuca ericifolia	D	-	-	-	-	-
Hymenophyllum flabellatum	D	-	-	-	-	-
Carpha alpina	-	D	-	-	-	-
Senecio pectinatus	-	D	-	-	-	-

Taxon	Site KB	LJ	LM	NF	S	W
Dichelachne spp.	-	D	-	-	-	-
Anemone crassifolia	-	D	-	-	-	-
Helichrysum milliganii	-	D	-	-	-	-
Bellendena montana	-	D	-	-	-	-
Astelia alpina	-	D	-	-	-	-
Gaultheria hispida	-	-	D	-	-	-
Sprengelia incarnata	-	-	D	-	-	-
**Cotoneaster franchetii*	-	-	D	-	-	-
**Acer* spp.	-	-	D	-	-	-
**Digitalis purpurea*	-	-	D	-	-	-
Acacia stricta	-	-	D	-	-	-
Epacris impressa	-	-	D	-	-	-
Richea pandanifolia	-	-	D	-	-	-
**Aira caryophyllea*	-	-	-	D	-	-
Lycopodiella diffusa	-	-	-	D	-	-
**Anthoxanthum odoratum*	-	-	-	D	-	-
Oxylobium ellipticum	-	-	-	D	-	-
Carex gaudichaudiana	-	-	-	D	-	-
**Centaurium erythraea*	-	-	-	-	D	-
Acacia dealbata	-	-	-	-	D	-
Juncus kraussii	-	-	-	-	D	-
Acianthus caudatus	-	-	-	-	D	-
Acacia myrtifolia	-	-	-	-	D	-
Acacia verticillata	-	-	-	-	D	-
**Holcus lanata*	-	-	-	-	D	-
Hypericum graminifolium	-	-	-	-	D	-
Hydrocotyle hirta	-	-	-	-	D	-
Eucalyptus obliqua	-	-	-	-	D	-
**Dactylis glomerata*	-	-	-	-	-	D
**Crocosmia X crocosmifolia*	-	-	-	-	-	D
**Pinus radiata*	-	-	-	-	-	D
**Cytisus scoparius*	-	-	-	-	-	D
Austrodanthonia caespitosa	-	-	-	-	-	D
Epacris lanuginosa	-	-	-	-	-	D
Atherosperma moschatum	C	-	-	C	C	D
Eucryphia lucida	D	-	-	C	C	C
Blechnum nudum	D	-	-	C	D	C
Gahnia grandis	D	-	-	C	C	-
Polystichum proliferum	C	-	D	C	-	-
Clematis aristata	C	-	D	C	-	-
Dicksonia antarctica	C	-	D	C	-	-
Coprosma nitida	D	-	-	C	-	-

Taxon	Site KB	LJ	LM	NF	S	W
Pomaderris apetala	C	-	D	-	-	-
Trochocarpa gunnii	-	D	-	-	-	C
Baloskion australe	-	-	D	C	C	-
Melaleuca squarrosa	-	-	D	C	C	-
Acacia melanoxylon	-	-	D	C	C	C
Juncus spp.	-	-	D	-	-	C
Gleichenia microphylla	-	-	D	-	-	C
Leptospermum scoparium	-	-	D	C	-	-
Leptecophylla juniperina	-	-	D	-	C	-
Pomaderris elliptica	-	-	-	C	D	-
Blechnum wattsii	-	-	-	C	C	-
Leptospermum glaucescens	-	-	-	-	C	D
Anopterus glandulosus	C	-	C	C	-	-
Nothofagus cunninghamii	C	-	-	C	-	C
Histiopteris incisa	C	-	-	-	C	-
Leptospermum nitidum	-	-	C	C	-	C
Bauera rubioides	-	-	C	C	-	-
Monotoca elliptica	-	-	C	C	-	-
Eucalyptus nitida	-	-	C	-	-	C
Phebalium squameum	-	-	C	C	-	-
Acacia mucronata	-	-	-	-	C	C
Cenarrhenes nitida	-	-	-	-	C	C
Microsorum diversifolium	C	-	-	-	-	-
Athrotaxis selaginoides	-	C	-	-	-	-
Richea scoparia	-	C	-	-	-	-
Diselma archeri	-	C	-	-	-	-
Nothofagus gunnii	-	C	-	-	-	-
Drymophila cyanocarpa	-	-	C	-	-	-
Telopea truncata	-	-	C	-	-	-
Acradenia frankliniae	-	-	-	C	-	-
Muehlenbeckia gunnii	-	-	-	C	-	-
Gymnoschoenus sphaerocephalus	-	-	-	-	C	-
Comesperma volubile	-	-	-	-	C	-
Isolepis nodosa	-	-	-	-	C	-
Agastachys odorata	-	-	-	-	C	-
Leptocarpus tenax	-	-	-	-	C	-
Melaleuca squamea	-	-	-	-	C	-
Banksia marginata	-	-	-	-	C	-
Drosera pygmaea	-	-	-	-	C	-
Hypolaena fastigiata	-	-	-	-	C	-
Phyllocladus aspleniifolius	-	-	-	-	-	C

The ordination diagram (Figure 109) shows that a high level of heterogeneity exists between the sites in ordination space. As shown in the diagram, there appears to be an absence of directional tendency between the disturbed and control areas. The outliers at Nelson Falls and Lake Johnston sites can be clearly indicated in the diagram (Figure 109) and possible explanations for their outlying positions may be related to differences in environmental conditions.

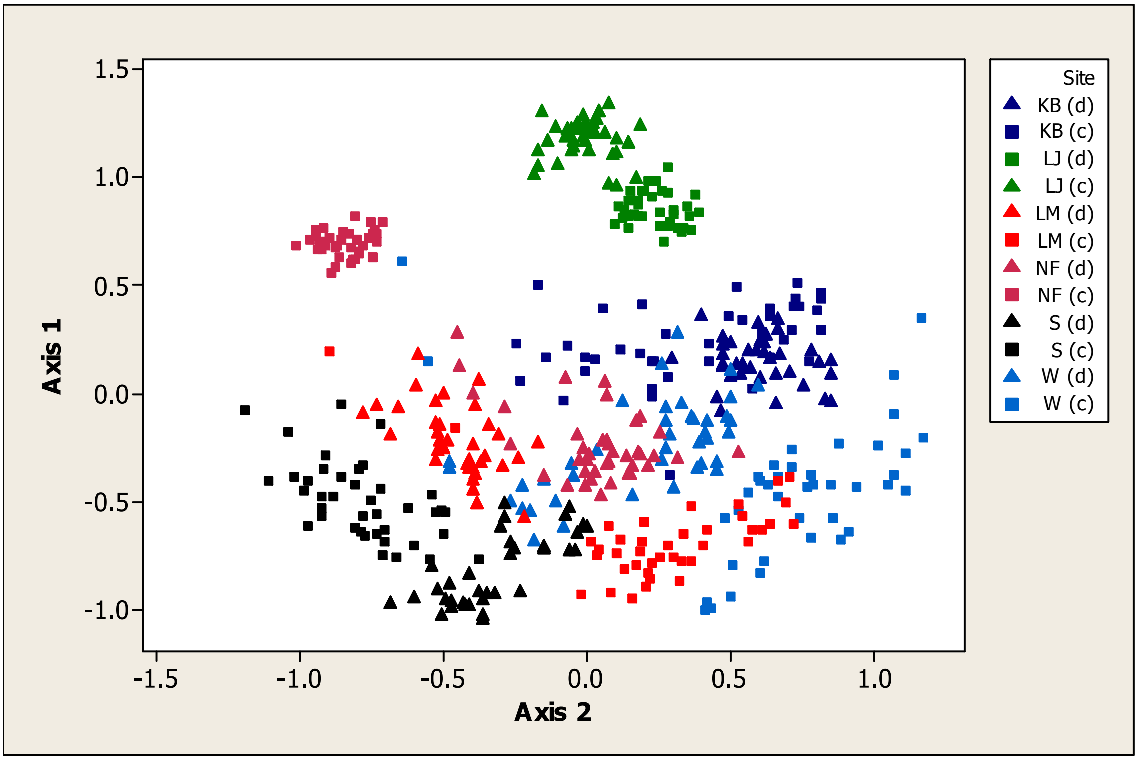

Figure 109. Ordination of all quadrats from within rainforest study sites. Legend: KB = Kelly Basin; LJ = Lake Johnstone; LM = Lake Margaret; NF = Nelson Falls; S = Strathgordon; W = Williamsford; d = disturbed; c = control.

Soils

Differences in soil quality within the rainforest sites examined may relate to the type of initial disturbance. Soil pH values had significant differences at five of the six rainforest study sites (Table 45). However, these reversed tendency between sites. Higher pH values were recorded from the disturbed areas at Kelly Basin, Lake Margaret and Strathgordon while in contrast, higher values were recorded within the controls at Nelson Falls and Williamsford. There were no significant differences recorded with soil pH between the control and disturbance at Lake Johnston and this may be the related to the low level of initial soil disturbance at this site.

The differences between total percentages of nitrogen were significant at four of the six study sites. All of these four study sites (Lake Margaret, Nelson Falls, Strathgordon and Williamsford) are likely to have been subjected to a much higher level of disturbance the other sites. However, historical records from Kelly Basin suggest that this site was intensively disturbed, yet, only pH differed significantly at this site with the higher value recorded within the disturbed area.

Phosphorus levels were found to be significantly different between the disturbed area and control at Lake Johnston and Nelson Falls. However, it reversed tendency between these sites with the higher values recorded within the control at the Lake Johnston and in the disturbed area at Nelson Falls. The higher P level found within the control at Lake Johnston may be related to the low level of initial disturbance which has effectively removed a shallow horizon of topsoil where most phosphorus is concentrated. The total percentage of carbon was significantly different between the disturbed area and control at three sites (Table 45) but reversed its tendency between sites. Both the Lake Johnston and Lake Margaret sites had higher carbon levels within the controls while a higher value was recorded from the disturbed area at Williamsford (Table 45).

Table 45. Significant soil properties at all rainforest study sites. Significant differences are indicated by the presence of letters and the higher values are denoted by D (disturbed) or C (control). Study sites: KB= Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; NF = Nelson Falls; S = Strathgordon; W = Williamsford.

	Study site					
Property	**KB**	**LJ**	**LM**	**NF**	**S**	**W**
pH	D	-	D	C	D	C
N	-	-	C	C	C	D
P	-	C	-	D	-	D
C	-	C	C	-	-	D
N:C	-	-	-	D	C	C

Discussion

The effects of anthropogenic disturbance and regeneration processes in the rainforests of Tasmania have been described in many ecological studies (e.g. Jackson, 1968 a, b, 1983; Hill and Read, 1984; Read and Hill, 1988; Williamson, 1990; Hickey et al., 1982; 1994; and others). Although considerable attention has been given to the regeneration of rainforest following fire, recent studies have focussed on soil disturbance and vegetation removal from activities such as forestry operations, road construction and mining. Hickey (1994) compared regeneration of old growth mixed forest after impact from fire and logging and found similarities between the floristics of silvicultural regeneration and wildfire existed. This study suggested that in the absence of further disturbance, areas actively managed for silvicultural operations could eventually return to rainforest.

A critical component of regeneration is related to the initial impact on soils. In some cases, this can profoundly affect the type of vegetation that will potentially develop. The striking feature of the soil results is the lack of consistency between sites in the relative values for disturbed areas and controls. In the case of nitrogen, variation can be related to the relative abundance of nitrogen-fixing plants. In the cases of other measured soil variables, these reversals may pertain to interactions of the type of initial disturbance with the characteristics of soils. For example, the soil disturbance resulting from line clearing at Lake Johnson reduced surface soil values for phosphorus and carbon, but at both Williamsford and Nelson Falls the disturbances were additive so phosphorus and carbon increased.

The reversal in tendency of nitrogen at the Williamsford site (Table 45) might be explained by a combination of the type of disturbance, underlying geology and the high frequency of a nitrogen fixing species, *Cytisus scoparius* (non-native Fabaceae). At Lake Margaret, Nelson Falls and Strathgordon, higher nitrogen was recorded within the controls and therefore, it might be reasonable to suggest that leaching within the disturbed areas has influenced nitrogen levels. However, this could also relate to the relative greater abundance of nitrogen fixing species in the control areas at these sites. For example, at Nelson Falls, the nitrogen fixing tree, *Acacia melanoxylon* was present in 52.50% of the control quadrats and absent from the disturbed area (Table 40). At the Strathgordon site, one nitrogen fixing species (*Acacia mucronata*) was present within 90% of all control quadrats (Table 40).

Other soil properties also displayed a lack of consistency in their differentiation between disturbed and controls between the sites, particularly pH and N:C within the

Lake Margaret, Nelson Falls and Strathgordon sites. These differences could relate to the interaction of disturbance type with geology and soils.

The ordination diagram for all sites (Figure 109) indicates a large degree of variability in the differences between the disturbed areas and controls. The outliers at Lake Johnston and the control quadrats at Nelson Falls may relate to differences in environment, as Nelson Falls is naturally fertile (Table 40) and Lake Johnston at approximately 1000 m has the highest elevation of the sites examined in this section.

As shown in Table 44, a total of 48 species were significantly more abundant within the disturbed quadrats than in the controls. However, only 10 of these were significantly more abundant within the disturbed quadrats at more than one site. There were 18 species that were more abundant in the controls than in the disturbed areas. A possible explanation for this may relate to the potential dispersability and/or the existence of a suitable habitat following cessation of disturbance. With respect to this, Kirkpatrick (1977) found that the most fire susceptible species such as *Athrotaxis selaginoides* and *N. gunnii* have limited dispersal ability which may account for their slower rates of recovery compared to other species.

Read and Hill (1983) found that bird dispersed species, such as *Tasmannia lanceolata*, were primary colonisers. Although *Tasmannia lanceolata* was recorded from the quadrats at three disturbed sites, it was significantly different in abundance between the disturbed area and control at two sites only. However, it was also recorded within the control quadrats at one additional site.

It is known that many Tasmanian native rainforest species have some capacity to establish following disturbance (e.g. Kirkpatrick 1984; Hickey and Wilkinson, 1999; Hickey, 1994; Jennings and Hickey, 2003; Turner and Kirkpatrick 2009). In some cases, the result of mechanical disturbance has been shown to increase the area of receptive seedbed and enable regeneration over a larger area (Forestry Tasmania, 1988). Native species including *Acacia melanoxylon*, *Eucryphia lucida*, and *Pteridium esculentum* are known colonisers of disturbed areas in western Tasmania (e.g. Read and Hill, 1983). All three were present in most disturbed areas.

Some species showed a reversal of tendency between the disturbed and control areas. While some of these such as *Acacia melanoxylon*, *Juncus* spp., *Gahnia grandis*, and *Leptospermum scoparium* are known to be early colonisers of disturbance in western Tasmanian rainforests (e.g. Williamson, 1990; Hickey, 1982, 1994; Read and Hill, 1988), additional species such as *Atherosperma moschatum* and *Eucryphia lucida* in particular, have been considered as late successional species (Neyland and Hickey, 1990; Hickey and Wilkinson, 1999) yet these species reversed tendency at the Kelly Basin and Williamsford sites (Table 44), possibly as a result of the regeneration niches provided by disintegrating buildings.

Chapter 7 – Variation in Ecosystem Recovery

Introduction

This chapter uses data from all 18 sites to determine the degree to which severity of disturbance, time since cessation of disturbance, soil and climate influence floristic differences between the disturbed and control vegetation. It also investigates the influence of severity of disturbance, time since cessation of disturbance, vegetation and climate on edaphic differences between disturbed and control areas.

Methods

Derivation of site distance values for vegetation and soil

Using the mid-point of abundance code ranges, Bray-Curtis distance values were calculated for vegetation between every pair of quadrats within each site. The values were reduced to those that involved a comparison of a control quadrat with a disturbed quadrat within each site. The mean and standard deviation of this reduced set of values were then calculated for each site.

Soil data for each site were standardised. The Euclidean distances between each pair of samples were calculated and reduced to those comparing a sample in the disturbed part of the site with a sample in the undisturbed part of the site. The mean and standard deviation of this reduced set of values was then calculated for each site.

Derivation of disturbance variables

Age of disturbance was calculated as the years between cessation of disturbance and the observations reported in this thesis. Types of disturbance ranged from ploughing through to heavy disturbance by mining. Disturbance was simplified into two categories: (1) superficial disturbance to the upper horizons of the soil profile; and (2) disturbed soil structure and /or modification of landscape features.

In the first category, disturbances were created from clearing of vegetation and/or ploughing, resulting in minimal disruption and mixing of the underlying soil profiles. In the second category, disturbed areas were impacted from construction and/or excavation, usually involving mixing of soil horizons and reworking of topography.

Derivation of environmental values

The slope values for each site were calculated by averaging the individual quadrat values for the undisturbed part of the site. The means and standard deviation for soil variables for each of the disturbed and the control were calculated for each site. The derivation of site climatic values is described in Chapter Two.

Data analysis

The number of sites restricted valid predictive analyses to one or two variables as the introduction of further variables tends to produce spurious significance values in the analyses. All ecologically meaningful models were tested. The highly intercorrelated precipitation and temperature variables were reduced to mean annual rainfall and the mean daily maximum temperature of the warmest months. These variables are the most ecologically meaningful and for that reason, were selected for the analyses.

The set of independent variables tested to predict both vegetation distance and soil distance were: disturbance type; age (years since disturbance ceased); slope, mean annual rainfall, mean daily maximum temperature of the warmest month, pH of the control, pH of the disturbed area; N in the control, N in the disturbed area; P in the control; P in the disturbed area; C in the control; C in the disturbed area.

All relationships between each of the independent variables and each of the dependent variables were examined on matrix graphs before being tested. One way ANOVA was used to test the significance of the relationships between the qualitative variable, disturbance type and the dependent variables, and Pearson's product moment correlation coefficient was used to test the significance of relationships between continuous independent variables and the dependent variables.

Two variable predictive models were created for combinations of continuous variables using the multiple regression procedure in Minitab 15. Where disturbance type was one of the variables, the continuous variable was treated as a covariate in a model created using the General Linear Model procedure in Minitab 15. Models were rejected if the probability for any component or the model as a whole was more than 0.05.

Results

Predictors of vegetation distance

The best single predictor of vegetation distance was disturbance type (ANOVA, F = 9.44, P = 0.007, r^2 = 37.1%). The severely disturbed sites had greater distances than the less disturbed sites, except for Nelson Falls (Figure 110). Carbon in the disturbed soils was also related to vegetation distance (r = 0.484, P = 0.042, see Figure 111), a relationship largely controlled by the high values on both variables for the Nelson Falls study site.

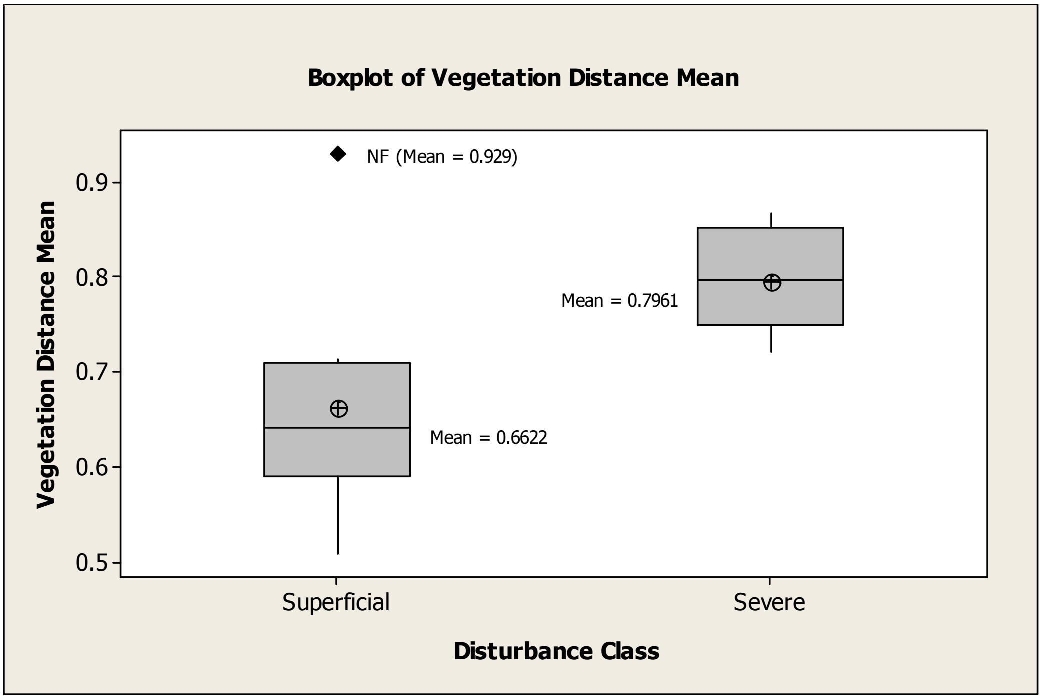

Figure 110.Box plots of vegetation distance mean by disturbance class. The symbol shown in the boxes indicates the position of the mean value. The Nelson Falls outlier (NF) is also shown.

The most explanatory of the two variable models consisted of disturbance class and soil carbon in the disturbed area (Table 46). The less severely disturbed sites tended to have higher vegetation distances as carbon increased (r = 0.758, P = 011), whereas the more disturbed sites had no clear relationship between vegetation distance and carbon in the soils of the disturbed area (r = 0.119, P = 0.779) (see Figure 111). The Minitab Version 15 equation utilised for the general linear models states that: Y=Xb +e, where Y is a vector of responses, b is a vector of parameters, X is the design matrix of constants and e is a vector of independent normal random variables.

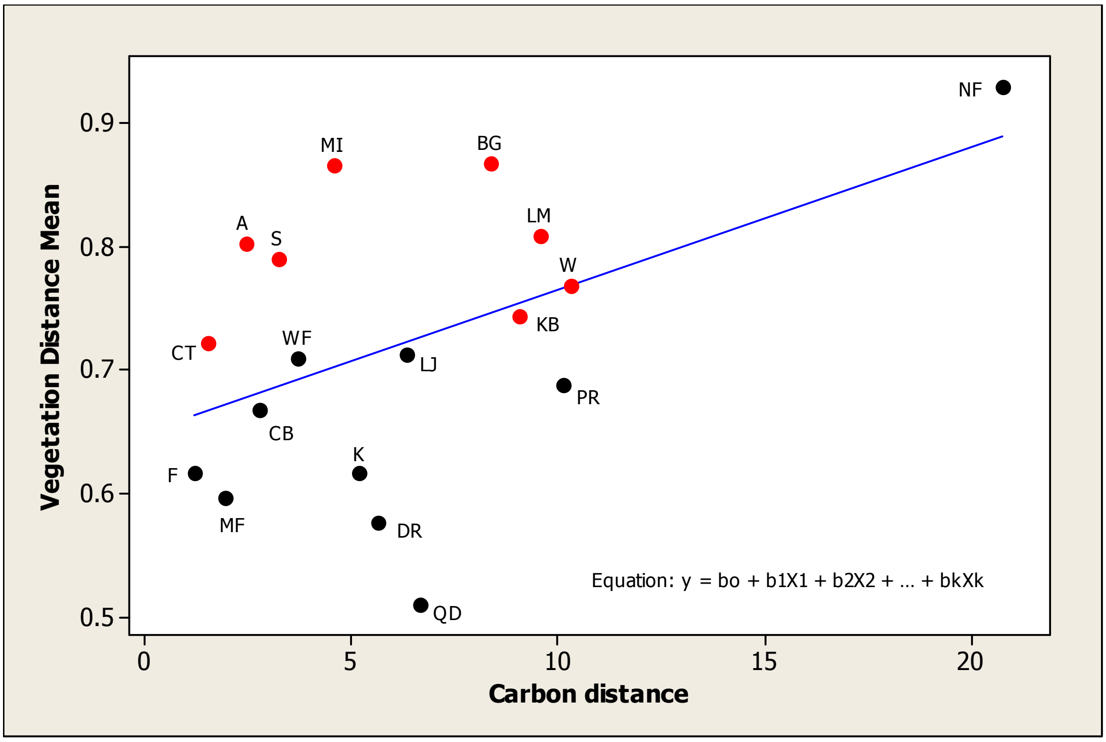

Figure 111. The relationship between vegetation distance and soil carbon in the disturbed area showing the regression line. Legend: A = Adamsfield; BG = Butlers Gorge; CB = Coles Bay; CT = Campbelltown Hospital; DR = Douglas Rd; F = Fosterville; K = Kettering; KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; MF = Mount Field; MI = Maria Island; NF = Nelson Falls; PR = Pottery Road; QD = Queens Domain; S = Strathgordon; W = Williamsford; WF = Wyre Forest Rd. Black symbols represent superficial disturbance, red symbols represent sever disturbance

Table 46. General linear model predicting vegetation distance from disturbance class (p = 0.001) and carbon (p = 0.006) in the soil of the disturbed area (C). Equation: Y=Xb +e; R^2 = 62.47; DF = 1.

