Impacts of rehabilitating degraded lands on soil health, pastures, runoff, erosion, nutrient and sediment movement. Part I: Rehabilitation methodologies to improve water quality flowing from grazing lands onto the Great Barrier Reef.

RRRD.024 Final Report for the Australian Government's Caring for Our Country Reef Rescue Water Quality Research and Development Program

RRRD.024 (A0000008317) Final Report

2014

Trevor J Hall
Department of Agriculture and Fisheries
PO Box 102, Toowoomba Qld 4350

Australian Government
Department of Sustainability, Environment, Water, Population and Communities

Supported by the Australian Government's
Caring for Our Country Reef Rescue Water Quality Research and Development Program

Queensland Government

CARING FOR OUR COUNTRY

Reef & Rainforest RESEARCH CENTRE

‘Impacts of rehabilitating degraded lands on soil health, pastures, runoff, erosion, nutrient and sediment movement.’

Project RRRD.024 Final Report (Parts I, II, III and IV) for the Australian Government’s Caring for Our Country Reef Rescue Water Quality Research and Development Program.

Reef Rescue Project RRRD.024 Final Report is published in four parts on the FutureBeef Program for Northern Australia web site.

This Final Report is published in four parts and should be cited as:

Trevor J. Hall (2014). Impacts of rehabilitating degraded lands on soil health, pastures, runoff, erosion, nutrient and sediment movement. Part I: Rehabilitation methodologies to improve water quality flowing from grazing lands onto the Great Barrier Reef. Project RRRD.024 Final Report for the Australian Government’s Caring for Our Country Reef Rescue Water Quality Research and Development Program.
http://futurebeef.com.au/

Richard G. Silcock and Trevor J. Hall (2014). Impacts of rehabilitating degraded lands on soil health, pastures, runoff, erosion, nutrient and sediment movement. Part II: Literature review of rehabilitation methods to improve water quality flowing from grazing lands onto the Great Barrier Reef. Project RRRD.024 Final Report for the Australian Government’s Caring for Our Country Reef Rescue Water Quality Research and Development Program.
http://futurebeef.com.au/

Timothy Moravek and Trevor J. Hall (2014). Impacts of rehabilitating degraded lands on soil health, pastures, runoff, erosion, nutrient and sediment movement. Part III: Economic analysis of rehabilitation techniques in the Burdekin River catchment to improve water quality flowing from grazing lands onto the Great Barrier Reef. Project RRRD.024 Final Report for the Australian Government’s Caring for Our Country Reef Rescue Water Quality Research and Development Program.
http://futurebeef.com.au/

Trevor J. Hall (2014). Impacts of rehabilitating degraded lands on soil health, pastures, runoff, erosion, nutrient and sediment movement. Part IV: The Kimberley rehabilitation program and lessons for the Great Barrier Reef catchments. Project RRRD.024 Final Report for the Australian Government’s Caring for Our Country Reef Rescue Water Quality Research and Development Program.
http://futurebeef.com.au/

Impacts of rehabilitating degraded lands on soil health, pastures, runoff, erosion, nutrient and sediment movement