Analysis of variance for vegetation distance, using adjusted SS for tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
C	1	0.053022	0.54470	0.54470	10.14	0.006
Disturbance Class	1	0.083863	0.083863	0.083863	15.61	0.001
Error	15	0.080606	0.080606	0.005374		
Total	17	0.214792				

S = 0.0733058 R-sq = 62.47

Term	Coefficient	SE Coef	T	P
Constant	0.65405	0.02931	22.32	0.000
C	0.011994	0.003767	3.18	0.006

The model that included disturbance type and P was also strong (Table 47). There was a tendency for the less disturbed sites to have lower vegetation distance as P in the disturbed area increased (r = -0.802, P = 0.005), while the more disturbed sites did not show such a relationship (r = -0.174, P = 0.680) (Figure 112).

The model for type of disturbance and N in the disturbed area seemed strong, but was overly influenced by two outlying values for N. Log_{10} and square root transformations resulted in models that better fitted the assumptions of GLM, but nitrogen in these models was not significant.

Table 47. General linear model predicting vegetation distance from disturbance class (p = 0.02) and phosphorus (p = 0.037) in the soil of the disturbed area (P).). Equation: Y=Xb +e. R2 = 53.7; DF = 1.

Analysis of variance for vegetation distance, using adjusted SS for tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
P	1	0.016947	0.034916	0.034916	5.23	0.037
Disturbance Class	1	0.097683	0.097683	0.097683	14.63	0.002
Error	15	0.100161	0.100161	0.006677		
Total	17	0.214792				

S = 0.073305 R-sq = 53.7

Term	Coefficient	SE Coef	T	P
Constant	0.80094	0.03689	21.71	0.000
P	-0.011222	0.004907	-2.29	0.037

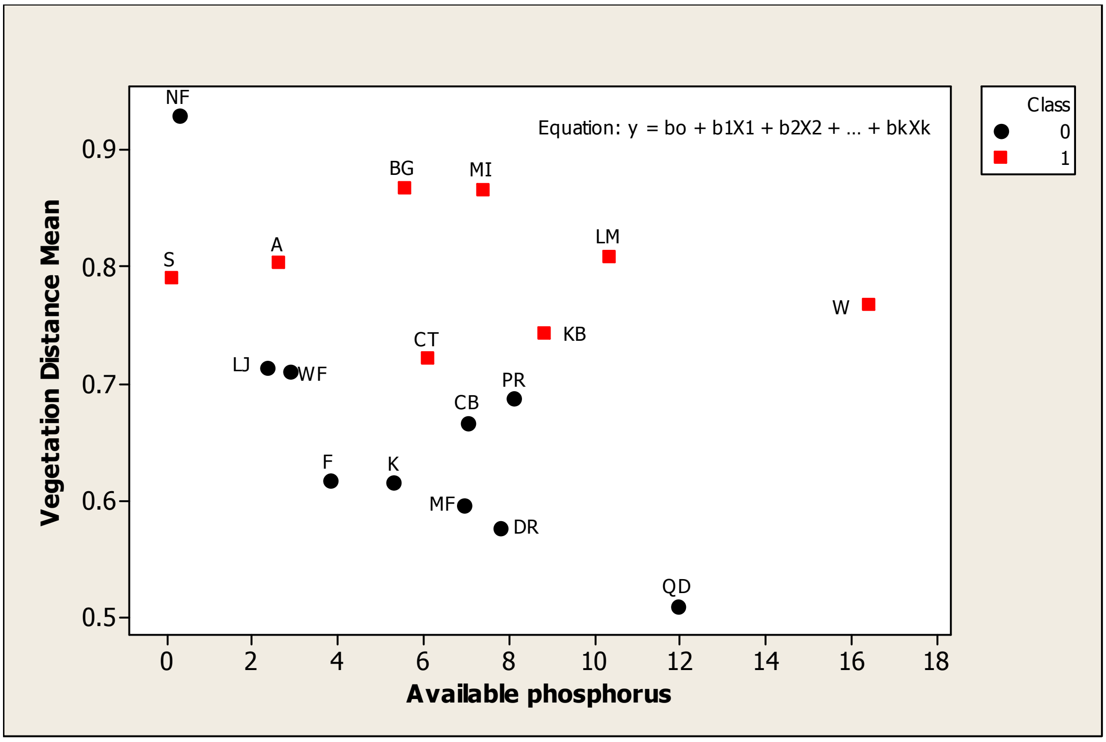

Figure 112. The relationship between vegetation distance and soil available phosphorus showing disturbance classes. Legend: 0 = Superficial disturbance; 1 = Severe Disturbance; A = Adamsfield; BG = Butlers Gorge; CB = Coles Bay; CT = Campbelltown Hospital; DR = Douglas Rd; F = Fosterville; K = Kettering; KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; MF = Mount Field; MI = Maria Island; NF = Nelson Falls; PR = Pottery Road; QD = Queens Domain; S = Strathgordon; W = Williamsford; WF = Wyre Forest Rd.

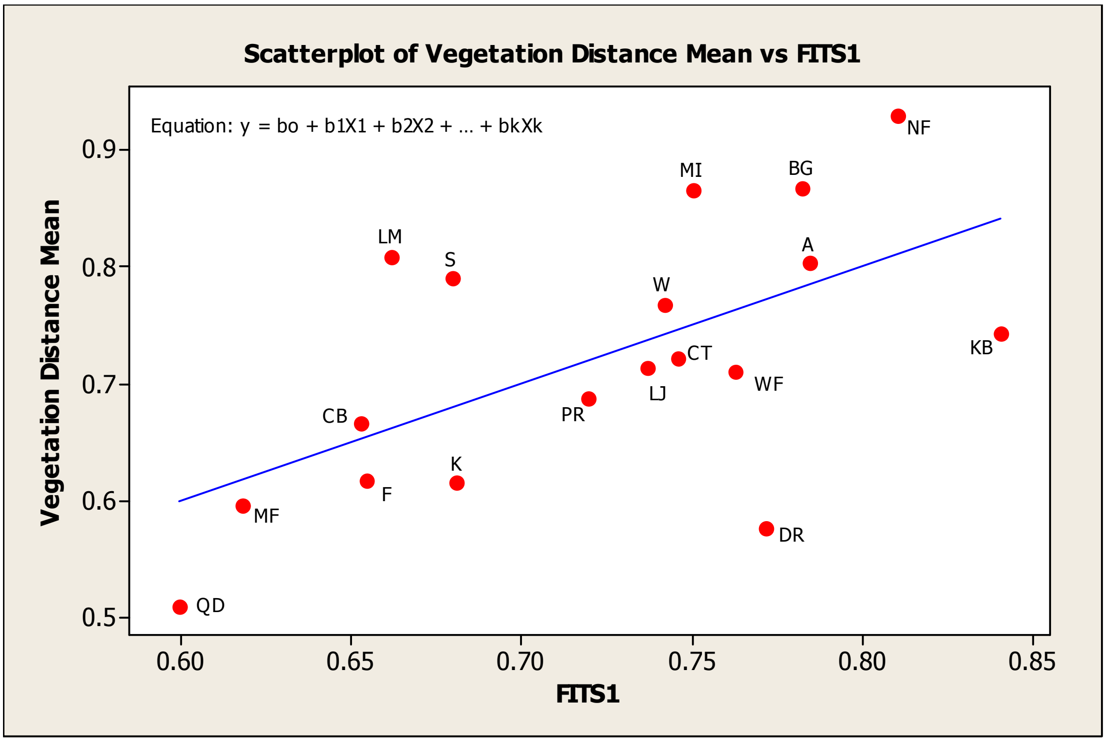

Figure 113. The relationship between vegetation distance and the predicted vegetation distance from the model including age since cessation of disturbance and pH of the disturbed area (FITS1). Legend: A = Adamsfield; BG = Butlers Gorge; CB = Coles Bay; CT = Campbelltown Hospital; DR = Douglas Rd; F = Fosterville; K = Kettering; KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; MF = Mount Field; MI = Maria Island; NF = Nelson Falls; PR = Pottery Road; QD = Queens Domain; S = Strathgordon; W = Williamsford; WF = Wyre Forest Rd.

The only other acceptable two variable model incorporated age since disturbance and pH of the disturbed area (Table 48). The greater the age since disturbance the greater the vegetation distance, the vegetation distance increasing with increased acidity of the soils of the disturbed area. Nelson Falls had a high positive residual, while Douglas Road had a high negative residual (Figure 113).

Table 48. Multiple regression model predicting vegetation distance from age since disturbance (p = 0.026) and pH (p = 0.018) of the soil of the disturbed area (pH dist).Regression equation: Vegetation distance mean = 1.15 + 0.00328 Age – 0.124 pH distance; R^2 = 36.4; DF = 1.

Multiple regression model: vegetation distance from age since disturbance and pH

Predictor	Coef	SE Coef	T	P	
Constant	1.1497	0.1866	6.16	0.000	
Age	0.003278	0.001332	2.46	0.026	
pH dist	-0.12350	0.04667	-2.65	0.018	
S = 0.0954269	R-sq = 36.4				
Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	2	0.078197	0.39099	4.29	0.034
Residual Error	15	0.136594	0.009106		
Total	17	0.214792			
Source	DF	Seq SS			
Age	1	0.014427			
pH dist	1	0.063770			

Where pH of the soils of the disturbed area was greater than 4.5, vegetation distance increased with age (r = 0.849, P = 0.032), whereas there was no such relationship in the more acid sites (r = 0.351, P = 0.263) (Figure 114).

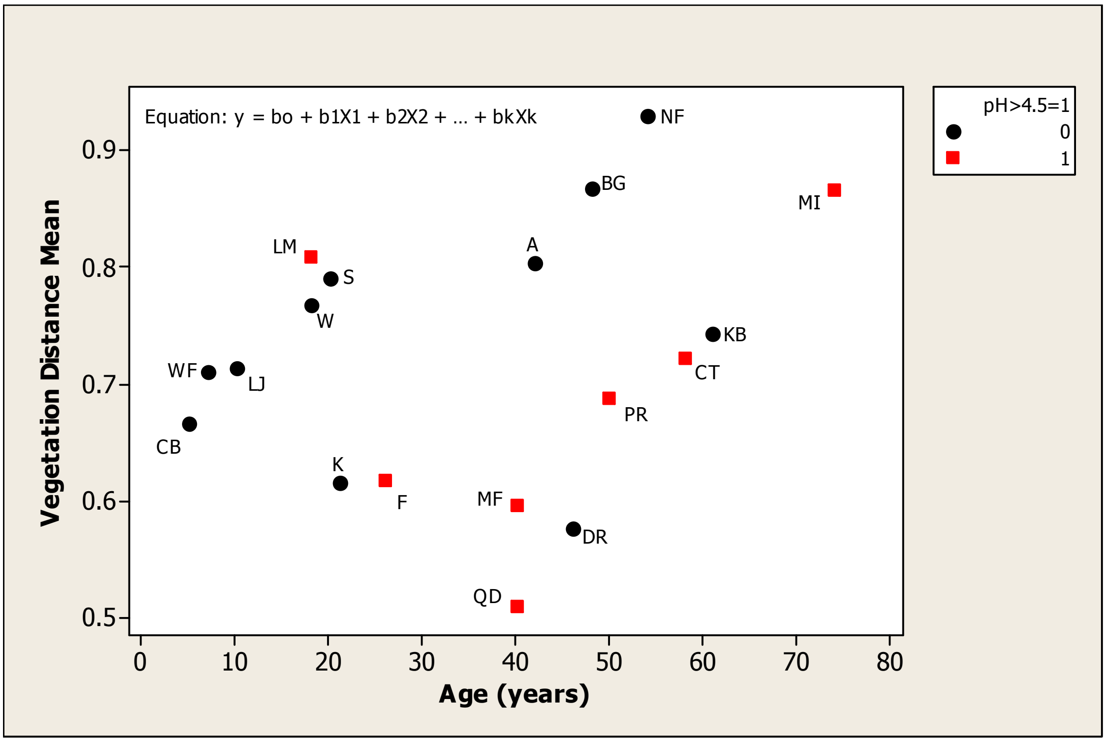

Figure 114. The relationship between vegetation distance and time since the cessation of disturbance, showing sites with pH in the disturbed area of < 4.5 = 0 and > 4.5 =1. Legend: A = Adamsfield; BG = Butlers Gorge; CB = Coles Bay; CT = Campbelltown Hospital; DR = Douglas Rd; F = Fosterville; K = Kettering; KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; MF = Mount Field; MI = Maria Island; NF = Nelson Falls; PR = Pottery Road; QD = Queens Domain; S = Strathgordon; W = Williamsford; WF = Wyre Forest Rd.

Predictors of soil distance

The only successful predictor of soil distance was phosphorus in the soils of the disturbed area (soil distance = 0.594 - 0.0300 phosphorus in the disturbed area (ppm), $r^2 = 44.5\%$, $P = 0.002$). The higher the levels of phosphorus in the disturbed area, the more similar were the soils between the disturbed area and the control (Figure 115).

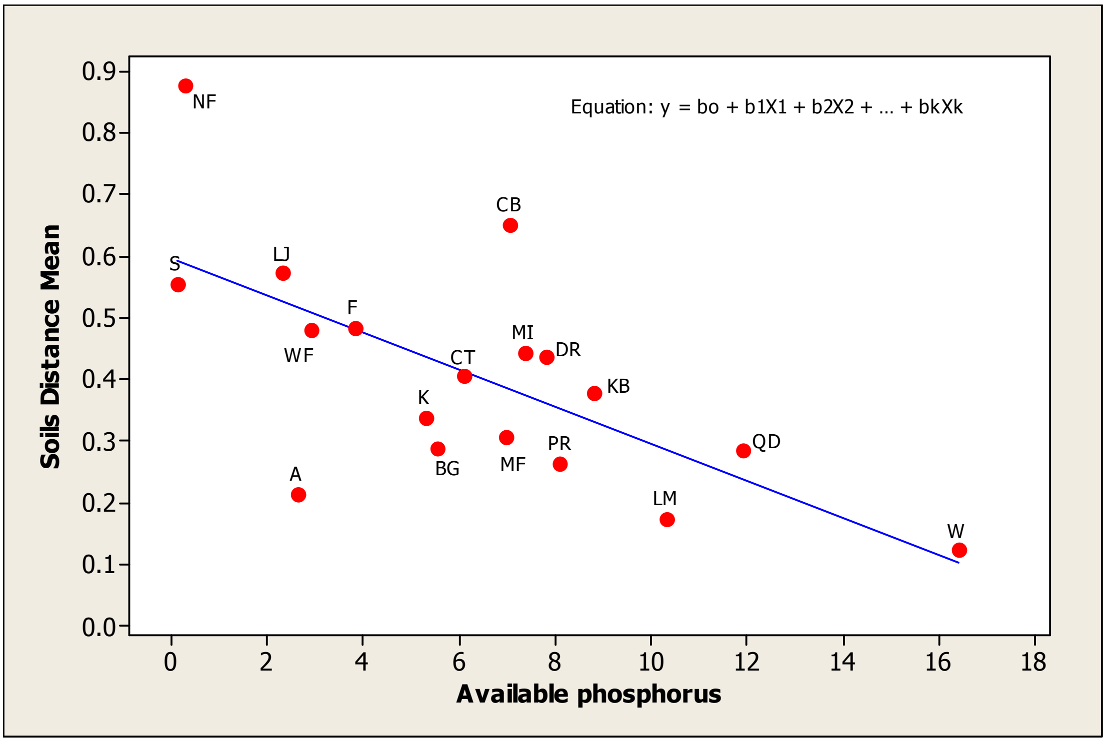

Figure 115. The relationship between soil distance and phosphorus in the soils of the disturbed area. Legend: A = Adamsfield; BG = Butlers Gorge; CB = Coles Bay; CT = Campbelltown Hospital; DR = Douglas Rd; F = Fosterville; K = Kettering; KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; MF = Mount Field; MI = Maria Island; NF = Nelson Falls; PR = Pottery Road; QD = Queens Domain; S = Strathgordon; W = Williamsford; WF = Wyre Forest Rd.

The relationship between vegetation and soil distances

Vegetation and soil distances were strongly positively related to each other within the less disturbed set of sites (Figure 116, $r = 0.804$, $P = 0.005$), but not within the severely disturbed sites (Figure 116, $r = -0.027$, $P = 0.950$). The general linear model with disturbance type as the predictor of vegetation distance and soil distance as the covariate was highly explanatory (Table 49).

Table 49. General linear model predicting vegetation distance from type of disturbance and soil distance). Equation: Y=Xb +e; R^2 = 60.53; DF = 1.

General linear model: vegetation distance from type of disturbance and soil distance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Soil Distance		0.008043	0.050290	0.050290	8.90	0.009
Disturbance Type	1	0.121962	0.121962	0.121962	21.58	0.000
Error	15	0.084786	0.084786	0.005652		
Total	17	0.214792				

S = 0.0751825 R-sq = 60.53

Term	Coef	SE Coef	T	P
Constant	0.60148	0.04637	12.97	0.000
Soil Distance	0.3221	0.1080	2.98	0.009

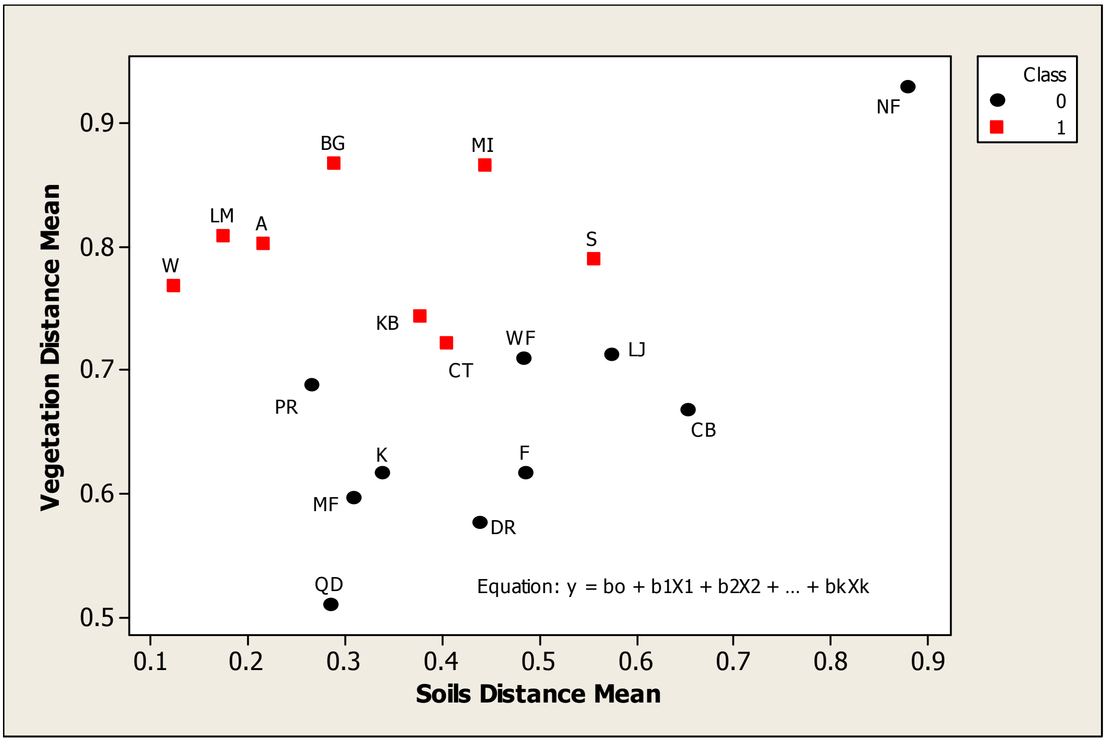

Figure 116. The relationship between vegetation distance and soil distance showing disturbance type. Legend: 0 = Superficial disturbance; 1 = Severe Disturbance; A = Adamsfield; BG = Butlers Gorge; CB = Coles Bay; CT = Campbelltown Hospital; DR = Douglas Rd; F = Fosterville; K = Kettering; KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; MF = Mount Field; MI = Maria Island; NF = Nelson Falls; PR = Pottery Road; QD = Queens Domain; S = Strathgordon; W = Williamsford; WF = Wyre Forest Rd.

Discussion

The meaning of the models

There are specific limitations related to a relatively small data set and problems in gaining totally equivalent control sites to achieve robustness in the analyses. While attempts were made to locate control quadrats in areas that were considered to be representative of the disturbed area prior to disturbance, it is likely that the control sites may be at different stages of succession within their ecosystems. This may be influenced by the extensiveness of the study and therefore inherent difficulties to control for temporal and therefore, successional stages within the control sites. This concept has been discussed in detail elsewhere and relates to alternative stable states and threshold models such as those proposed by Beisner et al. (2003), Schröder et al. (2005), Suding et al. (2004), Lindenmayer et al. (2008), Hobbs et al. (2006), Hobbs et al. (2009), Suding and Hobbs (2009) and others.

The results show that increasing phosphorus levels within the disturbed areas lead to increasing similarities between the soils of the disturbed and control. While it may be considered that the rate of change in disturbed areas is more rapid than the controls (i.e. Australian soils are generally considered to be low in phosphorus and plants are adapted to this condition), there are also other factors that are influencing the rate of colonisation of disturbed areas and therefore, the rates of vegetation development. There may be some association with a lack of organic rich horizons in the disturbed areas. However, there was no significant correlation found between soil carbon and available phosphorus.

Some types of soil disturbance in other parts of Australia modify phosphorus levels (i.e. Keith et al., 1997; Short et al., 2000; Johnston and Johnston, 2004) and this could be expected to affect plants. In particular, Keith et al. (1997) have shown that root activity changed when phosphorus was added to microsites within plots. Soil disturbance can potentially affect the availability of phosphorus and the hyphal networks of vesicular-arbuscular mycorrhizal fungi (Jasper et al. 1989). As a result, the rate of vegetation recovery following disturbance may be affected.

The analyses have shown that there is a relationship between vegetation similarities and soil similarities, but not in the severely disturbed subset of sites. It was expected that soil would have a major influence on vegetation, as is the case with the less disturbed sites (Figure 116). This result suggests that other factors, such as variation in the characteristics of within site topographic variation in the disturbed parts of the severely disturbed sites, may overwhelm the effects of soil characteristics. The fact that severity of disturbance is the best single predictor of vegetation differences between control and disturbed areas reflects persistence of topographic and edaphic affects where excavation and construction have occurred. Archaeologists have used the vegetation response to such disturbances to locate human settlements and mines thousands of years old. The percentage of carbon within the disturbed areas is also associated with greater vegetation distances in the less severely disturbed sites. The Nelson Falls site, where feedback mechanisms from native mammal grazing are having a persistent effect on vegetation recovery, controls this relationship, which is otherwise not strong. At Nelson Falls, grazing prevents the invasion of rainforest trees and shrubs, and the grass cover in the disturbed area produces higher levels of soil carbon than are produced in the adjacent rainforest.

In the present study, higher levels of phosphorus in the disturbed areas are associated with higher similarities between the disturbed and control areas. Phosphorus is considered to be a major macro-nutrient required for plant growth and Beadle (1953, 1954) has previously shown that the distribution of some forest types, in particular rainforest, contracted as a result of the widespread exhaustion of soil phosphorus through geological time. The sites with higher levels of phosphorus in the present study tend to be those with a large component of grasses and herbs in their control vegetation, rather than dense forest. Grasses and herbs can make a more rapid recovery from disturbance than shrubs and trees.

The divergence of the vegetation of control and disturbed area with age was not expected. It suggests that the disturbance events have set the vegetation on a different trajectory of change than that prevailing in the adjacent controls, despite both being largely dominated by native plants (Chapters 3 to 6). Wilson and Agnew (1992) and Agnew et al. (1993), suggest that although gradual changes are '*common in nature, hard edges are also present caused by sharp environmental changes or natural switches*'. The critical component for a switch to operate is positive landscape feedback that affects the vegetation processes. Accordingly, landscape features can be created or modified by switches and '*…small initial difference in biota can switch between alternative stable states of vegetation/environment across an abrupt boundary*' (Wilson and King, 1995). It is quite likely that positive feedback mechanisms are influencing the development of the vegetation communities on the disturbed sites of the present study.

The fact that the vegetation of the controls and disturbed areas is more different on the more acid sites than the less acid sites for any one age may relate to a slower absolute recovery in cover on the more acid sites in relation to the changes in cover that occurred in the controls. Much of the vegetation in the controls on the more acid sites is forest on a slow trajectory to old growth rainforest, whereas much of the vegetation on the controls of the less acid sites has a high grass and herb component which can attain original cover very rapidly after disturbance.

Chapter 8 – Conclusions

This research project has demonstrated that Tasmanian vegetation subject to a wide range of disturbances in a wide range of environments does recover within decadal time scales without any intervention by human beings, but not to any close approximation of its original state. It thereby supports multiple pathway and transition models of vegetation dynamics and suggests that the goals for restoration should be to achieve cover and a native species composition in an ecosystem that can function, rather than a return to a prelapsarian state. If these goals are accepted, human intervention after disturbance should be restricted to weed control, unless there are good reasons to accelerate the process of recovery to increase diversity, facilitate slope stabilisation or minimise the potential for soil erosion and discharge of sediment.

The states of vegetation and soils following disturbance within the ecosystems examined in this project are influenced more by the type of initial disturbance than the time elapsed since disturbance. Severe disturbance (mining and the construction of townships) was found to change vegetation and soils more than superficial disturbance caused by ploughing and land clearance. 'End points' are not fixed entities (Bradshaw, 1987a) and controls utilised for comparison in the present study may never reach a stable state and may be in different positions on trajectories of change. Nevertheless, it is possible to generalise that disturbed sites and the ages since disturbance included in the present study tend to have more heterogeneous and species-rich vegetation than their controls. A higher heterogeneity in disturbed areas than controls has also been observed over fire boundaries in alpine areas of Tasmania (Kirkpatrick and Dickinson 1984).

While severity of disturbance was a major influence on the species composition of vegetation and its relationship to control vegetation, the initial condition of any particular site prior to disturbance is also likely to have had some substantial influence on outcomes (e.g. Glenn et al., 1992). The response of individual species is also likely to have an effect on the successional processes and thus, the overall recovery rate from the effects of disturbance. However, most types of disturbance have the potential to increase the numbers of non-native species and these can persist within a disturbed area for long periods of time, in some cases for many decades following initial disturbance. This project demonstrates that vegetation distance between the control and disturbed areas may not represent a trajectory towards recovery but rather towards an alternative stable state which may include non-native species in a synthetic community (e.g. Bridgewater, 1990; Hobbs et al., 2006; Wilsey et al., 2009; Alemseged et al., 2011).

The influence of non-native species on trajectories of vegetation change after disturbance cannot be deduced from the control and disturbance data. Previous work on the Northern Midlands ecosystems has suggested that non-native species (i.e. weeds) add to diversity, rather than subtract from it (Fensham and Kirkpatrick 1988). However, weed control is often a component of vegetation management (Radosevich et al., 2007). Although effective weed control is usually difficult to achieve, in some situations it can be beneficial to the recovery of native vegetation communities (e.g. Nelson et al., 1981). Radosevich et al. (2007) suggested that weed control is the fostering of beneficial vegetation and the suppression of undesirable plants. One such species, *Ulex europaeus*, was present within three of the four bioregions investigated during this research project (Figure 3). *Ulex europaeus* is listed in Australia as a Weed of National Significance (WONS) because of its invasiveness, potential for spread and also economic and environmental impacts (DPIPWE, 2009; ARMCANZ, 2003). Thus, consideration of appropriate control techniques for this species is important for informing objectives of land management and restoration activities.

Herbaceous weeds and grasses are also an important component of land management activities and these were recorded from all study sites except Lake Johnston. While these may be having some impact on the potential for native vegetation to recover, complete removal or even control, in most circumstances, is likely to be difficult. However, herbaceous weeds are often the subject of land management issues and effects from their competition have been detailed by many with particular attention given to beneficial effects following their control (e.g. Nelson et al., 1981; Randall, 1996; Simmons, 2005; Radosevich et al., 2007; Williams et al., 2007; Davies and Sheley, 2011; Marushia and Allen, 2011).

Soil disturbance can also have impacts on nutrients and their availability which can have a significant influence on the type of ecological community that can develop (e.g. De Deyn, 2004; Dale et al, 2005; Bourne et al., 2007) on a site in the absence of further catastrophic disturbance. However, some types of disturbance can effectively result in permanent changes to the attributes of soils, through addition or subtraction of material (e.g. Joss et al., 1986; Mojiri et al., 2011). In a previous study, Wilson (1986) suggested that '*…changes in soil attributes, while secondary to vegetation in occurrence, are of primary importance for land monitoring objectives*'. Thus, the consideration of soil condition should form an integral component of restoration based activities.

The theory that a disturbed ecosystem can return to its former condition over time appears to be erroneous for the sites examined in this study. However, the processes of succession following disturbance may eventually lead to a stable alternative condition. Conversely, further development can occur over longer time periods (i.e. century scales) and this requires consideration where a natural and unassisted regeneration is the preferred method of recovery. The concept of alternative stable states was first proposed by Lewontin (1969) who indicated that ecosystems would not, as an end point, reach a pre-conceived state or condition but rather they could reach an alternative stable state. Therefore, it may be appropriate to measure restoration success by the percentage cover of native species rather than comparing composition to an appropriate control site. By utilising this approach, alternative stable states or ecological condition could potentially be accepted as recovery from disturbance (see for example: Hobbs and Norton, 1996; Petersen, 2002; Beisner et al., 2003; Guo, 2004; Mayer and Rietkerk, 2004; Didham et al., 2005; Schröder et al., 2005; Fukami and Lee, 2006; Hobbs, 2007; Hobbs and Suding, 2009; Warman and Moles, 2009; Zweig and Kitchens, 2009).

In addition, to the above, issues associated with climatic influences on the rate of recovery following disturbance may require consideration, particularly the short growing season at high elevations and drought conditions in eastern Tasmania. Although climatic variables were included in the process of developing models that predicted similarities between controls and disturbed areas, they were not powerful enough to be included in the best models.

It seems reasonable to suggest that the direction of restoration effort should focus on achieving outcomes based on ecosystem function rather than vegetation composition and structure (e.g. Ehrenfeld and Toth, 1997; Foster et al., 2007; Fierro et al., 2009; Hobbs and Cramer, 2009; Colloff et al., 2010). Choi (2007) has suggested that: '*…future-oriented restoration should* ***(1)*** *establish the ecosystems that are able to sustain in the future, not the past, environment;* ***(2)*** *have multiple alternative goals and trajectories for unpredictable endpoints;* ***(3)*** *focus on rehabilitation of ecosystem functions rather than recomposition of species or cosmetics of landscape surface; and* ***(4)*** *acknowledge its identity as a 'value-laden' applied science within an economically and socially acceptable framework*'. If these suggestions are accepted, a component of restoration efforts could effectively be directed towards minimising bare ground and eliminating those species (i.e. non-native) that could compete for available resources with more desirable native species.

The concept of establishing self-sustaining ecosystems is a fundamental, yet important consideration for land management and this is often overlooked. The preconceived thought that a damaged ecosystem can return to a pre-disturbance condition has been shown to be mostly unachievable through natural regeneration. As a result, desirable alternative stable states should become the goals in the repair of degraded ecosystems. Hobbs et al. (2009) have suggested three possible outcomes of disturbance: the ecosystem remaining in or near to its historical state; alteration to a hybrid state; or modification to such an extent that it can be considered to be an alternative or novel ecosystem. Thus, they conclude that management options are variable and these depend on the '*extent of change and on the presence of thresholds that might render a return to historical states difficult*'.

Although ecosystems can appear resilient to change, unexpected changes can occur as a result of critical thresholds being reached (Suding and Hobbs 2009). The motives for restoration effort and research are variable making the conditions for assessment or determination of restoration success peculiar to each particular area. Nevertheless, threshold models provide direction for the further evaluation of the uncertainty in management situations (Suding and Hobbs 2009). Thus, continuing development of threshold models are likely to become increasingly important in the ongoing development of restoration ecology.

Restoration ecology has experienced unprecedented growth, particularly within the last two decades. Its continuing development is providing a platform for testing new ideas and opportunities for the conservation of biological diversity, ecosystem management, and ecological theory (Choi, 2007). While this project has investigated the potential for recovery of vegetation and soil from 18 sites occurring in four bioregions (South East; Northern Midlands; Southern Ranges; and West), a total of nine bioregions are recognised in Tasmania. Therefore, further research effort could be directed towards investigating potential recovery rates of those areas not considered in the present study (i.e. Ben Lomond; Central Highlands; Flinders; King; and Northern Slopes). This research project has also demonstrated that the type and intensity of initial disturbance can have profound implications for vegetation recovery. While the data indicates that divergence between disturbed areas and controls occurs with major disturbance, this is based on a relatively small sample size. Many additional sites provide opportunities for further investigation of recovery rates in and would undoubtedly be beneficial to gaining a further understanding of the processes of recovery following anthropogenic disturbance in Tasmania.

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Appendix A – Species Distribution

Note: The tables in this section are ordered alphabetically by study site name and then by ecosystem in the order they appear within this thesis.

Grasslands and Grassy Woodlands: Campbelltown Hospital; Fosterville; and Queens Domain.

Dry Sclerophyll Communities: Coles Bay; Douglas Road; Kettering; Maria Island; Pottery Road; and Wyre Forest Road.

Wet Sclerophyll Forest: Adamsfield; Butlers Gorge; and Mount Field.

Rainforest Communities: Kelly Basin; Lake Johnston; Lake Margaret; Nelson Falls; Strathgordon; and Williamsford.

Distribution of species at the Campbelltown Hospital study site. 1d2c represents: disturbed (1) and control (2) quadrats = * = non-native species

```
                              2212212213 2112    1    22333111133333347777766477778455555566666655566744444544
                              24613907096627512374458989104135867235802135689847890723478901245601537034569612

*Arctotheca calendula         -1------------------------------------------------------------------------------
Cotula australis              ----------1---------------------------------------------------------------------
Ehrharta stipoides            ----------111-1--1-1--1---------------------------------------------------------
*Agrostis capillaris          ---11-111------111-11111--1-----------------------------------------------------
*Dactylis glomerata           --111---------1------------1----------------------------------------------------
Carex tasmanica               11-1--------------------------1-------------------------------------------------
Oxalis perennans              11--1-11---1------------------------11------------------------------------------
Gonocarpus tetragynus         -----1-1----------------1-11--1-111-11-1----------------------------------------
*Picris sp.                   11--111-111--------------1111------11111----------------------------------------
Eucalyptus viminalis          -1------------1---------11-11--1---------1--1-----------------------------------
*Cirsium vulgare              11---------1------------------------1-------1-----------------------------------
*Holcus lanatus               1-1--1111-11-11111-------11-------------11-11-1-11111---------------------------
Themeda triandra              -1--------111111-1111111-1111111111----11111111---1-1---------------------------
*Ulex europaeus               ---111--------1--------------------------1-----1------------------------1-----1-
1d2c                          11111111111111111111111111111111111111112222222222222222222222222222222222222222
Acetosella vulgaris           111111111-11111111111111111--1111-111---1111111111111-11111111111--1111---------
Pteridium esculentum          -11----111111111111111111111-1111111111111111--1111111-111111111111111--111111-1
Acacia dealbata               -1--1---1-111111111111111111111111-1111--1111-11-1111---1111-11111------111--111
Poa spp.                      1111111111--111----------11111-11111111111111111111111111111111111111111-----111
Juncus spp.                   11--1-1-1--------------1----------------11111---1-----11111----1111111-1-111-1--
Lomandra longifolia           -----1---------------------1---1----------111---1-11-11111111--1-1-11---11-1-111
Austrostipa spp.              --------1------11111---------111---111-111111111111-111-1------111111111--------
Pimelea humilis               --------11-----------------------------1-------1-1111-1-----1--1----------------
Geranium potentilloides       -------------------1-----------1--111--------11-1-111-1-------1-1---------------
Helichrysum scorpioides       ------------------------111-------------11--1-----1-----------------------------
*Plantago lanceolata          ----------------------------------------111111-1111-11-1-1--11111-11-111111111--
Austrodanthonia spp.          ---------------------------------11-----11-111111111111111111-111111111111111111
Eucalyptus amygdalina         -----------------------------------------11----1--1111-----11---1---------------
Bursaria spinosa              --------------------------------------------------------------------1---------11
```

Distribution of species at the Fosterville study site. 1d2c represents: disturbed (1) and control (2) quadrats. * = non-native species.

```
                              56566555644455644555777776664447784667773333 134  11222312223      1222233111113
                              04312128023779518456467893894561309670524589591067172482613971234893056736025480

*Geranium molle               ---------------------------------------1----------------------------------------
Lepidosperma laterale         -------------------------------------11-----------------------------------------
*Arctotheca calendula         -------------1---1--------------------------------------------------------------
*Sonchus asper                -----1111---111--111------------------------------------------------------------
*Juncus articulatus           11----------------------------1-------------------------------------------------
Lomandra longifolia           1-11-11------------------1------------------------------------------------------
*Oxalis corniculata           ---1---1111-11----------1--11----1----------------------------------------------
Juncus pallidus               --------------------1----1-1------11-1------------------------------------------
*Cynosurus cristatus          11111111-111--1111-1----11-11111-1-111------------------------------------------
Pteridium esculentum          --111-----------------111-11-----1---1------------------------------------------
Oxalis perennans              ----1------1-11-111-------------------1-----------------------------------------
*Lagurus ovatus               ------------1------------1---11--11-1-1-----------------------------------------
Pimelea spp.                  ---------1----1-----1-11--------1-----1-----------------------------------------
*Bromus catharticus           -1-111111--1111----11111111-11-111-----1----------------------------------------
*Aira caryophyllea            111111111--1-11----------1111-1--1-111-1----------------------------------------
*Leontodon taraxacoides       111-11111111111111111111-111111111111111----------------------------------------
1d2c                          11111111111111111111111111111111111111112222222222222222222222222222222222222222
Themeda triandra              1111-1-111111111111-11111--11-11111111111111111111111111-11111111111111111111111
Austrostipa spp.              -11111111-111-11111111111111111111-1-----11-1-1---11-1111--1-11--1---1---1------
Acacia dealbata               -----1----------11-11-111--------1--1-----1-------1-111-111-1--------------11---
*Holcus lanatus               ----------------------111111111--1----------1----------------1111----11--1------
Acaena novae-zelandiae        ----------------------1------------11-1------1-------1------1--------1-------11-
Juncus pauciflorus            ---------------------------1---1-----111-------------------11--------1----111--1
*Ulex europaeus               ----------------------------111111---11111111111---------1---1------------------
*Cirsium vulgare              -----------------------------111-11-1---1----1-11------1-------11-------------1-
*Briza minor                  ---------------------------------------1---------11-----------11--1-1--1--1-111-
Poa spp.                      ----------------------------------------1111-----------------1111-1--111---1-1-1
*Ehrharta erecta              ------------------------------------------11-1-1--------1-1----------11---------
Dichondra repens              ------------------------------------------1----1111-11111----11------1--1-1-----
Helichrysum scorpioides       ------------------------------------------1---------------------------1------1-1
Plantago varia                -------------------------------------------1-------------11--11111111111111-11--
*Dactylis glomerata           --------------------------------------------1-----------------1--1---1--1-------
*Agrostis capillaris          ---------------------------------------------1--1-1-11--111--1111111111-111-111-
*Picris spp.                  ----------------------------------------------1-----1-1111111111111-1-1-1-------
```

Distribution of species at the Queens Domain study site, ordered by position in the transect (left = west, right = east). 1d2c represents: disturbed (1) and control (2) quadrats * = non-native species.

```
                                       111111111122222222223333333333444444444455555
                              123456789012345678901234567890123456789012345678901234

1d2c                          222222222222222222222222222211111111111111111111111111
Dichelachne crinita           ----------------------------------------------------1-
Cynoglossum suaveolens        ----------------------------------------------------11
Petrorhagia nanteuilii        ---------------------------------------------------111
Dianella breviculmis          -------------------------------------------1-------1-1
Austrodanthonia spp.          ----------------------------11111111111111111111111111
Silene sp.                    ---------------------------1-----------------------1-1
*Briza minor                  ---------------------------111--------1--111-11-------
*Fumaria bastardii            ---------------------------111111111----------1-1-111-
*Cirsium vulgare              --------------------1111-1----1-----1---------1-----1-
*Sonchus asper                -------------------1----------111111111-1111111111111-
*Dactylis glomerata           -----11---------1-111-1-111111--1-1--111111-111-1---11
Geranium potentilloides       ----1-11-----111111111-111111111111111-1111--1111111-1
Themeda triandra              11111111111111111111111111111----1-111111111----------
Linum marginale               1-------11111111111111111111111111111111111111111-----
*Plantago lanceolata          111111111111111111111111111111111111111111111111111111
*Romulea rosea                -1----1-111111111111111111111111111111111111111-------
Acaena echinata               1111111111--1-------1-111111111111111111--111111111---
Plantago varia                111111----1111111-1-----------------11111-1111----1111
*Trifolium spp.               --11-------------1---11111111-1-11--11--1------1--11-1
*Urospermum dalechampii       11---------1---1----1---111-1-1111---11---11-1--1---1-
Poa spp.                      111111111111111----11-------------------------1-----11
Senecio hispidulus            -----1--11------1----1------------1-1-11--------------
Sanguisorba minor             -1111--1---11-11-1111--1------1-----------------------
Eucalyptus viminalis          ----1--11-111-----------------------------------------
Lepidosperma inops            1111111--11-------------------------------------------
Carex breviculmis             111111111---------------------------------------------
Asperula pusilla              -1111111----------------------------------------------
Lepidosperma gunnii           11111--1----------------------------------------------
Bossiaea prostrata            --111-1-----------------------------------------------
Schoenus apogon               --111-------------------------------------------------
Bursaria spinosa              11---------1------------------------------------------
Hypoxis glabella              ----------1---------1------------------------------1-1
Eucalyptus ovata              -----1------1-----------------------------------------
Callistemon pallidus          -------------1----------------------------------------
*Aphanes arvensis             ------------1-----------------------------------------
*Centaurium erythraea         --------1---------------------------------------------
Allocasuarina verticillata    --------1---------------------------------------------
Wurmbea dioica                -------1----------------------------------------------
Dianella revoluta             1-----------------------------------------------------
```

Distribution of species at the Queens Domain study site. 1d2c represents: disturbed (1) and control (2) quadrats * = non-native species.

```
                                   55545533333223333444444441234222222111112 1111
                                   234801123458906891234567972701345676894509012312673458

Dichelachne crinata                -1----------------------------------------------------
Cynoglossum suaveolens             -11---------------------------------------------------
*Petrorhagia nanteuilii            111---------------------------------------------------
*Silene sp.                        1-1--------1------------------------------------------
Dianella revoluta                  1-1-----------------1---------------------------------
Hypoxis glabella                   1-1--------------------------1-------------1----------
*Briza minor                       -----------111--1-111-11------------------------------
Austrodanthonia spp.               11111111111-1111111111111--11-------------------------
*Cirsium vulgare                   -1----1----------------1--11-111-1--------------------
*Fumaria bastardii                 1--11111111111--------1-----------1-------------------
*Sonchus asper                     11-11111111---11111111111--1------------1-------------
Linum marginale                    ---1--11111111111111111111111111111111111111111-------
*Urospermum dalechampii            -1----1111--1--11--11-1-1----1--1111--------1-11------
*Dactylis glomerata                -11-----1-1111-11111-11111--111-111--1--1-------11----
*Romulea rosea                     ------111111111111111111-111111111111111111111-1-1----
*Trifolium spp.                    1-11-11-11-11--1-1--------11--11111-1-------------11--
Geranium potentilloides            1-11111111111111-111--11111111-1111111111--------1--11
*Plantago lanceolata               111111111111111111111111111111111111111111111111111111
1d 2c                              111111111111111111111111111222222222222222222222222222
Plantago varia                     111--1---------111-1111--1-11------1-111---111111-111-
Poa spp.                           -11--------------------1-----1--------1111111111111111
Acaena echinata                     ---11111111111111--111111--11111111------11—111111111
Sanguisorba minor                  -------1----------------------1-1---111-11---11-1—1111
Themeda triandra                   ---------1-11-1111111----11111111111111111111111111111
Senecio hispidulus                 ----------1-----1--------1111------------11-----1-----
Carex breviculmis                  -----------------------------------------1----11111111
Eucalyptus ovata                   -----------------------------------------1-111------11
Lepidosperma inops                 ------------------------------------------11--1111111-
Bursaria spinosa                   --------------------------------------------1-11------
Lepidosperma gunnii                ----------------------------------------------11--1111
Asperula pusilla                   -----------------------------------------------1111111
Bossiaea prostrata                 -------------------------------------------------1111-
Schoenus apogon                    --------------------------------------------------111-
Eucalyptus viminalis               ---------------------------------------------1--1-----
Wurmbea dioica                     -----------------------------------------------------1
*Centaurium erythraea              -----------------------------------------1------------
Dianella breviculmis               ----------------------------------------------1-------
Allocasuarina verticillata         -----------------------------------------1------------
*Aphanes arvensis                  ---------------------------------------------1--------
Callistemon pallidus               --------------------------------------1---------------
```