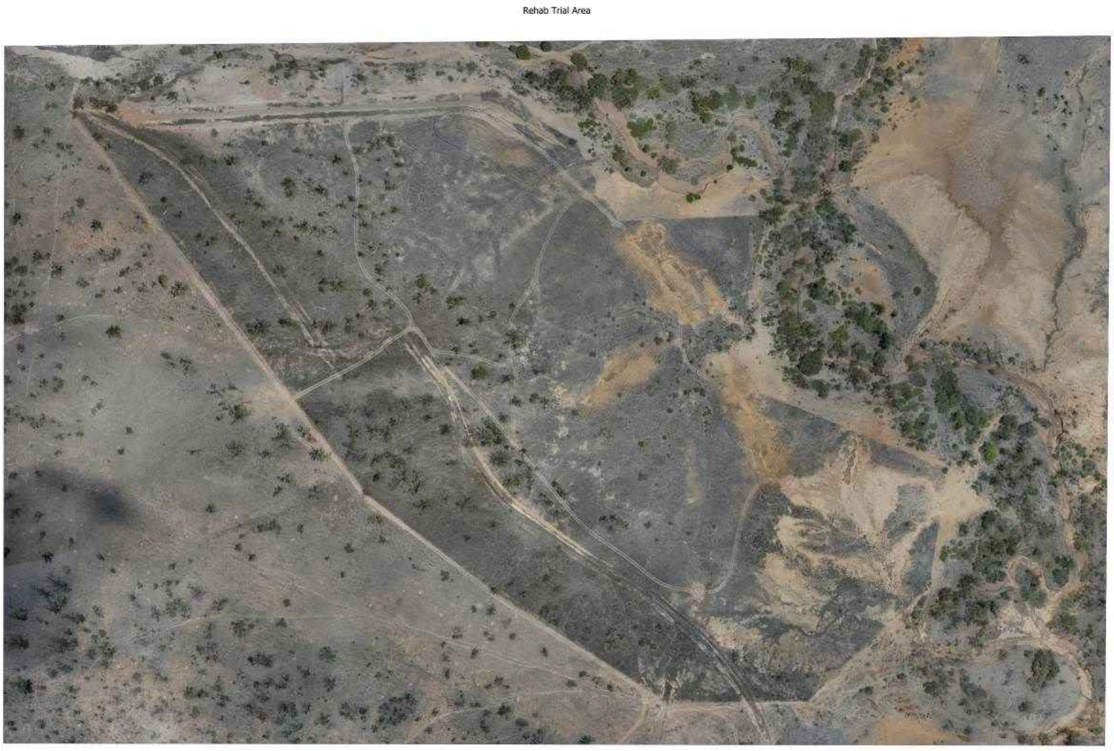
RRRD.024 (Final Report Part I)

Trevor J Hall
Department of Agriculture and Fisheries
203 Tor Street, Toowoomba Qld 4350 Australia

Reef Rescue Water Quality Research and Development

Queensland Government

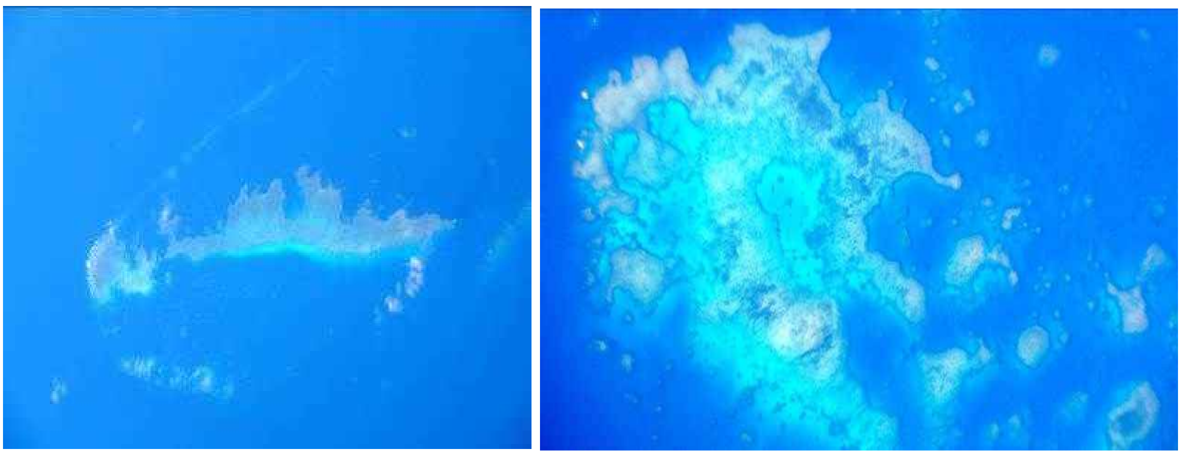
Australian Government
Department of Sustainability, Environment, Water, Population and Communities



Spyglass rehabilitation experiment site two years after pastures established (December 2013).

Published by the Reef and Rainforest Research Centre on behalf of the Australian Government's Reef Rescue Water Quality Research and Development Program.

The Reef Rescue Research and Development Water Quality Program (Reef Rescue R and D) is funded under the Australian Government's Caring for Our Country program, and contains 18 projects. The Reef Rescue R and D is designed to improve our understanding of the link between land management practices and environmental impacts, and improve water quality across the Great Barrier Reef by supporting a reduction in the amount of nutrients, chemicals and sediments reaching the Reef lagoon from agricultural lands. This Project RRRD.024, is researching how to rehabilitate bare, D-condition, eroding patches to improve water quality in the runoff from cattle grazing lands of eastern Queensland.