Distribution of species at the Coles Bay study site. 1d2c represents: disturbed (1) and control (2) quadrats. * = non-native species.

```
                              6555664677465574576457766746765845744475431133 113 3 13322 11  22221 2 21 323321
                              26726971151354389056887846972030314254900028727678564149098431336570982256345119

Billardiera longiflora        ----------------------11--------------------------------------------------------
Helichrysum dealbatum         ------------------1-----1-------------------------------------------------------
Gonocarpus tetragynus         ----1-------------------1-------------------------------------------------------
Allocasuarina monilifera      -----1---1---1----1----11-------------------------------------------------------
Astroloma humifusum           -1--1----1---1---------111------------------------------------------------------
Acacia verticillata           ------1--1--1-1--1-2---1-1-1------1---------------------------------------------
*Agrostis capillaris          121--11-11--22121--21-1--1--111-1-111-------------------------------------------
*Sonchus asper                -----------------2-------------1------1-----------------------------------------
Dillwynia sericea             1-12--111-1--1-1---11--1--2-112--1-111-2----------------------------------------
Geranium spp.                 3321213111112322312122111222122212111121----------------------------------------
Juncus pallidus               11-11-11--1-11-11-11-111-111--1111-11111-1---1----------------------------------
Exocarpos strictus            1---212-1--1--12--11--1-1-------1---22--1-11-----1-1---1------------------------
Oxylobium ellipticum          1----1-1--------------1-111-11-1--1--1------------------1----1------------------
Austrostipa spp.              11111111-1-111-11-11--1111111111111111------------1--1----11-----1--1-----------
*Centaurium erythraea         -11-1----------------------1--11-1-----11-1----22--------1-------------2--------
Poa labillardierei            -----1--11-------1---11--1-11--1--1---1---1-1--------------11-----------1-1-----
Leptocarpus tenax             11111-111-1111--1111111-1111211111111-1-12--142--1--12-1431512-34433-33-324124--
1d2c                          11111111111111111111111111111111111111112222222222222222222222222222222222222222
Pteridium esculentum          11111111111112221122111111222222222222332222223221212322232222222222424134111223
Leptospermum scoparium        -111111111111111211122222222122222222222223444232232353223243332333332234443452 2
Kunzea ambigua                1--1-121111-3111-111-11113--1111111122111-1121211112121-1-11122-11111-3111111111
Diplarrena moraea             -1----1-----1-------------1---1--1-1---2-1---1--1---1----------1---1----1-1-----
Monotoca glauca               --1---------------1-------------------------1-----------------1-------1---------
Callitris rhomboidea          ----1----------1---1---1-1-----------1-1--21-111111-1-----211-1-111111--11---111
Oxalis perennans              ------1-----1--------------------2-------11--1-1--1--1----3-1--11112-----211-11-
Lycopodium deuterodensum      ---------1-------1-------1--1---1-1-11--1122111321222121-1121221112-11212-123113
Stylidium graminifolium       ----------11--------1--1-------1---21----131-1121-112----1122111-1121221---21-12
Lomandra longifolia           -----------1-----1----1-1------------1------1--1--11-------1112-111---11--111-11
Eucalyptus amygdalina         -----------------2-----1-1--------1--------------------5---------1---4-----1--2-
Epacris impressa              ----------------------------------------3322324344444343445255554455545555445455
Acacia sophorae               ----------------------------------------1-2---------------------------1---------
Banksia marginata             ------------------------------------------2-2-22221122-2122221-12322-2213112-12-
Acacia dealbata               --------------------------------------------1----2-----2------------------------
Pimelea humilis               ----------------------------------------------1---------1----1------------------
Wahlenbergia spp.             -----------------------------------------------1----1-------12-----1--2-2-------
Leptecophylla juniperina      ---------------------------------------------------1------1----1-1------1-------
Dichondra repens              ------------------------------------------------1-------------------------------
Glycine clandestina           -------------------------------------------------1---------------------------1-5
Comesperma volubile           ---------------------------------------------------------------------------1----
```

Distribution of species at the Douglas Road study site. 1d2c represents: disturbed (1) and control (2) quadrats. * = non-native species.

```
                                   111 1 1  1 11111   1 1  1 11   111111111111111111111111111111111111111111111
                              88999211809199090011198818098180189001005523343342444435523322222245543433554655
                              12760097473541620962853718899451368340525014523253783172179098652493646618740089

Cassinia aculeata             ------------------------1-------1-----------------------------------------------
Juncus pallidus               -1------1-------------1-------1--1----------------------------------------------
Dianella tasmanica            1--11---111-1--11------1-1----1---1---------------------------------------------
Acaena novae-zelandiae        -------------1--------------------1---------------------------------------------
Geranium potentilloides       --1--------1--1-------------------1---------------------------------------------
Glycine clandestina           12--1---2-2--1-2------43-4--3-1--1---------2111------1----------------1---------
Dillwynia glaberrima          4444544445455434445454445553544344445434---1111------11-11--------1---1---------
Eucalyptus globulus           11--1-----1-11-1------11-1----11-1----1-1-111111-1-11111-1-111111--11--1--------
Lissanthe strigosa            ----11111111111111111111111111-1111111111-1--111111111111111111-1------1--11---
Dichondra repens              --13-21214524-4-243225354553523 21-422331-111-11-2221211-112--111222-11-2-1-121--
Epacris impressa              --1142222413233223233214342332242123233211232242322223222-21332432121-2122-2-222-
Astroloma humifusum           11111---111-1111-----11--111111--1-111-1-1-111111-111------11----------11-1-1-1-
Austrostipa spp.              --1-------------1-----------------1---11---11--1--1---1---1-------1-1111-1-11111
*Holcus lanatus               --------1--1--1111111-11-111--1111111111121111111-11-1-212-11222122--1--11---1-1
Eucalyptus obliqua            11111---111-21-12----1-1-1112-11-11-----11211-111-1--111--1111------1-2----1---1
Exocarpos strictus            21111323121321112223312131211311311213121111211-1--1--2-1121111111-11111-111---1
Acacia dealbata               --12211443432122112324232334232333322323222221342233224321 2-122223232222 1-1-222
1d2c                          22222222222222222222222222222222222222221111111111111111111111111111111111111111
Pteridium esculentum          34332345432213334432122131233321222232235455434432232222121122222322112212323222 2
Leptospermum scoparium        34433323321232122321233425334221234213322252222335212221241234344512321221232222
Senecio linearifolius         ---1---------1-------1------------------1-11--11-11---1---111111111---11-11-1-111
*Senecio vulgaris             ------------------------1---111-111111111-11-11-11111111111111111111-1111--111111
Themeda triandra              ----------------------------------------1--1111-----11--11-1111111-111-11—11111-
Comesperma volubile           ----------------------------------------1-1-1-1------1-211-111----1-111---11211-
Allocasuarina monilifera      ----------------------------------------1----1-11-----1----------11-----11---111
*Cirsium vulgare              -----------------------------------------1------1--11-21----------1----1-11--1-1
Bursaria spinosa              -----------------------------------------11-11111-11-1--1-111111-111111---111--1
Diplarrena moraea             -----------------------------------------1-1111-1111111-11--11-11111-1111111-11-
*Geranium molle               ------------------------------------------1---------1---1-----------1111--1-111-
Billardiera longiflora        -------------------------------------------111111111-11111111111--111-11111111--
Dodonaea viscosa              -------------------------------------------1--1------1---111111211-1111--11111-1
*Acetosella vulgaris          ------------------------------------------------1-111-11111--11--111----1-1---11
*Plantago major               ------------------------------------------------------1---1--------------1--1---
```

Distribution of species at the Kettering study site. 1d2c represents: disturbed (1) and control (2) quadrats. * = non-native species

	11111111111111121111111111111111111111111211122222112122222222222222222222222222
	88887797880689869977677766696867972986232239929323322421330101013101103112301000
	47899691630720558353972038652118749404596302186426814071317693375512842940720856
Gahnia grandis	-----1--
Pultenaea daphnoides	---1---1-----1-----11-11-1---1---1--
Exocarpos cupressiformis	-----111--111-1-11111211211121311--1--
Carex spp.	---122-------1-------1---------1----1---
Coprosma hirtella	-1---1-11---1-11--------1-1-111-1-----------1-----------------------------------
Correa reflexa	21121113111311131-3431322341111-13--12------1-----------------------------------
Billardiera longiflora	---1-----1---1--11----------------------1-1--1-------11-11--------1--11-1-------
Cassytha pubescens	----11-1----------1--2--1---2--1---1-1----------1--------------1--1----1-1-2----
Geranium potentilloides	-11111--1----1-----------------1--1-1-1-1-------11-11----11-------1--1-----1----
Allocasuarina monilifera	----11-------1-------1------1111-1--1----1-----1-1-11---111-------1---1-1-11111-
Juncus pallidus	--1--11111-11-111-1--111111111-1111--11-1-11-11--1-1111-1-111111--111-1--1-1111-
Pomaderris apetala	-----1---1-1------1-11-1----------1---2-2-1------------------------------------1
Notelaea ligustrina	1----111----1-1------------------------1-1----1--------1---------------------1---1
Bedfordia linearis	1------1----1-1--------1-----1-----------------1-----2---122----1-22--12-----22
Dianella tasmanica	----1---1--1----1---1----111-----1--11---------1-1---1---1---------------1-1---1
1d2c	22222222222222222222222222222222222222222111111111111111111111111111111111111111
Exocarpos strictus	11111-111-11111111111-111111212111111-1--1111112111-1111111112111312111 1-12-111
Glycine clandestina	33224332222332232244333323323324 24-142-1-2322-1223-2-1-211-22-12231--31122------
Dillwynia sericea	1---111-11121111--2221-1-12--11111-11-1-1111111122-12-131-121-13241211-232--1-1-
**Centaurium erythraea*	11111-12111-111-1-1-1111---1--21--211-2-2--111-1--1-------1---1-1-----1----1---2
Pultenaea juniperina	--11-1-1-1-11--11-111111-12-111---211-2223311212433322312232 2-232-222-22-22322--
Wahlenbergia spp.	---11-121113211311223133-23-1221-1211-21222--11-21----2---2--22---1212-----1--2-
Dichondra repens	-----4-3----22--123342443312-141-323-433333212-33122323-23242-23341-523443124-2-
Goodenia ovata	--------11--------------2---211-1--1-1------1-1-1--1-----1111121112-11-111-2---1
Billardiera longiflora	---------1-------------1--------------------1--1--------------1-1-11-1----1---11
Lomatia tinctoria	----------1---1-1---1------1----1---1-1-1---1--------1-1-2322-311--1211-1-112221
Dillwynia glaberrima	--------------4------43-4--32--4323-43----222-22--1---2521-4451-1425-22-5-----2-
Leptospermum scoparium	--------------------1---1----11------3-----------1---1-1--11321-1---11-11--1111-
Olearia viscosa	-------------------------1---1------1----1-
Leptecophylla juniperina	--------------------------------------1-11----------1-------1-----1-----1---1---
**Pinus radiata*	--------------------------------------1-1-1--1------1--------------------------1
Callistemon pallidus	--------------------------------------3-3---------------------------------------
Clematis aristata	---1--21-2--121-12-22212-122112-11---2
**Erica lusitanica*	--1-----1----1--11---1-2-21--12-
**Senecio vulgaris*	---1------1-1---11-1-11--2

Astroloma humifusum	--1-1-1--111-------1111-
Eucalyptus obliqua	---1-1---1------2------1
Ozothamnus ferrugineus	---111--1--1-----11-1-
Diplarrena moraea	--1---1--1--------12
Eucalyptus globulus	---1---1
Tetratheca pilosa	---1----

Distribution of species at the Maria Island study site. 1d2c represents: disturbed (1) and control (2) quadrats. * = non-native species.

	22232223223323222333333333323322223223332222222222222222222222222222222222222222
	88918980890091899110100010291198980981104476777856557754475574645464666457657656
	13619272477953689475548190030242183056863959671037582005482942077841135619843266
Allocasuarina littoralis	1---
Comesperma volubile	------------1---
Juncus spp.	----------1-----------1---
**Carduus tenuifolius*	1------1-----------1--
**Plantago lanceolata*	1--111--1111-11--1----111----1--1---
Helichrysum apiculatum	-----------------------1----------1---
Euchiton spp.	1-11-111-11111-11111-11111-11-1-1-1---
Acianthus spp.	1-11-1---1--1-11-1-1-1---------1--11--
Danthonia spp.	1-----------------------------------1---
Hydrocotyle hirta	111--11-1-----1--1-1-----------11-1-11--
Picris angustifolia	1-------1-----1-1-11-11--1-----1------1---
Lepidosperma lineare	111-111111111111111-1---1-1----111111-1---
Cotula reptans	1111111111111111111111111111111-1-11-11---
**Agapanthus praecox*	-------------1----1----------1--------11--
Senecio linearifolius	1--------------------------------1-11--1--
Bursaria spinosa	1-11-1-11111111111111-----11--111--111-11111111---------------------------------
Austrostipa spp.	1-1-1111-11111-1-11111111-11-11-1111111-11111111--------------------------------
**Verbascum virgatum*	1----11-11--1-111--1-1-1-111-11-1-1111-----1-----11111--------------------------
1d2c	11111111111111111111111111111111111111112222222222222222222222222222222222222222
Carex breviculmis	1--------1--1-1---------------111-----------------1-------11--------1-----------
Allocasuarina monilifera	-----------------1------------------------111111--1-11----1--1-----1-11111112111
Lissanthe strigosa	------------------1-----1-1---------------1--111------------1---------------1---
Exocarpos strictus	--------------------------------1-11-------11111-11111-1---11-1111111111111-1111
Cassinia aculeata	------------------------------------11115445454545444535544445444445544544545444
Glycine clandestina	--------------------------------------1----5-54--445-4-----4------5-555-34544445
Eucalyptus viminalis	--343245335354534243242524-3-32-2-3244-422
Dichondra repens	--5544454-4-444555545-45-545--5--5---55444
Pomaderris pilifera	--331-2-12-2--2-4-422-24-414-4---432122---
**Trifolium repens*	--3--3----------------------------------
**Senecio vulgaris*	--1-----------------------------------

Distribution of species at the Pottery Road study site. 1d2c represents: disturbed (1) and control (2) quadrats. * = non-native species.

	3333333333333333333333333333333333333333
	5554445445554456445533323223222432233323
	5437931616028290547805974862459062113837
Austrodanthonia caespitosa	---1------------------------------------
Comesperma volubile	1--------1------------------------------
Lomatia tinctoria	---------------1------------------------
*Dactylis glomerata	--1-111-1--1-11111----------------------
Eucalyptus globulus	111-1111111111--1-1---------------------
Billardiera longiflora	1-1-1-1-111-11111-1---------------------
*Rumex crispus	------1----1-111--11--------------------
*Verbascum virgatum	--1-1111111--1111111--------------------
Senecio linearifolius	1111111111111-1111-1--------------------
Allocasuarina verticillata	11111111111111111111--------------------
Acacia melanoxylon	-1-1--1---111-----1111-11111---1--------
Dichondra repens	------1----1------11-11--------1-----1-1
Epacris impressa	-----1----1--1------111---111-111-111111
Lepidosperma laterale	11-11111111--11111111-1-1-1-1---1-1-11-1
*Senecio vulgaris	1-11-11-111111111-1111-1--1-1-11111----1
1d2c	1111111111111111111222222222222222222222
Exocarpos strictus	-111111111111111111111111111111111111111
Austrostipa spp.	1--111-111-11111111-1111111111111111111-
Ozothamnus ferrugineus	1--------1--------1-1---------1-----1---
Glycine clandestina	--1---11-1111-1---1111111111111111111111
*Holcus lanatus	---1-----------1-----11--------11----1-1
*Acetosella vulgaris	----11--11-----1111-1-1-11-11-1111111111
Diplarrena moraea	----1-111-11-111111111-11111111-11111-11
Leptospermum scoparium	-----1--1---1-1-111111-1111111111111-111
Allocasuarina monilifera	-------1---1--1111-11-11-111111-1---1-1-
Dianella spp.	-------1-----------------------11----1--
*Prunella vulgaris	------------1-------------------1----1-1
Leptospermum scoparium	------------1--1------1-----11111---11-1
Wahlenbergia stricta	--------------11---11-11-11-11-1-11-111-
Acacia myrtifolia	--------------1-----------1--1----------
Lomandra longifolia	--------------------11------1-1-11111111
Olearia argophylla	--------------------1--11-1111--1----1-1
Bedfordia salicina	--------------------1-----1-----1-1-----
Geranium potentilloides	---------------------11--------11----1-1
Acacia dealbata	---------------------11--------11----1-1
Coprosma quadrifida	---------------------1---1-----11-1--1-1
Leucopogon virgatus	---------------------1-1-1------1-------
Eucalyptus amygdalina	----------------------1--------11----1--
Goodenia ovata	----------------------1-1-1-11-1------1-

Juncus pallidus	-----------------------111-1-11--1111-11
Brachyscome spp.	-----------------------1-1-1-1--1-11-111
Tetratheca glandulosa	-----------------------11-1-1----111-111
Eucalyptus viminalis	-----------------------1-11---1-1------1
Acacia mucronata	------------------------1---------1-1---
Pultenaea daphnoides	--------------------------11--1--111--11
Cassinia aculeata	--------------------------111--1---1-1--
Eucalyptus tenuiramis	----------------------------1-----1---1-
Acacia verticillata	----------------------------1-----------
Olearia viscosa	--------------------------------11-1-11-
Dillwynia sericea	-------------------------------11------1
Helichrysum scorpioides	---------------------------------1--1---

Distribution of species at the Wyre Forest Road study site. Legend: 1d2c represents: disturbed (1) and control (2) quadrats. * = non-native species.

```
                            33333333333333333333333333333333333333334444444444444444444444444444444444444444
                            66666666667777777777888888888899999999990000000000111111111122222222223333333334
                            12345678901234567890123456789012345678901234567890123456789012345678901234567890

Eucalyptus viminalis        1-----1--1--------------------1-1-----------------------------------------------
Bossiaea cinerea            11----1--1--------------------1-11----------------------------------------------
Amperea xiphoclada          ---1--------------------1---------------1---------------------------------------
Dillwynia glaberrima        -1-1--1------1---1-------1------11-----1----------------------------------------
Dianella tasmanica          --111--1-1-----11----------1-1--------11---------1-----11---------------1-------
Leucopogon virgatus         1----11--1----------------------1--1---------1----------1-------1--1-----1---1--
Cassinia aculeata           ----1----1--------------------1----------------1-1--------------1-1----------11-
Pimelea spp.                1----11--1--1-----------------1-1--1---------1---1--111------1-1111------------1
Juncus pallidus             1111111-11--------------1-----1-11-1---1111111111----111--11-1--1---1111-111-11
Glycine clandestina         111111-11---1--111--11-11--1-----1-1--111--11---------111---1--1-11--1-1-1111-11
1d2c                        11111111111111111111111111111111111111112222222222222222222222222222222222222222
Exocarpos strictus          111111-11----1-11111-1-1-111-1---1-11-11111111111111111111-11111-11--11111-111111
Leptospermum scoparium      1111111--11-11111111111111111111111-11111111-1111111-1111111111111-1111111-1-1-1
Acacia verticillata         1111-111-11111111111111111111-11111111111----1111-111-1---1-11-11--1--11--1-11-
Xanthosia pilosa            111111111------1-1----1-----11--11-1--1111111111-1-----111-11-11-1-1-1-1-1111-1-
Pultenaea juniperina        1--111111----1--111111-11111----1--11--111111----11----111111--11111-111--111-1-
Eucalyptus obliqua          1---11------11---------1-----------1----11-11--1-1-11-111---11--11--11-1--11-1-1
Epacris impressa            11----------------1----1---------1------1111111111111111111111111-111111111111
Allocasuarina monilifera    ----1---11------------------------------1--1111--111--111---1-1-11--11-1-111-1-1
*Ilex aquifolium            ---------------------1-11-----1---------1111111-1--1111--111111-11--111-1111-11
Lomatia tinctoria           ----------------------------------------111111111--11-1111-111111-1111-11-111-11
Eucalyptus globulus         -----------------------------------------11--111111111111111-111-1-11-111-----11
*Fumaria bastardii          ----------------------------------------1---111-111111111----11--1--1--111-1-1-1
Bedfordia salicina          ----------------------------------------11-11------------1-111-11--1---1---1111-
Indigofera australis        ----------------------------------------11-11----11------------1-11--------1-1--
Diplarrena moraea           ------------------------------------------1--111----111111-1-111--11---1-1--1-11
Billardiera longiflora      -------------------------------------------11-111111----11111-1-11-1111-111-111-
Lepidosperma concavum       -------------------------------------------111---------111-1--1-1--1-1111-1-1-1-
Goodenia ovata              -------------------------------------------11---------------1-1----------1---1--
Lissanthe strigosa          -------------------------------------------11-----------------1------1---1------
Dillwynia sericea           ----------------------------------------------1---------------11--1----------1--
Leucopogon collinus         ------------------------------------------------1--1------------1-1-1---11------
Leucopogon ericoides        ----------------------------------------------------------------1--------1---1--
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Distribution of species at the Adamsfield study site (- = absent, 1 = 1-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%, 1d 2c = disturbed (1) or control (2).

Drymophila cyanocarpa	1-1-1111-----1-1-11-1111--
Juncus spp.	-1--1-1-1-1111-111-1111-1-1---1---
Histiopteris incisa	1--1--111-111----1111-11-1-------1--
Leptecophylla juniperina	-11-11-1-1-1111-11-1--11-111--1-121---
Dodonaea viscosa	1---1--111-111111-----1--1-1-11----1--
Coprosma nitida	211--1--1-21111121--2-------11-----11---
Eucalyptus subcrenulata	-13122-11-1212113------111232---22321---
Stylidium graminifolium	11111111-1-----1-111-1111-11------1--1--
Baloskion tetraphyllum	-11------2-11221--111111111-1--------1--
Olearia pinifolia	1-----111-11111-1--1-1---11-11111111-1--
Monotoca elliptica	11212111211221-11121-222121--121-----1--
Xyris gracilis	1-1---11-1-1--1-11-111--111-----1---1-1---
Blechnum nudum	-111-1-1----1-12---2121---1111-1-1----1---
Sprengelia incarnata	-1----121-----1-11-11---11------1----111--
Pteridium esculentum	1-11-1-11-11-1--1---1-11-1-1-----1--1111--
Acacia mucronata	13-112-1-12121213121----111232--212312-1--
Leptospermum nitidum	323122332122233212212113-----232-1-22--1--
Melaleuca squarrosa	11-111-112-12121111----1--1----1---1---11---------------------11----11----------
Hakea epiglottis	111---11111--111-1-11--1111--------1------2--121-1-----------------1-1----------
Polystichum proliferum	---1---11--1----1--11--1-1-11-----1---1--------------1--1---211-211-------------
Eucalyptus nitida	443233221--1-2233333232323242223331-1222-3--1-1-------------3-322-21-2-12------1
Cenarrhenes nitida	111---122112111---11211-1-1--1232-----1------1-2------------21-1112-21-2-21211-1
Telopea truncata	-111--112--11111-1-11-1--111-1----------1-------------2-12-2-11---11-------1-11-
Allocasuarina zephyrea	1------2--1-11---2-1-111--1--------------111-112----2-1-1-1-2-1---21121-1--1--2-
Melaleuca squamea	1111--12-111111-11-1111111-112221212-1-1212-1111-11---------1-----1---11--1---1-
Banksia marginata	21221122-21131223-----1-1-2-1-12-------11222222------1-12---211-11-1-1-11--111-1
Gahnia grandis	111-111213121121--1-1---1121-12111------2--21121222--2-112-1-11--2121---1-1-11--
Bauera rubioides	---1111232-11-1212123232111-1--------1-1122211---22------2--32--1----1--1-2-2--1
Gymnoschoenus sphaerocephalus	11-1-11121--1-1---21--1-1----------1----1-2-121111112-1112----1121-1-1-2-12-11--
Agastachys odorata	11----11----1111--11-11--1--11-11111-11-1111---12---11-1---11-1---1-111--1---1--
Isolepis spp.	1-----2-11111--11-11111-111--11-11111---1-11-1-21--221121-1--11--11------1-111-1
1d 2c	11111111111111111111111111111111111111112222222222222222222222222222222222222222
Gleichenia microphylla	-------2-1------111---1-1221-1----1-----3233213--3322222221222211222221212122322
Baloskion australe	--11---2-1211-----11--21---1-1-111-11---1-
Blechnum wattsii	--11111---1-----------1--1--1111-1----1-1-
Dillwynia glaberrima	--11-2--11-11------1--1--1---1------------
Epacris serpyllifolia	--11----12-------2---1---111111---11-1-1-1
Hibbertia prostrata	--111-111-2--2--1-1-----1-------1--1-11-1-
Leptospermum glaucescens	--2222-------2-2-3--112212212222---1-22—1-
**Genista monspessulana*	--1-11-1-111-111--1111-11—111-111111---11-
Leptospermum scoparium	--2111211-1--1--1121-12121--221-11121-11-1
**Geranium dissectum*	--11-1-111-111111—1-1-11111-1-111-111-1111
Lycopodium deuterodensum	--1--111--12211111-------1--1-1-1-11-11--1

Orites revoluta	--121--1------1-1-1---1--1-11---1-1-1----1
Selaginella uliginosa	--11-----112111--1-------11-111-1--1-11-11
Eucalyptus obliqua	---121221221121-111---31--121-111-121-211-
Drosera spp.	---11----1---11-11----11-111------1--1-111
Cyathodes glauca	---1------1--1111111--1--1--11--1-1-----1-
Callistemon viridiflorus	--21-11--11-1-----1-1------1---111---1--
Eucalyptus delegatensis	--1-2-333323322231----1-211------121----
Orites diversifolia	--1---11211111-2----1----1-----1-1------
Acacia mucronata	---1-------------------1-1------------
Acacia melanoxylon	--1-11-11--1----2--11-111---1-11---1
Oxylobium ellipticum	---1-11--1---311-1-12-31----1111-122
Monotoca glauca	---1------1111--1111-1------------11
Leptospermum lanigerum	--111111--2--322111211-32-2-11---1
Acacia dealbata	--1--111-1-2--1--111111-11--11-111
Richea procera	---11112-111222121222121-1212112

Distribution of species at the Butlers Gorge study site. Legend: - = absent, 1 = 1-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%, 1d 2c = disturbed (1) or control (2). * = non-native species.

Dodonaea viscosa	--1--1------1----1-1111111--1-1--1111---
Pteridium esculentum	11-11111---11--1111-11---1--1--1---11---
Histiopteris incisa	-1----1--------1-11-1-1--11111-1---111--
Drymophila cyanocarpa	-1-----1-----1--11-1-1---111---1-1--11--
Olearia pinifolia	--11--1-111-1111-1--111111--111----1-11---
Allocasuarina littoralis	-1-----------1-1-1---11--22--1------1-1---
Xyris gracilis	1---1--1--1-11---1--1--1-11-11-1--1--111--
Polystichum proliferum	-1--11--11--1-----1-1----1--11-1---1----11------2---------12--1----1---1--------
Bauera rubioides	-2-1-----1-112--1-111-11-22112-3-2233111---211-212---21-11-3-1-2--2--2-2-2------
Isolepis sp.	1-1---1-1-1-11-1-1--1-1-1--11111-111121111-1-11--122-111--1--11--1-1--112--21--1
1d2c	22222222222222222222222222222222222222221111111111111111111111111111111111111111
Gleichenia microphylla	-----1--1---1-----------12112-----1-1-212233233213-2122212222123223221222222-211
Eucalyptus delegatensis	-----------------------------------11312---2-32---1--2---33-221-21-31-33---21323
Epacris serpyllifolia	------------------------------------11--1111-221-111---1------11-1---1-----11112
Monotoca glauca	--1---------111-1----1--1--1-1---1-1---1--
Leptospermum scoparium	--22112211-1-1111-1--2112-11--2121-1111-1-
Leptospermum glaucescens	--12-2-2-222-32212-2222------12-12--12---1
Leptospermum lanigerum	--11------1---1-112312--21--1211-21-311-2-
Richea scoparia	--22----1-2--21221-1122---11-122121111-121
Allocasuarina monilifera	--1211---1-12----112-2111--1--1---2----211
Hibbertia prostrata	--1-1111-1-----1-1-----11--1----1----2211-
Eucalyptus obliqua	---1122-111121-2--11-31211-112-1211--2211-
Lycopodium deuterodensum	---1--11---1-111111-1-11-2-12---1-1--11-1-
Oxylobium ellipticum	---1--1--1-111----21131---1---1-2111-3---2
Blechnum wattsii	---1-111-1-1--11---1-11---1---1-------11--
Orites revoluta	---1-1-1-2----1-1-1--1-11--1-1-1--1-----1-
Cyathodes glauca	---1-----1---11---1-11--1--1--1---11-1111-
Selaginella uliginosa	---1---1-11-111111----1--2--1-1-1-1--1111-
Acacia melanoxylon	---11-----1--11-111--21--1----11--1--11---
Acacia dealbata	---1----1-1--11-11--111---1--111--12-1111-
Callistemon viridiflorus	--12--1--1------1--1-1-11-1-1-1-1------1
Dillwynia glaberrima	--1--1-1-21-1------1---1--1-1----1------
Drosera sp.	---1--111-111-111--1-----1-1---11--1-1--
Orites diversifolia	--11------12------11---11-11--1-1--12---
Baloskion australe	---1-1--1------1-2-2111-111111-1--211-
Acacia stricta	---1-----11-----------
Austrodanthonia caespitosa	---111-1
Lomandra longifolia	---23212
Lomatia polymorpha	---21111
Poa spp.	---11111
Eucalyptus pauciflora	---12212

**Genista monspessulana*	--11121
**Geranium dissectum*	--11111
Carex gaudichaudiana	--111
Acaena novae-zelandiae	--11---
Pentachondra involucrata	---11
Tasmannia lanceolata	---1-1-
Hakea lissosperma	--1
Dianella tasmanica	---1-
Hakea microphylla	---1-
**Cirsium vulgare*	--1
Senecio sp.	--1
Lomatia tinctoria	--1

Distribution of species at the Mount Field study site. Legend: - = absent, 1 = 1-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%, 1d 2c = disturbed (1) or control (2). * = non-native species.

```
                             111121111      11   22223333422232233333
                             6789023451234580179623560349091477812568

Blechnum nudum                1-1-------------------------------------
Brachyscome spathulata        -----1----------------------------------
*Trifolium repens             -----------------11---------------------
Blechnum wattsii              1--------------11-------1---------------
Nothofagus cunninghamii       -2222-----------------------------------
Orites diversifolia           -1111-------------------1---------------
Grammitis poeppigiana         -1-11--1-1---1--------------------------
Astelia alpina                21----21-1-111--------------------------
Richea scoparia               --111-1--11----111----------------------
Rubus gunnianus               -1-------1111111-11---------------------
Polystichum proliferum        --------------1--111--------------------
Leptecophylla juniperina      2222--2--11-------22--------------------
Olearia ledifolia             -----1-1-111-1111-11--------------------
Richea sprengelioides         ---------11111----111-------------------
Blechnum penna-marina         -11---1--11111-11-11-1-1-11-------------
Monotoca submutica            -2212----1-------212---11---1-----------
Orites revoluta               -----212111211222222-11-1----------1----
Tasmannia lanceolata          121-1----1-111-1111111------1----------1
Coprosma nitida               212-11-121---2-1-1-21-111--1111---------
1d2c                          2222222222222222222111111111111111111111
*Sonchus asper                1111111111111111111111111111111111111111
*Centaurium erythraea         1111111111111111111111111111111111111111
Eucalyptus coccifera          22232233222333222223122-21-2212112222-2-
Ozothamnus rodwayi            22121211222122112211221111111-111211111-
Acaena novae-zelandiae        1--11-1-1--111111111-11-111-1-1-1111-111
Dichondra repens              1111---------11-111-1----1111111-111111-
Geranium potentilloides       11-1-111--------111-111-1-----1111111--1
Gaultheria hispida            -----1-111-111111-1---1-1-1111-------111
Poa gunnii                    ----------1-1111111111111111111111111111
Gonocarpus serpyllifolius     ----------11-------1-11-------1---------
Ewartia catipes               -------------1111111111-1111111111111111
Cotula alpina                 -------------1---1-1-1--11--1-111-------
Plantago tasmanica            ---------------------1111----1111111---1
Olearia phlogopappa           --------------------1---11-11-111-1---1-
Grammitis poeppigiana         --------------------1--1------1--1--11--
Telopea truncata              ---21----------------------------11---11
Leptospermum rupestre         -1-11-------------------------1-1----12-
*Cirsium vulgare              --------------------------------11--1--1
Hydrocotyle sibthorpioides    ----------------------------1-----1-----
```

Distribution of species at the Kelly Basin study site. Legend: - = absent, 1 = 1-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%, 1d 2c = disturbed (1) or control (2). * = non-native species.

```
                                46655675457576766767758457755447456466444333321333133122112221  31 12 12 2 21
                             84619357944289385271700469683360752501201163834254190552020196467793689417388257
Leptospermum scoparium       --------3-----1-----------------------------------------------------------------
Gleichenia dicarpa           ---1-2-1-122----------1-3-------------------------------------------------------
Monotoca glauca              ---21----1-----------2------2---------------------------------------------------
Leptecophylla juniperina     ---1----------------------------3-----------------------------------------------
Pittosporum bicolor          --------1-------------2---------1-----------------------------------------------
Gahnia grandis               -13112-2--1--222-121----2--1----2-----------------------------------------------
Acacia verticillata          -------2---2-------2-2--2------122----------------------------------------------
*Zantedeschia aethiopica     --------------------------1--------2--------------------------------------------
Leptospermum glaucescens     --2---2------1-21--------1-----------1------------------------------------------
Restio tetraphyllum          -11--1-1---3------------3-----------2------------------------------------------
Pteridium esculentum         1----------2-11-----1----1-1--------1------------------------------------------
Todea barbara                ----------1--21--1-----1--1--------3-3------------------------------------------
Trochocarpa gunnii           -----1---------------1------------1----------1--1-------------------------------
Pimelea drupacea             -1----1--1--1-11-1--------11-----------1--1------------------1------------------
Blechnum nudum               13245-33-11244-142333332-3431-12-33112-2-11123122-11---11122------1-------------
Coprosma nitida              1321112122-123-111222211-42111-122---11111121211211--12-----32-----1------------
Drymophila cyanocarpa        ---1-----1-----------------------------1-----------1--1----------------1--------
Acacia melanoxylon           -3--1--1-1-2-22---3321---33---242----11----12--121-21-2-----2-------1--2-2------
Melaleuca ericifolia         323--312413---1-4232---22---133-3331-------1-2------1-1---------2---2--1-2-1----
Blechnum wattsii             --1--41---11--41111-----2--12----32-1--1---1-2----1--1-11-----1111---1--1---11--
1d 2c                        11111111111111111111111111111111111111122222222222222222222222222222222222222222
Dicksonia antarctica         ---1----22-222-321415322--13-2-4-2-13253122223322222222324211213212322221112--2-
Pomaderris apetala           ---1---------------------2----3-1--1---2---11--111-2-------1-1--1--12--2--------
Anopterus glandulosus        ---------------3--------1---1---1----------1--11--2-22--2-1-11-1-2------1--111-1
Carex appressa               -----------------1-1-1-1------2-12-1-------111-11---1--1---11-------1--1-1------
Polystichum proliferum       ----------------------1--11--4-1-1----115112121-1112-1-111-1--1-22111121-1111211
Clematis aristata            -----------------------1----------------11-1---11---------11----11--1------1----
Atherosperma moschatum       ---------------------------3------2-41---23-212133111321-212212-22221122122121-1
Nothofagus cunninghamii      ----------------------------1--------2-3-232232212232422212212333313312332224232
Eucryphia lucida             -------------------------------------3-------13---3--3-121111132-232111121113222
Hymenophyllum flabellatum    --------------------------------------111-1111-1-111-11111-11---1-11-11111111111
Microsorum diversifolium     ---------------------------------------1-11--1--1-----1---1-11-----11----1------
Histiopteris incisa          ----3--2-----------------------------------1--------1-2-----1--11--21--211-1-11-
Juncus spp.                  -------------------------------------------1----1---1-1-------------1--1---1----
Urtica incisa                ------------------------------------------------1-------------------1--1-1------
Gleichenia microphylla       --------------------------------------------------2-----1---------1-------1---1-
Acaena novae-zelandiae       --------------------------------------------------1-----11-----1--1--1----1----1
Prionotes cerinthoides       ---------------------------------------------------1---1-1-----1----------1--1-1
Cenarrhenes nitida           -------------------------2---------------------------1--1-----------------------
Anodopetalum biglandulosum   -------------------------------------------------------1-----1----1--2--------1-
```

Distribution of species at the Lake Johnston study site. (Legend: - = absent; 1 = 1-5%; 2 = 5-25%; 3 = 25-50%; 4 = 50-75%; 5 = > 75%; 1d 2c = disturbed (1) or control (2).

```
                              1 1  111  1 11   111      1 11 11 111 111111111111111111111111111111111111111111
                              09199010891800999112989889181080080108113332224534252442356244355254342555334453
                              09358587267196234250167850074491243183690125128834876273840469725935917601640395

Orites diversifolia           ------1---1--------------------21-----------------------------------------------
Trochocarpa thymifolia        3----------1-111--------1-----11----1-------------------------------------------
Richea pandanifolia           33223---1--2------2-------------------1-----------------------------------------
Leptecophylla juniperina      ----------------11---------------------1-1--------------------------------------
Nothofagus gunnii             3233323123342223332434234223323223122222---111----------------------------------
Richea scoparia               -----3---1-1-3--111--21-2-1--3-2212--21-------111---1---1----11-----------------
Athrotaxis selaginoides       33-2--22-22-----3-2---2--3---22---1---1----------------1--1------1--------------
Diselma archeri               -23323-4332233322231-2-2-233222-21121222221-1111-111-11--1--1--11-1-------------
1d 2c                         22222222222222222222222222222222222222221111111111111111111111111111111111111111
Bellendena montana            1---11---1--11--1--11--1-11-11-11--11-111111--11-11111-11-11-11--1-11111111-1111
Olearia pinifolia             --2----1--------2-----------1--21---1-----1---11111--1-1-1-1---11------11-------
Tasmannia lanceolata          ---1--1---1-----1-11-------1---------111111--1-1111111111--11-1--1-111111111-111
Coprosma nitida               ----1--------------1----1-----1-----1-------11----1-1-----11--------1-1---1---1-
Astelia alpina                -------1-1-1-111111114-14112112--3-1-31122331221321131122112122111122221111211—-
Anemone crassifolia           --------1--1----------------------------111111--111-1-11---11----1--1--1--1-11--
Dichelachne sp.               -----------1---------------------1-------11121111111111111211-11111--111-1--1111
Helichrysum milliganii        ------------2------------------1--1-------11-11-1-1-111-11--1--1------1--1----1—
Carpha alpina                 ----------------------------------------33311111211111-1111111111111112111111211
Trochocarpa gunnii            ----------------------------------------122-1111-11-11--1-----1-1-1-1-1111121—1-
Lycopodiella diffusa          --------------------------------------------11------1--1---1-------1------------
Leptospermum rupestre         -------1--------------------------------1---------1----1------------------------
Senecio pectinatus            -----------------------------------------------1----------1---11----1----11-1-11
Restio complanatus            ----------------------------------------------------------2---------------------
Telopea truncata              -------------------------------------------------------------1----------1-------
Microcachrys tetragona        ---------------------------------------------------------------------1----------
```

Distribution of species at the Lake Margaret study site. Legend: - = absent, 1 = 1-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%, 1d 2c = disturbed (1) or control (2). * = non-native species.

	22222222222222222222222222222222222222221111111111111111111111111112111111111111
	12133113002333212310100220423300112220316696996669678788979898788790967896777788
	86091572484043369729927285058661140713533134405682280756196792318450876379120549
Tasmannia lanceolata	------------------1---
Prionotes cerinthoides	--------------------------------1---
Cenarrhenes nitida	----------------------------------2---
Selaginella uliginosa	----------------1--1--
Coprosma nitida	------------11--1---1--1--
**Vinca major*	-------23--------2-----2--
Polystichum proliferum	12--1-1-1-32-32--1--1--3----1---
**Narcissus pseudonarcissus*	--1----------------1---1-2----1---
Billardiera longiflora	----------2-12-------1-21---11-1--
Leptospermum glaucescens	-2-1--------2--------2------11-3--
**Holcus lanatus*	---------1-------------1-1------1---
Histiopteris incisa	-1---------1----1------1----------2---
Geranium potentilloides	---1----------------------11----1--1--
Blechnum nudum	-111----------------------------1--1--
**Ilex aquifolium*	------2-------2-------2-2-1-------2-1---
Clematis aristata	11-----1--1111--1--1---11-11--------1---
Oxalis magellanica	-------------1-1-1-----11-1---------1---
**Salix alba*	------3--------3----3-------------3-3---
Epacris impressa	---1--------1---1----1-211--11-1-----1--
Gaultheria hispida	1-11-1-1111-111-1--111-1--1111-11-1--1--
**Rubus fruticosus*	1---1-1-11--1--21----12-12--1122---2-2--
Sprengelia incarnata	---11---2211111-1111-1-1-2---1-2-----2--
Acacia mucronata	--------2-2-12-------1-1--11---2--2-1-1---
**Cotoneaster franchetii*	---1-2--3--1--112---2-2-2322-----2-12-2---
**Digitalis purpurea*	1--11-11-----1---1--1-----1-11------1-1---
Leptospermum scoparium	1----2-----22--2-1-2----2-1----22-----2---
Dicksonia antarctica	-2-21---2-22-22-1-------1-2222-1--2-2-2---
Acaena novae-zelandiae	1---1-11----1--1-1----121111--1----11-1---
Pomaderris apetala	-1221----2-1--1--221------221--1212-222---
Restio tetraphyllum	-1-----1--2--2-111-----21-11-2-----11-1---
Juncus spp.	1111111111-11--1--11--1112---111------11--
Eucryphia lucida	2--12-1-----1----2---1-----------2-----2--
**Acer* spp.	---11--1---1--12-12-----1311--3-----1-12--
Baloskion tetraphyllum	111-111-1111111---11211-1111-121111-1-11--
Gleichenia microphylla	--11--2--2--1---1-2221---2-----221-----1--
Melaleuca squarrosa	13211-121------12221--1-2222-12-11212121--

Acacia melanoxylon	--31-23-3312-1222-3-3-222-22-2---2322222--
Richea pandanifolia	2-----------1-121---1--1----------2-----11--------------------------------------
Leptecophylla juniperina	--221-1-2122-1---1--21111------11--11--113-2--11--2-----------------------------
Pteridium esculentum	111-1111111---1111-1111211111111-11111--11---1-----1----------------------------
Blechnum wattsii	-1---11-11-11--1--111112111-1111111-121112112133222-113211-122-1----11-1--------
1d 2c	11111111111111111111111111111111111111112222222222222222222222222222222222222222
Gahnia grandis	--21-----------21--22-1--2--11221112-2-111112-2211-112112-1-11121221--1---------
Monotoca glauca	-----1--2-2-11211-1---22-3222212-3-22-212222223-22123122222231--1-223221-2131212
Bauera rubioides	---------2--2---1111-22-1-11-132-1--1-12-221321112212223-1322112-122--2-31-----2
Pimelea lindleyana	-----------2--2----1----1-11-------1----111--1---1----11-1-1----1------------1--
Nothofagus cunninghamii	--------------1--------1----------3-1---11-1------12------1-------------1--1----
Eucalyptus nitida	-----------------------21311-1-33---1212-3322222432132323242223422422-213223-232
Anopterus glandulosus	----2-----------------------------312-1211-11111-112111111-1111111111-1-11111-11
Leptospermum nitidum	--4423313323422322311122222321231124323222
Drymophila cyanocarpa	--11-1-111--1111111-11--11-1111-1-11-111-1
Correa reflexa	--11---1---------------------------------1
Phebalium squameum	---2-2--2211-11122-1-221-1-11111--11-1-211
Telopea truncata	---11---111111--1111--11-1---111-1-1---11-
Phyllocladus aspleniifolius	--1--1-11-------------------------1---1-
Senecio linearifolius	---1----1---------------------

Distribution of species at the Nelson Falls study site. Legend: - = absent, 1 = 1-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%, 1d 2c = disturbed (1) or control (2).