Coral reefs in the Great Barrier Reef off the Queensland east coast

Cover photographs: by Trevor J Hall

This report is available from the Reef Rescue Research and Development website:
http://www.reefrescueresearch.com.au

August 2014


'Spyglass' experimental site erosion at the start of experiment (August 2011) and after the first summer after rehabilitation (March 2012).

Executive Summary

The project RRRD.024 investigated the potential to mechanically rehabilitate degraded, bare, D-condition grazing lands to improved condition in the Burdekin and Fitzroy River catchments of north-east Queensland. With successful rehabilitation there will be increased pasture health and productivity which will reduce water, sediment and nutrient runoff, with the aim of improving the quality of water flowing into the Great Barrier Reef lagoon from grazing land. There were six set objectives of the study and a three-way research approach was developed to identify and quantify mechanical rehabilitation information for these objectives. Seven key findings were identified from the study.

The six set objectives of the study were:

1. *to identify social and economic drivers that motivate land managers to rehabilitate degraded grazing lands*
2. *to identify the barriers to rehabilitating degraded grazing lands*
3. *to validate the effectiveness of mechanical approaches to initiating the rehabilitation of degraded grazing lands on improving water quality*
4. *to assess the effectiveness of maintaining different levels of groundcover and soil surface condition on managing erosion*
5. *to estimate the costs and benefits of rehabilitating degraded grazing lands and the likely level of incentives required to accelerate the adoption practices to improve the condition of degraded grazing lands, and*
6. *to quantify the time-lag between mechanical intervention and improved pasture condition, soil condition and animal production.*

The three research approaches to answer these objectives were:

1. *three field experiments were established and monitored over three years to identify and quantify mechanical rehabilitation methods*
2. *a survey of landholders of their rehabilitation works for improving land condition; and*
3. *a literature review and field review of rehabilitation of degraded land for improved water quality.*

The three research approaches are summarised:

a. Mechanical rehabilitation. *Three degraded, D-condition field experimental sites were selected in the Burdekin and Fitzroy catchments. They were located by an analysis of long-term, consistently bare or low cover areas in both catchments from Landsat satellite imagery over the last 22 years. A ten hectare eroded creek frontage in open* Eucalypt *woodland previously supporting native pasture with three soil types, a heavy textured cracking clay (vertosol), a clay loam (sodosol) and a sodic dermosol, was selected for the Burdekin site on* 'Spyglass'*, 130 kilometers north of Charters Towers. In the Fitzroy, two sites were selected: a cleared open* Eucalypt *woodland supporting native pasture on a medium textured clay soil type near Banana; and a cleared brigalow forest on a heavy textured clay soil type previously sown with exotic grass pasture near Injune. At these three experiment sites a range of mechanical rehabilitation (soil disturbance) methods, plus sowing grass and legume pastures, was investigated. The pasture establishment,*

cover, and productivity were measured, as were the soil surface conditions, and sediment and nutrient losses. There were multiple aspects of rehabilitation investigated at the experimental sites over three years 2011-2014. The economic costs and potential returns of the rehabilitation treatments were calculated, and an economic calculator was developed for landholders to conduct an economic analysis for their own rehabilitation work.

b. Landholder survey. *The second approach of the project was to survey landholders who had attempted their own mechanical rehabilitation to improve cover and pasture productivity. The aim of the survey was to confirm and expand the results of the mechanical rehabilitation experiments to other regions and soil types beyond the experiment localities. The method was to select properties with consistently bare areas and had conducted mechanical rehabilitation. The property owners were surveyed by face to face or telephone interviews to find the results of their rehabilitation, which methods worked and those that did not, how they managed the rehabilitated sites, their costs and benefits, what limitations they have to further rehabilitation on their properties, any social pressures, and what external (Government) incentives they considered appropriate for continuing their rehabilitation work, and what incentives may encourage others to conduct similar rehabilitation work.*

c. Literature and field sites review. *The third approach of the project was to conduct a literature review of published pasture and land rehabilitation work that has relevance to the D-condition grazing lands of the Burdekin and Fitzroy catchments, and also to improving water quality flowing into the reef lagoon. These papers, reviews and reports, over 200 potential sources, reinforce and expand the results of the field experiments, the economic analysis and the landholder surveys. An additional component was a field review of the large scale mechanical rehabilitation works conducted in the Ord River and recently in the Fitzroy River catchments of the Kimberley region of Western Australia. This Government sponsored rehabilitation work has been conducted and publicised over the past 50 years, with the initial aim of reducing sediment losses and improving the quality of water flowing into the Ord River Dam, preserving Lake Argyle for agriculture.*