```
                              33332322222222223332223233332333323333222222222222222222222222222222222222222222
                              11118188899889991219990811009000180000985675557775655784764575467665744644476664
                              97685348113690824015497725266591033480725074613590178805293963621482084779143562

Cenarrhenes nitida            --------------------------------------------------------------------------1----1
Pteridium esculentum          ----------------------------------------------------------------------1---1----1
Histiopteris incisa           -----------------------------------------------------------------1----1-1-------
*Ilex aquifolium              --------------------------------------------------22---------------2------------
Eucalyptus nitida             --------------------------------------------------1------2-------21----1----232-
Phyllocladus aspleniifolius   --------------------------------------------------1--------1---2----1-------1---
Eucryphia lucida              -----------------------------------------------22-2--3--1--2----2-1-2--3-----23-
Drymophila cyanocarpa         ----------------------------------------------1------1---1---------1--------1-1-
Zieria arborescens            ---------------------------------------------2-2--------1----11--1121-1--111----
Clematis aristata             -------------------------------------------1--11---------11----1-----------1-111
Phebalium squameum            ------------------------------------------1------2---11--1---------1-21---11---1
Atherosperma moschatum        ------------------------------------------2---2-3---434-1--4----12---------2-12-
Nothofagus cunninghamii       ------------------------------------------2---1-1-3--122222-111-223-321221221223
Blechnum wattsii              ------------------------------------------2--4-2132--1-222--1-43221232-23211-211
Anopterus glandulosus         ------------------------------------------1---21--2-----22-----1221----1---1222-
Acacia melanoxylon            ------------------------------------------2--3----4----3321-3224-333-1-3-23-322-
Muehlenbeckia gunnii          ------------------------------------------3---221----22-21--2---1-1-2--1---2----
Pomaderris elliptica          -----------------------------------------1--1-------1-1-1--1-1--111---------111-
Coprosma nitida               -----------------------------------------2-111----222--------2-2---1-----11-1--1
Dicksonia antarctica          -----------------------------------------12--232--2-2-2-2-222---2---3--2---3--2-
Bauera rubioides              -----------------------------------------21---------12--22--1--2122----2---2232-
Gahnia grandis                -----------------------------------------2-1-122-1111--3-12-1-22-111121-11111111
Leptospermum scoparium        -----------------------------------------2----21-1--11-21--21-2212---11112121-1-
Monotoca glauca               -----------------------------------------1-112---3122-12---11212--12-2112211-211
Polystichum proliferum        ----------------------------------------11--------1----1--12-------1--2-1-2-1--2
Melaleuca squarrosa           ----------------------------------------22234---2-2222-2121313213-1-21-111--222-
Leptospermum nitidum          ----------------------------------------32-2232-122221111122122212-2222332223221
Blechnum nudum                ----------------------------------------54355-231-44422512553451233-255242411335
*Senecio vulgaris             ----------------------------1-3-2---12121--111---1111--------1-----1--------1---
*Rubus fruticosus             ----------------1-------11-1-----1-------------1---1---1--1--------21--11-11---1
1d 2c                         11111111111111111111111111111111111111112222222222222222222222222222222222222222
Geranium potentilloides       ---1---2-21-2---1--3------11---2---------1--------1-------------------1---------
Acaena novae-zelandiae        -----1-323213423---222-3----21-11111-11-111--1----------11--1-11----------------
Juncus pallidus               1-11-------------11-21222233-2-4-333243311-1------1-1--1------------------1-----
Oxalis perennans              --------2---------1---1-2--2-13214111--2-11-1-1---------------------------------
*Aira caryophyllea            2332333413343232223534222541553412443343----------------------------------------
Lycopodiella diffusa          3332435333512211432232122223324312111--3----------------------------------------
```

**Anthoxanthum odoratum*	1-1-2-2321132212---311-3----2----2---12---
Oxylobium ellipticum	-11-3-24-4223442---224-2----2--------22---
Dichondra repens	1--1-----1----------31---------------2--
Carex gaudichaudiana	2131-2----------223---2-12-2--3-4---4---
**Agrostis capillaris*	11-121-25---------1---1-1----11-1---
Baloskion tetraphyllum	3232-4----------222-----53-3-------------2-111-311-11-12111-21122--1211-1113211-
**Plantago lanceolata*	---1----1111--------1-------1---
Cassinia aculeata	-------------------3--------1---------1-----------1--------1--------------------

Distribution of species at the Strathgordon study site. Legend: - = absent, 1 = 1-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%, 1d 2c = disturbed (1) or control (2).

	33333333333333333333333333333333333333333333343333333333333333333333333333333333
	35454345465434344253345322225542335523228680768999898898679987986787796776667769
	67591768206457890432135469832082094173515830776798160752684289395246003144923511
Tasmannia lanceolata	----1-----------1---------------------1---
Danthonia caespitosa	----1-----111---
Atherosperma moschatum	1111-11111---11---
Phyllocladus aspleniifolius	----1---11---11---
Gaultheria hispida	----1---------------1111----1---
Phebalium squameum	1111-1111111111------111-1---1--
Blechnum wattsii	11111111--111--------111------1--1--
Histiopteris incisa	11111111--111----1---111---1--1--1--
Isolepis spp.	----1-----111--11-111-----1-1---1--1--
Agastachys odorata	111-1---11------1-11-1111--1---1----1---
Pimelea cinerea	----1---1-------1-----------------1--1--
Leptocarpus tenax	----1---11---11-1-111---1---1---1-1111--
Calorophus elongatus	1-1-11111-1111-11-111111111--11-1-1--1--
Baloskion australe	---------------111--1----11111-11--11-1---
Gymnoschoenus sphaerocephalus	-----------------1111---11-111-11-11-11--------------------------------1--------1
Drosera pygmaea	111-----11111--1-1111111111-11-11--1--1---
Melaleuca squamea	111111111------111111---111111-2----1-1---
Cenarrhenes nitida	--------1-111----1--1111---11-1-11-1--12--
Pultenaea juniperina	----------------1----111---1---1-------2--
Banksia marginata	--------1------11-11----1111-1-21-111112--
Melaleuca squarrosa	111111111-111---1----------1------1--1-2--
Bauera rubioides	-22121112121-2321111212-22112-1211211232--
Eucryphia lucida	1111-1111111111------111------1--11-----1111-11122-1--1-------------------------
Eucalyptus nitida	111-1----1111111111111111111113111111123-21---132-12---1111-11---2--1----------
Telopea truncata	1111-111111111111--11111-111-12-1--1-11111------1--1-1-----11-1-----1----------
Leptospermum glaucescens	1111-1111-111--11111111111111112111111131----111221111111-11111-111------1-1----
1d 2c	22222222222222222222222222222222222222222111111111111111111111111111111111111111
Gahnia grandis	1111-11111111111-11111111122111-11111121---1111232--2-1-1111--1-12-11112213112–
Nothofagus cunninghamii	1111-11111111111-----111-------------------3---323-1-11---1-1--1------1---------
Acacia melanoxylon	1111-1111-111--------111----------------3-12-1233332-232-132--3---------2------2
Leptospermum nitidum	---1111111---11-1----111---1--12-1--1-13311121221232321231232221232212321433222 2
Acacia mucronata	---11111-1111111111111111111111211111112--2211-11-112--2-1---1----11------------
Sprengelia incarnata	----1-----111--11---1111111-111--11-111-1-11-111-1-1---11-11--1-2---------1----1
Comesperma volubile	----1---1------111111---111-11-11-111111-1----------------1----1------1--------1
Gleichenia microphylla	--------11111111-1--111111111111211111111--1----11--1111111-111111--13-111-------
Oxylobium ellipticum	---------1---------11------------1-11-11---1-------1----1--11-1------------1-1–1
Lycopodium deuterodensum	--2423242232223223413322224332224244344352

Baloskion tetraphyllum	--1---121-11111-112-1111-11211113111221-21
*Centaurium erythraea (introduced, marked * on page)	--1111-111111111111111-11111111-1-111-1-1-
Blechnum nudum	--11--2---11-1-1-1----1--11--1-211-121----
Acacia dealbata	--3-1--1-122-2--1131232-311121--1111-2----
Pteridium esculentum	--1-1---12-1111111-11-1111--1--1----------
Leptospermum rupestre	--1----1----1-------11--1---------1------1
Pomaderris elliptica	--1-1-------1---11--111------1-----------1
Eucalyptus obliqua	--1-11--1-21-1------1-11-1----------------
*Erica lusitanica	--1-1------1----------------1-------------
Gonocarpus micranthus	--111-----1---1------------1--1-----1----1
Acacia myrtifolia	---11--111-1--121211--1--1-1-11--1--------
Poa spp.	---11-1-1---1--11-1111-11--1-11--11-------
Monotoca elliptica	---1------1--11-1-----11------------------
Acacia verticillata	--11---11--1--111-11--1---11-2---------1
Juncus spp.	--11---111-11-----111-11111--12111-11121
Acaena novae-zelandiae	--11----1--11-11-1--11--1--1----1--1--1-
*Sonchus asper	---1-1-1---1--1-11-1--1-1--111111111--1-
Acianthus caudatus	---1---111-11-1-11111-111--1111-1-11--11
*Holcus lanatus	---11111-1---1---1-------1-111----1---1-
Juncus pallidus	---2---1--1-1-11---1--1-------11-21---
Pittosporum bicolor	---1--1------------------1--------------11
Hypericum gramineum	---1-----1-11----1---1-----1--1--11-1-11-1
*Lotus corniculatus	--1---1--------------------------1---11-
*Dactylis glomerata	--1----1---1---1-----1--1--------1-1---1
Senecio elegans	--1--1111--1-----1--------1-----1-------
Trochocarpa cunninghamii	--1------11---1-1-11-----1----------
Leptecophylla juniperina	--1---1-1111-11-111-------------1---
Restio complanatus	---111111-1---1--111--11-1-------1--
Geranium potentilloides	---1---1-11---1--11---11--1-1--11-1-
Oxalis perennans	--11---11-11111-111--11--1-111--11
Hydrocotyle hirta	---1--1--111-11-----1-1--1-1-1
Pimelea spp.	---1---1-1---1--1-------11
*Rorippa nasturtium-aquaticum	---1--------1-1--1--1-
Pomaderris apetala	---1---1-----1-----1
Orites diversifolia	---1--------------------------------------
Clematis aristata	---------------------------------------1--
Xyris operculata	---1----

Distribution of species at the Williamsford study site. Legend: - = absent, 1 = 1-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%, 1d 2c = disturbed (1) or control (2).

```
                                44444444444444444444444444444444444444444444444444444444444444444444444444444444
                                74454475476786746455665555674775645666770101010020103112023013311232132332222343
                                73266115484002271587931423598439890670565096788621439734432255721147936685980001

Acacia verticillata             ------------1-------------------------------------------------------------------
*Narcissus pseudonarcissus      -------------------1------------------------------------------------------------
*Ilex aquifolium                -----11-------------------------------------------------------------------------
*Rubus fruticosus               ---2112131--2--1-2-----1---2----------------------------------------------------
Acacia dealbata                 -12--1---------2----------11-----1----------------------------------------------
Tasmannia lanceolata            ------11----1--1-11--------1----1-1--------------1-----1------------------------
*Salix alba                     ------2----2--------3-----------3--22-------------------------------------------
*Aira caryophyllea              --1--11-------1-----1---------1-1---1-------------------------------------------
*Sonchus asper                  --11-11-1--111------111-11-1---1-1--11------------------------------------------
Oxalis perennans                11111111111111111111111111--1--11111-1------------------------------------------
Poa spp.                        --1--11-1---12--221-11----111-1-----1-1-----------------------------------------
Juncus spp.                     11-21122--11112111-111111111111-1111121-----------------------------------------
Pteridium esculentum            ------1--1211111--111112112-12211112211-----------------------------------------
*Cytisus scoparius              -11121112-22111--22112112111-1122--12111----------------------------------------
*Pinus radiata                  ---2222221333222212122112232222212222-21----------------------------------------
Austrodanthonia caespitosa      11111211111--11111111111--1-11-111111-11----------------------------------------
*Dactylis glomerata             2221221112121122111111112121111112121111----------------------------------------
1d 2c                           11111111111111111111111111111111111111112222222222222222222222222222222222222222
Dicksonia antarctica            -2--132-2-232-11-22-3-----2121-222212---22212-3222212-2-22-2---12---2-2-2-----3-
Polystichum proliferum          --11111----1--12-1-111-----11-11--11111-111111111111-1111--11------11--1-1--1-1-
Leptospermum glaucescens        ---2-----2--322---2---2122-2-223----1-32---2-3--2----2---2-----3----3-----------
Gaultheria hispida              -----1---------1--2--11-11---1------121-----11--111-1111-111111------1----------
Nothofagus cunninghamii         ------2----------2--21----1-2--222-12212222333332333323322-23-2222--3---221-3-21
Blechnum wattsii                -------2----1-----1----1--11--1-1111111--1---11--1-1-1-1-1-1-11-11-1--1--111—111
Gleichenia microphylla          -------1--------------2222---2122----311---122122211-1221222--222-31-2121-111-12
Clematis aristata               -------2----------1---------1--------------------1---------1--------1-----------
Leptospermum scoparium          --------2221321-2-1122112122222-2322222323322222323211-22223322232322-32-32222—-
Eucryphia lucida                ------------2----------1---2---132123-2333322222223323322--33-232--33-32-322-233
Gahnia grandis                  -------------2-322-2121-32211112-2232211-1-22---21--2112221222122-221112213212-2
Coprosma nitida                 1-----------------2--1---------2---22--11-----------------------1---------------
Histiopteris incisa             -------2-1--------------11-1--1--11---1---1---1--1----------------------1-------
Blechnum nudum                  ---------------1----------------------1--1--------1---1---1-1--11-----------11—-
Atherosperma moschatum          --------------------------------2---------32--2-2322-33-2---2----2--2---2------2
Acacia melanoxylon              ----------------------------------------2-2-23322-32-22-12-22--2----------------
Cenarrhenes nitida              --------------------------------------------2-----1---2-2-2---2-222--2----322-3—
Acacia mucronata                ------------------------------------------------1----1-2-22--2----121-11-122122-
Monotoca glauca                 --------------------------------------------------2--1----2-2----1--1------2--2—
```

Phyllocladus aspleniifolius	---2----1--12--32---2-------2-22
Phebalium squameum	---2-------------211-221-2-2
Trochocarpa gunnii	--1--1-1----1--1-11-1111--
Eucalyptus nitida	---22--2-----2-223--33-2-2
Bauera rubioides	--1--2-------1-2---2-2-2
Sprengelia incarnata	---11---11--11--------
Pimelea humilis	---1--------1--1---1-1
Leptospermum nitidum	--2---33-322-2-2-233
Telopea truncata	--2---2-1-----------
Anopterus glandulosus	--3---------2------------2----3-------3---
Pimelea lindleyana	------------1-----------------1---
Melaleuca squarrosa	-------------------------------2-----2-------------2----------------------------
Drymophila cyanocarpa	--1--------1---------1--------------------
Helichrysum milliganii	--1----------------1------------1---------
Olearia phlogopappa	------------1-------------------------------1---11--------------------1---------
Prostanthera lasianthos	---1---------1------------------1-
Athrotaxis selaginoides	--2-------------------------------

Appendix B – Species Frequency by Treatment

Note: The tables in this section are ordered alphabetically by ecosystem in the order they appear within this thesis.

Grasslands and Grassy Woodlands;

Dry Sclerophyll Communities;

Wet Sclerophyll Forest; and

Rainforest Communities.

Frequency of all species recorded within the three grasslands and grassy woodlands study sites. Legend: CTH = Campbelltown Hospital; F = Fosterville; QD = Queens Domain. The suffixes D or C = disturbed or control. * = non-native species.

	CTH(D)	**F(D)**	**QD(D)**	**QD(C)**	**CTH(C)**	**F(C)**
**Leontodon taraxacoides*	95.00	–	–	–	–	–
Themeda triandra	62.50	40.00	62.50	22.50	97.50	100.00
Austrostipa spp.	80.00	–	32.50	60.00	40.00	–
**Cynosurus cristatus*	67.50	–	–	–	–	–
**Bromus catharticus*	62.50	–	–	–	–	–
**Aira caryophyllea*	55.00	–	–	–	–	–
**Oxalis corniculata*	27.50	–	–	–	–	–
Acacia dealbata	25.00	–	77.50	62.50	27.50	–
**Holcus lanatus*	25.00	–	37.50	25.00	20.00	–
Pteridium esculentum	25.00	–	85.00	85.00	–	–
**Sonchus asper*	25.00	88.00	–	–	–	3.45
**Ulex europaeus*	22.50	–	10.00	10.00	25.00	–
**Lagurus ovata*	20.00	–	–	–	–	–
Oxalis perennans	20.00	–	20.00	–	–	–
**Cirsium vulgare*	17.50	16.00	10.00	2.50	17.50	17.24
Pimelea spp.	17.50	–	7.50	20.00	–	–
Juncus pauciflora	15.00	–	–	–	–	–
Lomandra longifolia	15.00	–	7.50	60.00	–	–
Juncus pallidus	12.50	–	–	–	17.50	–
Acaena novae-zelandiae	10.00	–	–	–	15.00	–
**Juncus articulatus*	7.50	–	–	–	–	–
**Arctotheca calendula*	5.00	–	2.50	–	–	–
Lepidosperma laterale	5.00	–	–	–	–	–
**Geranium molle*	2.50	–	–	–	–	–
Austrodanthonia spp.	–	100.00	100.00	95.00	57.50	3.45
**Plantago lanceolata*	–	100.00	–	75.00	–	100.00
Geranium potentilloides	–	84.00	12.50	22.50	–	62.07
Acaena echinata	–	80.00	–	–	–	65.52
Linum marginale	–	80.00	–	–	–	75.86
**Romulea rosea*	–	72.00	–	–	–	79.31
**Dactylis glomerata*	–	60.00	12.50	–	12.50	41.38
Plantago varia	–	52.00	30.00	–	47.50	48.28

	CTH(D)	F(D)	QD(D)	QD(C)	CTH(C)	F(C)
**Fumaria bastardii*	–	44.00	–	–	–	10.34
**Urospermum dalechampii*	–	44.00	–	–	–	31.03
**Trifolium arvense*	–	40.00	–	–	–	37.93
**Briza minor*	–	28.00	–	–	30.00	6.90
Senecio hispidulus	–	16.00	–	–	–	17.24
Dianella breviculmis	–	12.00	–	–	–	–
**Petrorhagia nanteuilii*	–	12.00	–	–	–	–
Poa spp.	–	12.00	67.50	87.50	37.50	58.62
Cynoglossum suaveolens	–	8.00	–	–	–	–
Hypoxis glabella	–	8.00	–	–	–	6.90
**Silene latifolia*	–	8.00	–	–	–	3.45
Dichelachne crinita	–	4.00	–	–	–	–
Poterium polygamum	–	4.00	–	–	–	48.28
Rumex acetosella	–	–	82.50	70.00	–	–
Picris angustifolia	–	–	42.50	–	45.00	–
**Agrostis capillaris*	–	–	35.00	–	60.00	–
Gonocarpus tetragynus	–	–	30.00	–	–	–
Ehrharta stipoides	–	–	17.50	–	20.00	–
Eucalyptus viminalis	–	–	17.50	5.00	–	6.90
Juncus spp.	–	–	15.00	57.50	–	–
Carex tasmanica	–	–	10.00	–	–	–
Helichrysum scorpioides	–	–	7.50	10.00	10.00	–
Eucalyptus pulchella	–	–	–	25.00	–	–
Bursaria spinosa	–	–	–	7.50	–	10.34
**Plantago australis*	–	–	–	–	47.50	–
Dichondra repens	–	–	–	–	37.50	–
Carex breviculmis	–	–	–	–	–	31.03
Lepidosperma inops	–	–	–	–	–	31.03
Asperula pusilla	–	–	–	–	–	24.14
Eucalyptus viminalis	–	–	–	–	–	20.69
Lepidosperma lineare	–	–	–	–	–	20.69
Bossiaea prostrata	–	–	–	–	–	13.79
Schoenus apogon	–	–	–	–	–	10.34
Allocasuarina verticillata	–	–	–	–	–	3.45
**Aphanes arvensis*	–	–	–	–	–	3.45

Callistemon pallidus	–	–	–	–	–	3.45
**Centaurium erythraea*	–	–	–	–	–	3.45
Dianella revoluta	–	–	–	–	–	3.45
Wurmbea dioica	–	–	–	–	–	3.45

Frequency of all species recorded within the six dry sclerophyll study sites. Legend: CB = Coles Bay; DR = Douglas Road; K = Kettering; MI = Maria Island; PR = Pottery Road; WF = Wyre Forest Road. * = non-native species.

	CB(D)	**DR(D)**	**K(D)**	**MI(D)**	**PR(D)**	**WF(D)**	**CB(C)**	**DR(C)**	**K(C)**	**MI(C)**	**PR(C)**	**WF(C)**
Pteridium esculentum	100	100	–	–	–	55	100	–	10	–	15	–
**Geranium* spp.	100	–	–	–	–	–	–	27.5	–	–	–	–
Leptospermum spp.	97.5	100	–	–	5	55	100	100	10	–	15	37.5
Leptocarpus tenax	82.5	–	–	–	–	–	70	–	–	–	–	–
Kunzea ambigua	80	–	–	–	25	–	87.5	42.5	–	–	60	65
Austrostipa spp.	80	–	–	77.5	75	–	15	42.5	–	–	–	–
Leptospermum scoparium	75	–	–	–	10	–	–	75	–	–	–	–
Juncus pallidus	70	95	62.5	–	–	12.5	5	–	–	–	75	65
**Agrostis capillaris*	57.5	–	–	–	–	–	–	–	72.5	–	15	–
Dillwynia sericea	52.5	–	72.5	–	–	92.5	–	–	–	–	5	12.5
Exocarpos strictus	37.5	–	85	7.5	95	–	15	72.5	–	–	–	87.5
Oxylobium ellipticum	30	–	–	–	–	–	5	–	–	–	–	–
Poa labillardierei	30	87.5	–	–	–	–	15	–	–	15	–	–
Acacia verticillata	25	–	–	–	–	7.5	–	–	25	57.5	55	52.5
Lycopodium deuterodensum	20	–	–	–	–	–	92.5	–	–	–	–	–
**Centaurium erythraea*	20	100	30	–	–	62.5	15	–	92.5	75	100	–
Diplarrena moraea	20	12.5	12.5	–	65	–	20	75	–	20	95	52.5
Astroloma humifusum	17.5	–	25	–	–	–	–	42.5	–	–	–	–
Callitris oblonga	17.5	–	–	–	–	–	60	–	–	–	85	–
Stylidium graminifolium	17.5	–	–	–	–	–	70	–	–	–	–	–
Allocasuarina monilifera	15	62.5	40	2.5	40	–	–	30	–	–	–	57.5
Lomandra longifolia	12.5	–	–	–	–	–	45	–	–	–	–	–
**Sonchus asper*	7.5	100	–	–	–	22.5	–	–	35	–	–	–
Oxalis perennans	7.5	–	–	–	–	–	–	–	–	–	–	–
Eucalyptus viminalis	7.5	–	–	–	–	–	7.5	–	–	–	–	–
Monotoca glauca	5	–	–	–	–	–	7.5	–	–	–	–	–
Gonocarpus tetragynus	5	–	–	–	–	–	–	–	–	–	–	–
Helichrysum dealbatum	5	–	–	–	–	–	–	–	7.5	–	–	–
Billardiera longiflora	5	–	22.5	–	65	–	–	77.5	–	–	–	65
Eucalyptus pulchella	2.5	–	–	–	–	12.5	10	–	–	–	30	–

	CB(D)	DR(D)	K(D)	MI(D)	PR(D)	WF(D)	CB(C)	DR(C)	K(C)	MI(C)	PR(C)	WF(C)
Banksia marginata	–	92.5	–	–	–	87.5	77.5	–	–	5	90	–
Dianella tasmanica	–	85	17.5	–	–	–	–	–	60	72.5	25	10
Eucalyptus globulus	–	60	5	–	75	–	–	57.5	–	–	30	70
Dillwynia glaberrima	–	55	50	–	–	17.5	–	25	–	–	–	–
Dichondra repens	–	32.5	–	–	–	52.5	2.5	–	100	50	100	–
Eucalyptus obliqua	–	32.5	12.5	–	–	27.5	–	50	27.5	–	–	55
**Holcus lanatus*	–	30	–	–	10	–	–	70	–	2.5	55	–
Comesperma volubile	–	12.5	–	2.5	10	37.5	2.5	50	70	–	60	–
Acaena novae-zelandiae	–	10	–	–	–	–	–	–	–	–	–	–
Senecio linearifolius	–	10	–	12.5	90	–	–	60	22.5	–	30	–
Geranium potentilloides	–	5	30	–	–	7.5	–	–	–	100	30	–
**Senecio vulgaris*	–	5	22.5	–	80	–	–	85	–	–	–	–
Pultenaea juniperina	–	–	85	–	–	–	–	–	27.5	–	35	–
Clematis aristata	–	–	57.5	–	–	–	–	–	–	60	–	–
Glycine clandestina	–	–	57.5	2.5	50	–	7.5	15	–	–	–	42.5
Lomatia tinctoria	–	–	55	–	5	–	–	–	2.5	–	–	80
Goodenia ovata	–	–	47.5	–	–	–	–	–	25	–	40	15
Wahlenbergia spp.	–	–	47.5	–	15	–	–	–	62.5	–	–	–
Leptospermum spp.	–	–	40	–	–	–	–	–	–	–	–	80
Bedfordia linearis	–	–	30	–	–	–	–	–	–	–	–	–
Billardiera longiflora	–	–	27.5	–	–	–	–	–	15	–	–	–
Ozothamnus ferrugineus	–	–	20	–	15	–	–	–	–	–	–	–
**Erica lusitanica*	–	–	20	–	–	35	–	–	–	–	–	–
Leptecophylla juniperina	–	–	20	7.5	–	–	12.5	62.5	–	–	–	–
Cassytha pubescens	–	–	15	–	–	–	–	–	15	–	–	–
Notelaea ligustrina	–	–	15	–	–	–	–	–	87.5	–	–	–
**Pinus radiata*	–	–	15	–	–	–	–	–	–	–	15	–
Pomaderris apetala	–	–	12.5	–	–	–	–	–	25	–	–	–
Olearia viscosa	–	–	7.5	–	–	–	–	–	12.5	–	–	–
Melaleuca squarrosa	–	–	5	–	10	–	–	–	62.5	–	–	7.5
Callistemon pallidus	–	–	5	–	–	–	–	–	–	–	–	–
Tetratheca pilosa	–	–	2.5	–	–	–	–	–	–	–	–	–
Cotula reptans	–	–	–	90	–	–	–	–	–	–	–	–
Lepidosperma laterale	–	–	–	70	85	–	–	–	–	–	–	–
Bursaria spinosa	–	–	–	67.5	–	–	–	67.5	–	–	–	–

	CB(D)	DR(D)	K(D)	MI(D)	PR(D)	WF(D)	CB(C)	DR(C)	K(C)	MI(C)	PR(C)	WF(C)
Euchiton argentifolius	–	–	–	65	–	–	–	–	–	–	–	–
**Verbascum virgatum*	–	–	–	55	75	–	–	–	–	5	–	–
**Plantago lanceolata*	–	–	–	40	–	–	–	–	–	–	–	–
Acianthus spp.	–	–	–	35	–	–	–	–	–	–	–	–
Hydrocotyle hirta	–	–	–	35	–	–	–	–	–	–	–	–
Picris angustifolia	–	–	–	27.5	–	–	–	–	–	–	–	–
Carex breviculmis	–	–	–	17.5	–	–	–	–	–	15	–	–
**Agapanthus praecox*	–	–	–	12.5	–	–	–	–	–	–	50	–
Cassinia aculeata	–	–	–	10	–	–	–	–	–	17.5	–	15
**Carduus tenuifolius*	–	–	–	7.5	–	–	–	–	–	–	15	–
Austrodanthonia spp.	–	–	–	5	–	–	–	–	–	–	–	–
Helichrysum apiculatum	–	–	–	5	–	–	–	–	–	–	–	–
Juncus kraussii	–	–	–	5	–	–	–	–	–	–	–	–
Allocasuarina littoralis	–	–	–	2.5	–	–	–	–	–	–	–	–
Allocasuarina	–	–	–	–	100	–	–	–	–	–	–	–
**Dactylis glomerata*	–	–	–	–	55	–	–	–	–	–	–	–
**Rosa rubiginosa*	–	–	–	–	55	–	–	–	–	–	–	–
**Ulex europaeus*	–	–	–	–	50	–	–	–	–	–	–	–
Acacia melanoxylon	–	–	–	–	40	–	–	–	–	–	15	–
**Acetosella vulgaris*	–	–	–	–	40	–	–	45	–	–	–	–
**Rumex crispus*	–	–	–	–	35	–	–	–	–	–	–	–
**Fumaria bastardii*	–	–	–	–	25	–	–	–	–	–	–	57.5
Epacris impressa	–	–	–	–	15	–	–	87.5	–	–	30	97.5
**Aira caryophyllea*	–	–	–	–	10	–	–	–	–	–	–	–
Acacia myrtifolia	–	–	–	–	5	–	–	–	–	–	–	–
Danthonia caespitosa	–	–	–	–	5	–	–	–	–	–	–	–
Dianella spp.	–	–	–	–	5	–	–	–	–	–	20	–
**Festuca arundinacea*	–	–	–	–	5	10	–	–	–	–	–	–
**Prunella vulgaris*	–	–	–	–	5	–	–	–	–	–	35	–
Pimelea prostrata	–	–	–	–	–	57.5	–	–	–	–	–	27.5
Bossiaea cinerea	–	–	–	–	–	47.5	–	–	–	–	–	–
Pultenaea daphnoides	–	–	–	–	–	37.5	–	–	10	–	40	–
**Ilex aquifolium*	–	–	–	–	–	20	–	–	–	–	–	75
Hibbertia procumbens	–	–	–	–	–	17.5	–	–	–	–	–	62.5
Tetratheca glandulosa	–	–	–	–	–	15	–	–	–	–	20	–

	CB(D)	DR(D)	K(D)	MI(D)	PR(D)	WF(D)	CB(C)	DR(C)	K(C)	MI(C)	PR(C)	WF(C)
Acacia dealbata	–	–	–	–	–	–	7.5	–	–	–	–	–
Acacia sophorae	–	–	–	–	–	–	7.5	–	–	–	–	–
Pimelea humilis	–	–	–	–	–	–	7.5	–	–	–	–	–
Themeda triandra	–	–	–	–	–	–	–	65	–	–	–	–
Dodonaea viscosa	–	–	–	–	–	–	–	55	–	–	80	–
**Cirsium vulgare*	–	–	–	–	–	–	–	30	–	–	–	–
**Plantago major*	–	–	–	–	–	–	–	10	75	–	65	–
Gahnia grandis	–	–	–	–	–	–	–	–	35	–	–	–
Carex gaudichaudiana	–	–	–	–	–	–	–	–	20	–	–	–
Exocarpos cupressiformis	–	–	–	–	–	–	–	–	17.5	–	–	–
Correa reflexa	–	–	–	–	–	–	–	–	17.5	–	–	–
Coprosma hirtella	–	–	–	–	–	–	–	–	2.5	–	25	–
Pomaderris pilifera	–	–	–	–	–	–	–	–	–	10	–	–
Bedfordia salicina	–	–	–	–	–	–	–	–	–	–	50	40
Brachyscome spp.	–	–	–	–	–	–	–	–	–	–	50	–
Eucalyptus amygdalina	–	–	–	–	–	–	–	–	–	–	50	–
Helichrysum scorpioides	–	–	–	–	–	–	–	–	–	–	40	–
Coprosma quadrifida	–	–	–	–	–	–	–	–	–	–	15	–
Leucopogon virgatus	–	–	–	–	–	–	–	–	–	–	20	15
Olearia argophylla	–	–	–	–	–	–	–	–	–	–	15	–
Acacia mucronata	–	–	–	–	–	–	–	–	–	–	10	–
Eucalyptus tenuiramis	–	–	–	–	–	–	–	–	–	–	10	–
Xanthosia pilosa	–	–	–	–	–	–	–	–	–	–	–	62.5
Lepidosperma concavum	–	–	–	–	–	–	–	–	–	–	–	42.5
Indigofera australis	–	–	–	–	–	–	–	–	–	–	–	27.5
Leptecophylla juniperina	–	–	–	–	–	–	–	–	–	–	–	12.5
Leucopogon ericoides	–	–	–	–	–	–	–	–	–	–	–	7.5
**Trifolium repens*	–	–	–	–	–	–	–	–	–	–	–	0.05

Frequency of all species recorded within the three wet sclerophyll ecosystem study sites. Legend: A = Adamsfield; BG = Butlers Gorge; MF = Mount Field. The suffixes D or C = disturbed or control. * = non-native species.

	A(D)	**BG(D)**	**MF(D)**	**A(C)**	**BG(C)**	**MF(C)**
Eucalyptus nitida	90.00	–	–	100.00	32.50	–
Melaleuca squamea	80.00	–	–	–	37.50	–
Leptospermum nitidum	77.50	–	–	–	–	–
Acacia mucronata	75.00	–	–	–	–	–
Monotoca elliptica	72.50	–	–	42.50	–	–
Gahnia grandis	65.00	–	17.50	–	60.00	–
Bauera rubioides	62.50	–	27.50	–	42.50	–
Eucalyptus subcrenulata	62.50	–	–	–	–	–
Cenarrhenes nitida	60.00	–	–	–	42.50	–
Isolepis spp.	60.00	–	–	–	55.00	–
Banksia marginata	57.50	–	5.00	35.00	57.50	5.00
Olearia pinifolia	57.50	–	–	–	–	–
Agastachys odorata	55.00	–	–	52.50	45.00	–
Leptecophylla juniperina	55.00	45.00	–	77.50	–	–
Melaleuca squarrosa	52.50	–	–	–	12.50	–
Stylidium graminifolium	52.50	–	–	–	–	–
Pteridium esculentum	50.00	–	–	–	–	–
Baloskion tetraphyllum	47.50	–	–	–	–	–
Blechnum nudum	47.50	10.00	–	–	–	–
Hakea epiglottis	47.50	–	42.50	35.00	17.50	–
Telopea truncata	47.50	10.00	–	–	30.00	20.00
Coprosma nitida	45.00	60.00	2.50	–	–	40.00
Juncus spp.	45.00	–	100.00	–	–	–
Xyris gracilis	45.00	–	–	–	–	–
Dodonaea viscosa	42.50	–	–	–	–	–
Histiopteris incisa	40.00	–	–	–	–	–
Gymnoschoenus sphaerocephalus	37.50	–	27.50	–	65.00	–
Sprengelia incarnata	37.50	–	–	–	–	–
Drymophila cyanocarpa	35.00	–	–	–	–	–
Polystichum proliferum	32.50	20.00	5.00	2.50	20.00	–

	A(D)	BG(D)	MF(D)	A(C)	BG(C)	MF(C)
Gleichenia microphylla	30.00	–	–	–	95.00	–
Allocasuarina littoralis	27.50	–	–	–	–	–
Ozothamnus rodwayi	–	100.00	–	–	–	90.00
Orites revoluta	–	75.00	–	–	37.50	20.00
Acaena novae-zelandiae	–	70.00	100.00	65.00	–	70.00
Tasmannia lanceolata	–	65.00	15.00	45.00	–	20.00
Blechnum penna-marina	–	60.00	–	–	–	20.00
Gaultheria hispida	–	55.00	–	–	–	45.00
Olearia phlogopappa	–	55.00	–	–	–	–
Rubus gunnianus	–	50.00	30.00	–	–	–
Dichondra repens	–	45.00	–	–	–	70.00
Geranium potentilloides	–	65.00	62.50	2.50	–	60.00
Poa gunnii	–	45.00	–	–	–	100.00
Richea sprengelioides	–	45.00	–	–	–	–
Astelia alpina	–	40.00	–	–	–	–
Monotoca submutica	–	40.00	–	–	–	15.00
Ewartia catipes	–	35.00	–	–	–	95.00
Richea scoparia	–	35.00	40.00	–	67.50	5.00
Orites diversifolia	–	20.00	–	–	35.00	5.00
Blechnum wattsii	–	15.00	–	–	37.50	5.00
Cotula alpina	–	15.00	10.00	–	–	35.00
Gonocarpus serpyllifolius	–	15.00	42.50	–	–	15.00
Leptospermum rupestre	–	15.00	–	–	–	20.00
Eucalyptus pauciflora	–	12.50	–		–	–
*Trifolium repens	–	10.00	–	–	–	–
Agrostis tenuis	–	–	100.00	–	–	–
Baloskion australe	–	–	100.00	–	47.50	–
*Centaurium erythraea	–	–	100.00	–	–	–
*Sonchus asper	–	–	100.00	–	–	–
Pultenaea juniperina	–	–	85.00	–	–	–
Hakea microphylla	–	–	70.00	–	–	–
Poa spp.	–	–	70.00	57.50	–	–
Gonocarpus montanus	–	–	60.00	–	–	–
*Holcus lanatus	–	–	52.50	–	–	–

	A(D)	BG(D)	MF(D)	A(C)	BG(C)	MF(C)
Lomandra longifolia	–	–	52.50	60.00	–	–
Leptospermum lanigerum	–	–	47.50	–	55.00	–
Oxylobium ellipticum	–	–	37.50	–	47.50	–
Picris angustifolia	–	–	35.00	–	–	–
Lepidosperma filiforme	–	–	25.00	–	–	–
Coprosma hirtella	–	–	20.00	–	–	–
Hydrocotyle hirta	–	–	20.00	–	–	–
Nothofagus cunninghamii	–		–	–	–	20.00
**Cirsium vulgare*	–	–	12.50	–	–	10.00
Epacris gunnii	–	–	12.50	–	–	–
Epacris lanuginosa	–	–	12.50	–	–	–
Lomatia tinctoria	–	–	10.00	–	–	–
Olearia erubescens	–	–	7.50	–	–	–
Cytisus scoparius	–	–	5.00	–	–	–
Gleichenia alpina	–	–	5.00	–	–	–
Senecio spp.	–	–	5.00	–	–	–
Callistemon viridiflorus	–	–	5.00	–	35.00	–
Carex gaudichaudiana	–	–	–	80.00	–	–
Eucalyptus delegatensis	–	–	–	80.00	52.50	–
Lomatia polymorpha	–	–	–	77.50	–	–
Eucalyptus coccifera	–		–	75.00	–	80.00
**Geranium dissectum*	–	–	–	75.00	–	–
Epacris serpyllifolia	–	–	–	70.00	42.50	–