Summary of seven key findings

The success of rehabilitation of D-condition, severely eroded grazing lands was highly correlated to seven key aspects:

1. *a high degree of mechanical disturbance (intervention) is required (deep ripping, blade ploughing or, adding mulch after heavy disturbance) to increase water holding and infiltration: disturbance includes overland water flow control measures*
2. *selecting the most suitable and responsive soil types (non-sodic clays, clay-loams and loams)*
3. *sowing well-adapted pasture species (tropical grasses and legume cultivars)*
4. *long-term total grazing control to allow for rainfall-dependent pasture establishment, seeding and spread over the first 3-7 years, depending on rainfall*
5. *conduct mechanical disturbance and seeding rehabilitation programs in years of predicted above average seasonal rainfall conditions (*la Niña *years preferably)*

6. *start rehabilitation before all topsoil is lost, and exposing more serious chemical and physical constraints to pasture development; and*
7. *plan and monitor grazing management strategies early to prevent the development and spread of bare D-condition areas by maintaining healthy soils and pastures. Grazing land management training is desirable.*

Benefits and application of the work:

The field experiments demonstrated the rehabilitation success of several commercially applicable mechanical methods on some soil types; the pasture establishment and high ground cover possible in the first year with above average rainfall; the necessity of grazing management for many years after initial treatments; and that sediment losses can be greatly reduced by appropriate rehabilitation methods. The sites were used for field days to demonstrate to landholders that some bare D-condition patches can be rehabilitated successfully and that it may be economically feasible for landholders to conduct their own rehabilitation on some fertile soil types. Aggressive disturbance with successful pasture establishment can greatly increase infiltration, ground cover and pasture productivity, and reduce sediment and nutrient losses, for at least ten years on better quality soil types. There are sodic soil types that cannot be rehabilitated effectively by current methods. Results of successful rehabilitation can be included in education and training packages for the grazing Best Management Practice programme to encourage improved land management in the future.

Addressing the six project objectives:

1. **Social and economic drivers identified.** *There is no or limited social pressure on conducting rehabilitation work, except within some local 'Landcare orientated' groups with an interest in improved grazing land management. Costs and failure risks are the main concerns, with other issues including equipment and labour availability, lack of confident knowledge, and relatively low contribution to total property productivity. Landholder knowledge of potential improvement in off-farm water quality by their rehabilitation of D-condition areas is non-existent, while knowledge of pasture and grazing management, and the value of maintaining ground cover are increasing. Attending grazing management training courses is becoming more acceptable, so over time this improved pasture management knowledge should provide consistently higher cover on grazing lands, with associated water quality benefits.*

2. **Barriers to rehabilitation identified***.* *The high initial costs, potential failure of pasture establishment (risk averse), negative financial returns and limited whole-property benefits, are major barriers to landholders doing their own rehabilitation work. Other barriers include insufficient knowledge of disturbance methods and what pasture species are suited to different soil types, labour and equipment shortages, level of property development and owners' equity level, reoccurring droughts, attitude to pasture management, and the extent of D-condition lands on the property. Long-term grazing control is required after rehabilitation, so fencing and water development must be at a stage to allow paddock exclosure and controlled grazing for at least several years. This may require capital expenditure on infrastructure development and management practice changes.*

3. **Effectiveness of mechanical approaches validated.** *Aggressive surface disturbance is required to achieve water infiltration, limit sediment and nutrient losses, and establish protective pasture ground cover. Lower cost and light disturbance methods such as a crocodile plough seeder or strip cultivation, is insufficient on all but the most favourable soil types, such as fertile self-mulching heavy clays and clay loams. The high level of disturbance required for rehabilitation makes the surface more susceptible to erosion losses initially, especially if there is a pasture establishment failure, so mechanical disturbance needs to be conducted in average to higher rainfall years (La Niña preferably) to assist rapid pasture establishment. More reliable long-term weather forecasting is required to reliably select these years.*

   On some soil types (e.g., sodic dermosols) mechanical disturbance with pasture seeding alone is inadequate to produce surface cover, and requires additional, as yet unknown, soil amelioration treatments. The surface chemical and physical properties after the A-horizon and the top of the B-horizon have been eroded away have serious constraints for seedling establishment, plant growth, and their subsequent survival. These soil constraints can also occur in the sub-soil of other more favourable soil types, such as the sodosol and vertosol at the Burdekin experiment site. Preventing further surface soil losses from these areas is critical to allow successful pasture establishment at a cost more acceptable to landholders. Commencing rehabilitation early before these subsoil sodicity and salinity constraints to pasture development are exposed at or near the surface will give more positive rehabilitation results.