**Genista monspessulana*	–	–	–	67.50	–	–
Austrodanthonia caespitosa	–	–	–	57.50	–	–
Dianella tasmanica	–	–	–	45.00	–	–
Hakea lissosperma	–	–	–	32.50	–	–
Pentachondra involucrata	–	–	–	32.50	–	–
Cassinia aculeata	–	–	–	2.50	–	–
Eucalyptus obliqua	–	–	–	–	72.50	–
Leptospermum scoparium	–	–	–	–	72.50	–
Leptospermum glaucescens	–	–	–	–	57.50	–
Lycopodium deuterodensum	–	–	–	–	52.50	–
Acacia dealbata	–	–	–	–	50.00	–

	A(D)	BG(D)	MF(D)	A(C)	BG(C)	MF(C)
Allocasuarina monilifera	–	–	–	–	50.00	–
Selaginella uliginosa	–	–	–	–	50.00	–
Drosera spp.	–	–	–	–	42.50	–
Acacia melanoxylon	–	–	–	–	40.00	–
Cyathodes glauca	–	–	–	–	40.00	–
Hibbertia prostrata	–	–	–	–	40.00	–
Monotoca glauca	–	–	–	–	30.00	–
Dillwynia glaberrima	–	–	–	–	27.50	–
Acacia stricta	–	–	–	–	7.50	–
Plantago tasmanica	–	–	–	–	–	60.00
Olearia ledifolia	–	–	–	–	–	50.00
Grammitis poeppigiana	–	–	–	–	–	30.00
Hydrocotyle sibthorpioides	–	–	–	–	–	10.00
Brachyscome spathulata	–	–	–	–	–	5.00
Richea procera	–	–	–	–	–	5.00

Frequency of all species recorded in the six rainforest study sites. Legend: KB = Kelly Basin; LJ = Lake Johnston; LM = Lake Margaret; NF = Nelson Falls; S = Strathgordon; W = Williamsford. The suffixes D or C = disturbed or control. * = non-native species.

	KB(D)	**LJ(D)**	**LM(D)**	**NF(D)**	**S(D)**	**W(D)**	**KB(C)**	**LJ(C)**	**LM(C)**	**NF(C)**	**S(C)**	**W(C)**
Coprosma nitida	82.5	25	12.5	–	–	17.5	40	12.5	–	35	–	5
Blechnum nudum	80	–	12.5	–	45	5	42.5	–	–	92.5	–	22.5
Dicksonia antarctica	62.5	–	45	–	–	57.5	92.5	–	–	42.5	–	55
Melaleuca ericifolia	57.5	–	–	–	–	–	22.5	–	–	–	–	–
Acacia melanoxylon	45	–	67.5	–	47.5	–	30	–	–	52.5	35	40
Blechnum wattsii	40	–	70	–	–	35	37.5	–	60	67.5	40	50
Gahnia grandis	40	–	45	–	67.5	57.5	–	–	62.5	72.5	92.5	77.5
Pimelea drupacea	22.5	–	–	–	–	5	7.5	–	–	–	–	–
Polystichum proliferum	20	–	32.5	–	–	52.5	80	–	–	30	–	60
Todea barbara	20	–	–	–	–	–	–	–	–	–	–	–
Gleichenia alpina	20	–	–	–	–	–	–	–	–	–	–	–
Acacia verticillata	20	–	–	–	37.5	2.5	–	–	–	–	–	–
Carex gaudichaudiana	20	–	–	37.5	–	–	30	–	–	–	–	–
Pteridium esculentum	20	–	80	–	47.5	70	–	–	10	7.5	–	–
Restio tetraphyllum	17.5	–	77.5	–	–	–	–	–	–	75	35	–
Leptospermum laevigatum	17.5	–	17.5	–	–	–	–	–	–	–	–	–
Monotoca glauca	12.5	–	–	–	17.5	–	–	–	–	–	–	–
Pomaderris apetala	12.5	–	50	–	10	–	32.5	–	–	–	–	–
Atherosperma moschatum	10	–	–	–	–	2.5	87.5	–	–	32.5	27.5	37.5
Anopterus glandulosus	10	–	15	–	–	–	42.5	–	85	37.5	–	12.5
Pittosporum bicolor	7.5	–	–	–	12.5	5	–	–	–	–	–	–
Trochocarpa gunnii	7.5	60	–	–	–	–	5	–	–	–	–	27.5
**Zantedeschia aethiopica*	5	–	–	–	–	–	–	–	–	–	–	–
Drymophila cyanocarpa	5	–	–	–	–	–	10	–	70	15	–	7.5
Clematis aristata	5	–	35	–	–	7.5	25	–	–	25	2.5	7.5
Leptecophylla juniperina	5	2.5	50	–	30	–	–	7.5	15	–	–	–
Histiopteris incisa	5	–	12.5	–	–	22.5	35	–	–	7.5	45	10
Nothofagus cunninghamii	5	7.5	10	–	27.5	35	100	100	20	70	45	77.5
Leptospermum scoparium	5	–	30	–	–	72.5	–	–	–	57.5	–	87.5
Hymenophyllum flabellatum	5	–	–	–	–	–	75	–	–	–	–	–

	KB(D)	LJ(D)	LM(D)	NF(D)	S(D)	W(D)	KB(C)	LJ(C)	LM(C)	NF(C)	S(C)	W(C)
Asplenium flabellifolium	2.5	–	–	–	–	–	–	–	–	–	–	–
Billardiera scandens	2.5	–	–	–	–	–	–	–	–	–	–	–
Billardiera longiflora	2.5	–	22.5	–	–	–	–	–	–	–	–	–
**Fuchsia magellanica*	2.5	–	–	–	–	–	–	–	–	–	–	–
Muehlenbeckia gunnii	2.5	–	–	–	–	–	–	–	–	35	–	–
Bauera rubioides	2.5	–	45	–	–	–	–	–	72.5	40	90	17.5
Eucryphia lucida	2.5	–	22.5	–	27.5	27.5	70	–	–	30	50	80
Leptospermum glaucescens	2.5	–	–	–	57.5	42.5	–	–	–	–	90	17.5
Melaleuca squarrosa	2.5	–	70	–	–	5	–	–	–	72.5	42.5	2.5
Rubus fruticosus	2.5	–	45	12.5	–	30	–	–	–	27.5	–	–
Cenarrhenes nitida	2.5	–	2.5	–	–	–	5	–	–	5	42.5	35
Poa spp.	2.5	–	–	–	45	42.5	–	–	–	–	–	–
Carpha alpina	–	97.5	–	–	–	–	–	–	–	–	–	–
Astelia alpina	–	95	–	–	–	–	–	62.5	–	–	–	–
Dichelachne spp.	–	82.5	–	–	–	–	–	5	–	–	–	–
Tasmannia lanceolata	–	75	2.5	–	–	22.5	–	25	–	–	7.5	5
Bellendena montana	–	75	–	–	–	–	–	50	–	–	–	–
Anemone crassifolia	–	50	–	–	–	–	–	5	–	–	–	–
Diselma archeri	–	42.5	–	–	–	–	–	85	–	–	–	–
Helichrysum milliganii	–	40	–	–	–	–	–	7.5	–	–	–	7.5
Olearia pinifolia	–	35	–	–	–	–	–	17.5	–	–	–	–
Senecio pectinatus	–	25	–	–	–	–	–	–	–	–	–	–
Richea scoparia	–	17.5	–	–	–	–	–	45	–	–	–	–
Lycopodiella diffusa	–	15	–	–		–	–	–	–	–	–	–
Leptospermum rupestre	–	7.5	–	–	20	–	–	2.5	–	–	–	–
Athrotaxis selaginoides	–	7.5	–	–	–	–	–	37.5	–	–	–	2.5
Telopea truncata	–	5	–	–	25	–	–	–	55	–	77.5	7.5
Restio complanatus	–	2.5	–	–	37.5	–	–	–	–	–	–	–
Microcachrys tetragona	–	2.5	–	–	–	–	–	–	–	–	–	–
Monotoca elliptica	–	–	62.5	–	–	–	–	–	82.5	67.5	5	20
Juncus spp.	–	–	60	–	–	85	17.5	–	–	–	–	–
Gaultheria hispida	–	–	60	–	–	27.5	–	–	–	–	15	40
Sprengelia incarnata	–	–	47.5	–	40	–	–	–	–	–	52.5	15
**Cotoneaster franchetii*	–	–	42.5	–	–	7.5	–	–	–	–	–	–

	KB(D)	LJ(D)	LM(D)	NF(D)	S(D)	W(D)	KB(C)	LJ(C)	LM(C)	NF(C)	S(C)	W(C)
Acaena novae-zelandiae	–	–	42.5	57.5	37.5	–	20	–	–	22.5	–	–
**Acer* spp.	–	–	40	–	–	–	–	–	–	–	–	–
Gleichenia microphylla	–	–	37.5	–	52.5	30	12.5	–	–	–	72.5	75
Baloskion tetraphyllum	–	–	37.5	27.5	80	–	–	–	–	–	–	–
**Digitalis purpurea*	–	–	32.5	–	–	–	–	–	–	–	–	–
Acacia stricta	–	–	30	–	–	–	–	–	–	–	–	–
Eucalyptus nitida	–	–	30	–	40	–	–	–	92.5	20	87.5	27.5
Epacris impressa	–	–	27.5	–	–	–	–	–	–	–	–	–
Richea pandanifolia	–	–	20	–	–	–	–	22.5	5	–	–	–
Pimelea humilis	–	–	17.5	–	–	–	–	–	27.5	–	–	12.5
**Ilex aquifolium*	–	–	17.5	–	–	5	–	–	–	7.5	–	–
Oxalis perennans	–	–	17.5	35	50	82.5	–	–	–	10	–	–
**Narcissus pseudonarcissus*	–	–	12.5	–	–	2.5	–	–	–	–	–	–
**Salix alba*	–	–	12.5	–	–	15	–	–	–	–	–	–
Geranium potentilloides	–	–	12.5	25	35	–	–	–	–	7.5	–	–
**Vinca major*	–	–	10	–	–	–	–	–	–	–	–	–
**Holcus lanatus*	–	–	10	–	35	–	–	–	–	–	–	–
Selaginella uliginosa	–	–	5	–	–	–	–	–	–	–	–	–
Prionotes cerinthoides	–	–	2.5	–	–	–	17.5	–	–	–	–	–
**Aira caryophyllea*	–	–	–	100	–	20	–	–	–	–	–	–
Lycopodiella diffusa	–	–	–	95	100	–	–	–	–	–	–	–
Juncus pallidus	–	–	–	55	30	–	–	–	–	17.5	–	–
**Anthoxanthum odoratum*	–	–	–	52.5	–	–	–	–	–	–	–	–
Oxylobium ellipticum	–	–	–	47.5	22.5	–	–	–	–	–	20	–
**Agrostis capillaris*	–	–	–	32.5	–	–	–	–	–	–	–	–
**Senecio vulgaris*	–	–	–	17.5	–	–	–	–	–	27.5	–	–
**Plantago lanceolata*	–	–	–	17.5	–	–	–	–	–	–	–	–
Dichondra repens	–	–	–	15	–	–	17.5	–	–	–	–	–
Cassinia aculeata	–	–	–	7.5	–	–	–	–	–	5	–	–
Leptospermum nitidum	–	–	–	–	100	–	–	–	100	92.5	50	27.5
**Centaurium erythraea*	–	–	–	–	82.5	–	–	–	–	–	–	–
Juncus kraussii	–	–	–	–	62.5	–	–	–	–	–	–	–
Acacia dealbata	–	–	–	–	62.5	17.5	–	–	–	–	–	–
**Sonchus asper*	–	–	–	–	50	45	–	–	–	–	–	–

	KB(D)	LJ(D)	LM(D)	NF(D)	S(D)	W(D)	KB(C)	LJ(C)	LM(C)	NF(C)	S(C)	W(C)
Acacia myrtifolia	–	–	–	–	45	–	–	–	–	–	–	–
Acacia mucronata	–	–	–	–	35	–	–	–	–	–	90	42.5
Hypericum gramineum	–	–	–	–	35	–	–	–	–	–	–	–
Hydrocotyle hirta	–	–	–	–	30	–	–	–	–	–	–	–
Eucalyptus obliqua	–	–	–	–	27.5	–	–	–	–	–	–	–
Pomaderris elliptica	–	–	–	–	25	–	–	–	–	32.5	–	–
**Senecio elegans*	–	–	–	–	22.5	–	–	–	–	–	–	–
Gonocarpus micranthus	–	–	–	–	22.5	–	–	–	–	–	–	–
**Dactylis glomerata*	–	–	–	–	22.5	100	–	–	–	–	–	–
Trochocarpa cunninghamii	–	–	–	–	20	–	–	–	–	–	–	–
Pimelea spp.	–	–	–	–	17.5	–	–	–	–	–	–	–
**Rorippa nasturtium-*	–	–	–	–	12.5	–	–	–	–	–	–	–
**Lotus corniculatus*	–	–	–	–	12.5	–	–	–	–	–	–	–
Comesperma volubile	–	–	–	–	12.5	–	–	–	–	–	52.5	–
**Erica lusitanica*	–	–	–	–	10	–	–	–	–	–	–	–
Gymnoschoenus	–	–	–	–	5	–	–	–	–	–	37.5	–
Orites diversifolia	–	–	–	–	2.5	–	–	10	–	–	–	–
Xyris operculata	–	–	–	–	2.5	–	–	–	–	–	–	–
**Crocosmia Xcrocosmiiflora*	–	–	–	–	–	97.5	–	–	–	–	–	–
**Pinus radiata*	–	–	–	–	–	90	–	–	–	–	–	–
**Cytisus scoparius*	–	–	–	–	–	82.5	–	–	–	–	–	–
Austrodanthonia caespitosa	–	–	–	–	–	82.5	–	–	–	–	10	–
Epacris lanuginosa	–	–	–	–	–	45	–	–	–	–	–	–
**Ulex europaeus*	–	–	–	–	–	22.5	–	–	–	–	–	–
**Cupressus macrocarpa*	–	–	–	–	–	17.5	–	–	–	–	–	–
**Prunus domestica*	–	–	–	–	–	7.5	–	–	–	–	–	–
**Hebe elliptica*	–	–	–	–	–	7.5	–	–	–	–	–	–
Xerochrysum subundulatum	–	–	–	–	–	5	–	–	–	–	–	–
Muehlenbeckia axillaris	–	–	–	–	–	5	–	–	–	–	–	–
**Prunus spinosa*	–	–	–	–	–	5	–	–	–	–	–	–
**Agapanthus praecox*	–	–	–	–	–	2.5	–	–	–	–	–	–
**Convolvulus arvensis*	–	–	–	–	–	2.5	–	–	–	–	–	–
**Malus Xdomestica*	–	–	–	–	–	2.5	–	–	–	–	–	–
**Lonicera periclymenum*	–	–	–	–	–	2.5	–	–	–	–	–	–

	KB(D)	LJ(D)	LM(D)	NF(D)	S(D)	W(D)	KB(C)	LJ(C)	LM(C)	NF(C)	S(C)	W(C)
Olearia phlogopappa	–	–	–	–	–	2.5	–	–	–	–	–	10
Microsorum pustulatum	–	–	–	–	–	–	30	–	–	–	–	–
Anodopetalum biglandulosum	–	–	–	–	–	–	12.5	–	–	–	–	–
Urtica incisa	–	–	–	–	–	–	10	–	–	–	–	–
Nothofagus gunnii	–	–	–	–	–	–	–	100	–	–	–	–
Trochocarpa thymifolia	–	–	–	–	–	–	–	22.5	–	–	–	–
Phebalium squameum	–	–	–	–	–	–	–	–	67.5	27.5	47.5	22.5
Phyllocladus aspleniifolius	–	–	–	–	–	–	–	–	15	12.5	12.5	25
Correa reflexa	–	–	–	–	–	–	–	–	10	–	–	–
Senecio linearifolius	–	–	–	–	–	–	–	–	5	–	–	–
Acradenia frankliniae	–	–	–	–	–	–	–	–	–	32.5	–	–
Blechnum penna-marina	–	–	–	–	–	–	–	–	–	15	–	–
Hypolaena fastigiata	–	–	–	–	–	–	–	–	–	–	67.5	–
Drosera pygmaea	–	–	–	–	–	–	–	–	–	–	62.5	–
Melaleuca squamea	–	–	–	–	–	–	–	–	–	–	60	–
Banksia marginata	–	–	–	–	–	–	–	–	–	–	45	–
Leptocarpus tenax	–	–	–	–	–	–	–	–	–	–	40	–
Agastachys odorata	–	–	–	–	–	–	–	–	–	–	40	–
Isolepis nodosa	–	–	–	–	–	–	–	–	–	–	32.5	–
Pultenaea juniperina	–	–	–	–	–	–	–	–	–	–	17.5	–
Pimelea cinerea	–	–	–	–	–	–	–	–	–	–	12.5	–
Prostanthera lasianthos	–	–	–	–	–	–	–	–	–	–	–	7.5

Appendix C – Soil Analyses

Results of the soil analyses from the Campbelltown Hospital study site.

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	4.5	0.15	9.71	2.5	4.9	0.18	6.28	1.8
2	4.8	0.22	15.56	2.7	4.9	0.05	2	0.9
3	5.1	0.14	3.94	1.4	5.1	0.1	4.47	0.9
4	4.9	0.14	9.15	1.4	5.1	0.09	14.01	2
5	4.6	0.15	10.06	1.6	4.8	0.14	5.74	2.2
6	4.7	0.11	7.67	1	4.6	0.02	3.72	1.4
7	4.8	0.08	1.92	0.9	4.6	0.11	7.64	2.4
8	4.6	0.13	2.84	0.7	4.6	0.07	5.51	1.3
9	4.8	0.13	6.79	1.7	4.6	0.08	6.71	1.5
10	4.9	0.16	7.97	1.2	5	0.03	4.91	0.6
Mean	4.7	0.062	5.93	1.5	4.5	0.08	7.04	2.74

Results of the soil analyses from the Fosterville study site.

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	4.3	0.02	5.69	2.8	4.7	0.04	4.32	0.8
2	4.4	0.13	8.27	1.8	4.7	0.11	6.01	0.2
3	4.3	0.18	8.9	2.6	4.8	0.16	4.11	4.1
4	4.4	0.12	0.6	1.6	4.9	0.07	2.47	0.9
5	4.4	0.07	3.12	5	4.7	0.06	5.24	0.5
6	4.5	0.12	3.22	8.3	4.6	0.13	1.78	1.7
7	4.5	0.2	6.36	6.3	4.5	0.14	1.9	1
8	4.3	0.05	2.94	8.1	4.7	0.09	3.95	1.6
9	4.4	0.06	1.19	7.6	4.7	0.08	4.26	0.4
10	4.3	0.19	1.6	5.5	4.7	0.11	4	0.4
Mean	4.38	0.114	4.189	4.96	4.7	0.009	3.804	1.16

Results of the soil analyses from the Queens Domain study site

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	5.0	0.31	14.05	2	5.4	0.36	14.05	2
2	5.1	0.43	22.4	1.9	5.5	0.58	22.40	1.9
3	5.2	0.49	9.89	1.8	5.6	0.38	9.89	1.8
4	4.9	0.51	11.09	1.6	5.5	0.33	11.09	1.6
5	4.9	0.63	9.71	11.8	5.8	0.52	9.71	11.8
6	4.9	0.8	12.19	12.9	5.6	0.84	12.19	12.9
7	5.0	0.4	9.17	9.3	5.4	0.51	9.17	9.3
8	4.6	0.44	7.02	8.8	5.4	0.47	7.02	8.8
9	4.8	0.54	16.33	9.3	5.6	0.25	16.33	9.3
10	4.8	0.2	7.32	6.9	5.4	0.27	7.32	6.9
Mean	4.92	0.45	11.54	9.3	5.52	0.47	11.91	6.63

Results of soil analyses from Coles Bay

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	4.2	0.07	15.2	1.7	4.3	0.07	23.52	2.4
2	4.5	0.11	8.6	1.5	4.1	0.03	11.77	3.7
3	4.7	0.02	4.14	1.5	4	0.07	4.4	2.7
4	4.4	0.08	3.56	1.5	4.2	0.12	2.53	2.7
5	4.4	0.07	3.59	1.1	4.5	0.12	6.36	2.9
6	4.5	0	5.08	1.2	4.2	0.08	5.72	2.5
7	4.6	0.04	6.48	1.2	4	0.07	5.69	2.7
8	4.5	0.08	4.49	2.1	4.2	0.08	4.53	2.3
9	4.5	0.09	4.17	1.7	4	0.07	2.7	3.1
10	4.5	0.06	3.94	1.5	4.1	0.1	3.15	2.4
Mean	4.7	0.062	5.93	1.5	4.5	0.08	7.04	2.74

Results of soil analyses from Douglas Road

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	4.7	0.28	29.67	8	4.6	0.32	7.12	5.2
2	4.6	0.21	7.66	5.8	4	0.33	15.11	7.3
3	4	0.19	4.93	6	4.3	0.17	3.72	5.6
4	4.4	0.19	3.17	5	4.2	0.24	4.69	5.5
5	4.2	0.2	3.98	5.4	4.4	0.2	10.39	4.8
6	4	0.13	3.13	4.7	4	0.21	7.91	4.2
7	4.2	0.19	22.75	8.4	4.1	0.21	4.17	5.6
8	4.2	0.19	4.9	7.3	4	0.3	12.07	5
9	4.4	0.27	26.61	6	4.6	0.24	7.05	6.9
10	4.6	0.2	6.75	4.8	4.6	0.24	5.74	6.3
Mean	4.33	0.205	11.36	6.14	4.28	0.246	7.80	5.64

Results of soil analyses from Kettering

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	5	0.09	6.68	4.3	4.2	0.05	2.05	3.7
2	5	0.06	2.7	4.4	4.1	0.11	3.79	7.4
3	5.2	0.23	2.69	4.9	4.4	0.02	1.28	3.9
4	5.3	0.21	2.44	2.1	4.5	0.01	3.93	4
5	5.3	0.19	6.18	4.6	4.8	0.08	5.82	3.7
6	5.4	0.11	16.87	5.9	4.7	0.09	8.95	3.7
7	5.4	0.09	8.54	4.8	4.4	0	3.26	2
8	5.1	0.01	4.99	4.6	4.3	0.17	7.49	8
9	5.2	0.04	6.06	3.9	4.5	0.27	6.79	10.7
10	4.9	0.05	5.58	3.7	4.5	0.02	4.51	4
Mean	5.18	0.108	6.27	4.32	4.44	0.082	4.787	5.11

Results of soil analyses from Maria Island

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P ppm**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	5.1	0.48	5.46	6	5	0.33	6.61	5.3
2	5	0.2	8.02	3.6	5.2	0.34	7.79	3.1
3	5.2	0.28	16.2	14.9	5.2	0.22	8.54	1.9
4	5.3	0.29	9.54	3.6	5.1	0.16	10.37	4
5	5.3	0.14	7.51	3.6	5.1	0.15	7.77	3.2
6	5.3	0.24	7.21	8.1	5.3	0.15	5.53	2.9
7	5.3	0.28	6.34	6.4	5.2	0.14	6.19	3.1
8	5.2	0.38	6.37	4.9	5.3	0.15	7.73	2.7
9	5.3	0.24	4.99	5	5.3	0.29	7.63	13.6
10	5.2	0.37	2.38	6.2	5.3	0.2	5.52	5.8
Mean	5.2	0.29	7.40	6.23	5.2	0.213	7.36	4.56

Results of soil analyses from Pottery Road

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P ppm**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	4.9	0.01	2.4	5	4.8	0.45	8.74	11.6
2	4.6	0.2	16.92	8.3	4.8	0.27	6.76	10.6
3	4.6	0.09	3.11	6.3	4.9	0.28	4.16	10.3
4	4.6	0.04	2.87	8.1	5	0.37	2.95	10.8
5	4.7	0.06	4.89	7.6	5	0.6	19.97	11.4
6	4.3	0.05	6.18	5.5	5.1	0.35	2.44	8.8
7	4.1	0.1	2.87	5.1	4.8	0.44	3.53	9.1
8	4.2	0.08	1.52	5.6	4.5	0.52	25.19	11.3
9	4.4	0.15	12.05	9.2	4.5	0.3	3.21	6.7
10	4.5	0.11	2.3	6.2	4.7	0.32	4.06	10.3
Mean	4.49	0.089	5.51	6.69	4.81	0.39	8.1	10.09

Results of soil analyses from Wyre Forest Road

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	4.3	0.14	3.26	3.7	3.5	0.05	3.26	3.9
2	4.5	0.06	1.94	2.5	3.8	0.13	2.05	3.5
3	4.2	0.09	1.95	3.1	3.1	0.19	2.79	4.9
4	4.2	0.2	1.8	4.5	3.2	0.06	2.32	4
5	4	0.07	3.51	3.6	3.5	0.02	6.36	3
6	4.5	0.1	2.57	3.8	3.2	0.19	2.44	5.3
7	4.4	0.12	2.39	4	3.3	0.16	2.21	3.6
8	4.1	0.15	2.04	3.6	3.2	0.08	2.2	3.8
9	4.3	0.07	2.12	2.4	3.1	0.07	2.61	3
10	4.2	0.12	3.88	3.6	3.3	0.08	2.6	1.9
Mean	4.27	0.112	2.546	3.48	3.32	0.103	2.884	3.69

Results of soil analysis obtained from the study site at Adamsfield.

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	3.9	0.24	8.32	16.2	4.4	0.06	1.11	2.1
2	3.7	0.23	4.93	14.7	4.3	0.11	1.12	1.3
3	3.4	0.09	1.86	3.5	3.9	0.08	2.11	2.2
4	3.3	0.18	8.7	4.9	4	0.08	2.6	2.6
5	3.5	0.14	4.79	3.1	4	0.1	2.92	2.5
6	3.3	0.12	2.31	2.2	4	0.12	3.87	3.6
7	3.5	0.52	2.52	2	4	0.02	2.51	2.3
8	3.6	0.12	6.41	1	4.1	0.01	2.19	2.2
9	3.4	0.24	6.53	2.2	3.9	0.05	4.45	2.4
10	3.3	0.18	4.64	2.5	4	0.04	3.33	2.9
Mean	3.49	0.206	5.101	5.23	4.06	0.067	2.621	2.41

Results of soil analysis obtained from the study site at Butlers Gorge.

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	4.4	0.08	8.98	1.3	4.4	0.24	8.47	16.9
2	4.1	0.02	6.54	1.5	4.1	0.17	10.08	15.9
3	4.2	0.09	2.41	4.1	4.2	0.16	4.88	9
4	4.2	0.11	1.96	3.7	4.2	0.32	4.15	8.8
5	4.6	0.11	5.46	3.4	4.6	0.53	3.69	3.8
6	4	0.1	4.03	3.6	4	0.32	3.33	2.2
7	4.6	0.04	4.19	2.6	4.6	0.33	3.6	3.1
8	4.1	0.12	8.21	2.2	4.1	0.19	6.01	10.3
9	4	0.12	3.58	3.4	4	0.25	3.7	3.5
10	4.3	0.09	6.54	3.6	4.3	0.27	7.38	9.9
Mean	4.25	0.088	5.19	2.94	4.25	0.278	5.529	8.34

Results of soil analysis obtained from the study site at Mount Field.

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	5	0.2	6.13	4.7	4.9	0.11	1.69	1.8
2	4.6	0.35	3.14	10.6	5.1	0.26	2.16	4.3
3	4.8	0.25	2.45	5.5	5.3	0.15	1.96	0.6
4	4.5	0.49	2.18	12.2	5.4	0.14	14.11	0.8
5	4.2	0.22	2.55	8.4	5.4	0.06	11.66	1.4
6	4.7	0.34	2.62	8.7	5.4	0.12	4.79	0.5
7	4.3	0.4	3.58	12.2	5.5	0.14	13.46	2.1
8	4.2	0.3	2.76	8.8	5.6	0.12	6.62	1.2
9	4.2	0.26	2.79	8.3	5.6	0.11	7.28	0.8
10	4.3	0.51	7.11	11.3	5.5	0.11	5.8	5.7
Mean	4.48	0.332	3.531	9.07	5.37	0.132	6.95	1.92

Results of soil analyses from the control and disturbed quadrats at Kelly Basin

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	4	0.10	2	6.5	4	0.13	5	9.8
2	4.1	0.24	6	6.2	4.2	0.31	3	13.1
3	4	0.08	2	4.8	4.1	0.24	7	6.7
4	4	0.15	6	7.3	4.1	0.43	4	6.8
5	4	0.55	9	14.2	4.2	0.49	10	12.6
6	4	0.15	3	4.1	4.2	0.22	23	10.3
7	4.1	0.58	7	7.5	4	0.18	14	8.5
8	4.1	0.53	6	13.6	4.3	0.22	10	6.6
9	4.1	0.23	4	8.3	4	0.19	8	12.2
10	4	0.21	2	8.8	4.1	0.28	5	5.0
Mean	4.04	0.282	4.7	8.13	4.12	0.269	8.9	9.16
N:C	28.8:1				34.05:1			

Results of soil analyses obtained from the control and disturbed sites at Lake Johnston.

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	3.5	0.17	5	9.8	3.8	0.05	4	2.2
2	3.8	0.15	6	9.5	3.6	0.09	4	9.0
3	3.8	0.05	4	8.1	3.7	0.10	3	7.5
4	3.6	0.12	4	6.6	3.7	0.05	2	8.0
5	3.7	0.14	5	9.2	3.7	0.06	1	4.1
6	3.5	0.13	7	8.8	3.6	0.10	2	4.7
7	3.5	0.19	4	7.6	3.6	0.03	2	3.8
8	3.4	0.16	3	6.9	3.7	0.09	2	8.5
9	3.6	0.24	7	9.0	3.8	0.22	2	10.5
10	3.5	0.17	8	9.4	3.7	0.15	2	4.4
Mean	3.59	0.152	5.3	8.49	3.69	0.094	2.4	6.27
N:C	55.8:1				66.7:1			

Results of soil analyses obtained from the control and disturbed sites at Lake Margaret.

	Control site				**Disturbed site**			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	4	0.72	6	23.9	4.8	0.21	7.66	9
2	3.1	0.91	6	24.1	4.6	0.24	6.87	9.8
3	3.8	1.06	10	>25.0	4.7	0.2	5.72	9.9
4	4	1.36	7	>25.0	4.5	0.27	22.39	9
5	4	1.13	8	>25.0	4.6	0.42	7.57	12
6	3.1	1.36	11	>25.0	4.1	0.43	22.28	11.9
7	3.4	0.50	9	15.8	4.3	0.24	6.38	7.8
8	3.1	0.34	5	17.2	4.2	0.37	7.32	8.4
9	3.1	1.10	8	>25.0	4.4	0.22	9.33	9.2
10	3.1	0.86	8	22.4	4.1	0.44	7.75	9.1
Mean	3.47	0.934	7.8	22.4	4.43	0.304	10.327	9.61
N:C	23.4:1				31.6:1			

Results of soil analyses obtained from the control and disturbed sites at Nelson Falls.

	Control site				**Disturbed site**			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	5	0.52	7	16.4	4.5	0.23	63	9.6
2	5.4	0.66	9	16.7	4.3	0.16	39	9.3
3	4.6	0.14	3	9.8	4.6	0.15	7	9.9
4	4.7	0.34	3	9.7	4.1	0.31	29	9.1
5	4.7	0.25	2	3.6	4	0.53	12	10.1
6	4.6	0.21	3	2.1	4	0.31	5	12.2
7	4.5	0.16	4	3.2	4	0.32	9	7.2
8	4.4	0.29	4	11.1	4	0.18	5	8.7
9	4.3	0.39	3	4.0	4.1	0.24	21	10.8
10	4.4	0.37	6	10.5	4.2	0.26	17	7.5
Mean	4.66	0.333	4.4	8.71	4.18	0.269	20.7	9.44
N:C	26.1:1				35.09:1			

Results of soil analyses obtained from the control and disturbed sites at Strathgordon.

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	3.8	0.06	1	3.1	4	0.14	1	1.2
2	3.9	0.12	5	3.8	4.5	0.24	6	3.7
3	4.1	0.12	5	7	4	0.15	3	0.9
4	4.2	0.05	5	4	4.3	0.05	4	1.0
5	3.8	0.18	7	3.5	4	0.03	1	1.1
6	4.1	0.20	2	10.5	4	0.02	4	0.9
7	3.8	0.26	2	10.5	4.4	0.05	2	1.2
8	3.9	0.15	3	7	4.8	0.05	4	1.9
9	4.2	0.05	4	5.5	5.1	0.09	5	1.4
10	3.8	0.07	3	1.4	4.4	0.04	2	1.3
Mean	3.96	0.126	3.7	5.63	4.35	0.086	3.2	1.46
N:C	21.6:1				18.6:1			

Results of soil analyses obtained from the control and disturbed sites at Williamsford.

	Control site				Disturbed site			
Sample	**pH**	**% N**	**P (ppm)**	**% C**	**pH**	**% N**	**P (ppm)**	**% C**
1	4.8	0.17	7	7.3	3.6	0.51	14	11.5
2	4.5	0.36	5	10.3	3.6	0.16	8	8.4
3	4.7	0.39	4	13.7	3.5	0.47	5	12.7
4	4.6	0.25	3	9.2	3.6	0.62	18	11.7
5	4.4	0.81	11	>25.0	3.7	0.36	48	10.4
6	4.8	0.51	2	10.4	4.1	0.47	20	12.6
7	4.6	0.32	7	6.6	4	0.27	2	5.7
8	4.2	0.19	8	8.0	3.7	0.35	34	10.5
9	4.4	0.33	2	12.7	3.8	0.35	0	7.1
10	4.3	0.30	1	10.2	4.2	0.53	14	12.4
Mean	4.53	0.363	5	9.58	3.78	0.409	16.3	10.3
N:C	26.4:1				25.2:1			