4. **Ground cover and soil surface conditions assessed.** *Maintaining perennial herbaceous vegetation cover reduces erosion from grazed landscapes. However, the ground cover levels required to reduce sediment losses is not well quantified. At the experiment sites over 60% cover was most effective in reducing sediment losses. A general level of maintaining a minimum of 40% cover is suggested in the literature as desirable in tropical grazing lands. From an economic grazing perspective, maintaining 3P (perennial, persistent and productive) grasses is desirable and was achieved by the more aggressive rehabilitation techniques at the experiment sites on the better soil types. When well managed these rehabilitated pastures provide sufficient ground cover to minimise sediment losses in average or better rainfall years. These perennial pastures also provide surface conditions suitable for adequate water infiltration. The optimal level of cover varies with slope, soil type, pasture condition, recent annual rainfall and grazing history and rainfall intensity. A tropical perennial grass dominant pasture in A or B-condition with 50-70% ground cover, a basal cover of 3-6%, and a rough soil surface, will be productive for grazing, contain sediment movement and prevent nutrient losses. Managing ground cover on grazed hillsides will increase infiltration and help reduce sediment losses and the expansion of gullies.*

5. **Costs and benefits of rehabilitation and incentives estimated.** *No disturbance and seeding options were profitable under the varying seasonal conditions experienced in north Queensland during the experimental period. Landholders require external financial assistance, of some 50-60% of total costs to break even on renovating D-condition lands using the options tested. The costs and benefits of rehabilitation of patches of D-condition grazing land are integrated in whole property development and require a high level of*

fencing and water improvements to control grazing for a minimum of several years. Direct costs of rehabilitation are high relative to the grazing value of the new pasture on all but the most favourable soil types and above average rainfall seasons are required to guarantee success. An economic calculator was developed for landholders to assist in determine their own costs and benefits of conducting rehabilitation on their land types. Community benefits of rehabilitation of bare patches are perceived to be much greater than the landholder benefits relative to their property enterprise, as the areas of D-condition patches are often considered expensive to manage and are insignificant in total production capabilities of the whole property.

There is no clear incentive model for all situations, as many factors interact to influence a landholder's perception of the importance of doing rehabilitation works. The stage of property development, especially paddock sizes, fencing and water distribution, the owners' knowledge, management abilities and attitude to risk, confidence in a successful outcome, financial equity, equipment access, availability of adapted pasture cultivars and labour supply, all affect the value of any external incentive. The 'standard' of 50% incentive payment is a good compromise for owners of established properties, with little debt, a well-developed property and some good rainfall seasons. Owner input is necessary to give a sense of 'ownership' of the work and to encourage subsequent on-going management. On low fertility and light textured soil types, and in below average rainfall periods, a higher incentive was suggested, such as 75%, to reduce the owners' financial risk of rehabilitation failure. Incentives encouraging grazing land management training could have longer-term benefits by encouraging better pasture management and the maintenance of improved soil health with associated higher ground cover levels. Preventing any further D-condition patches from developing is possible with pasture management education and training.

6. **Time-lags to rehabilitation quantified.** *There is no set time period for 'successful rehabilitation', and the definition of success varies from some ground cover e.g., 30%, to a productive grazing pasture. Sites have had >60% ground cover and a productive pasture within one year after a high rainfall summer, while other sites required 7-10 years of controlled grazing to achieve a similar result, when rainfall conditions were less favourable. These extended time-lags add significantly to the total costs of rehabilitation. Some sodic soil types do not have suitable rehabilitation methods available at present. The time-lag is strongly correlated with good seasonal conditions at initial establishment, provided the mechanical rehabilitation process was effective for the environment. Seasonal conditions in the establishment year have the most influence on the time taken to provide surface protection, and subsequent annual rainfall totals and its distribution affect the time to provide an acceptable grazing pasture. A general rule of 2-4 years with average or better rainfall seasons will provide both erosion protection and some grazing value providing the pasture cultivars sown are responsive to the soil type. Irrespective of disturbance method, pasture establishment failure will occur in drought years.*

Table of Contents

Executive Summary i
List of Figures viii
List of Tables xi
Abbreviations / Acronyms xii
Acknowledgements xiii
Introduction 14
Project Objectives 19
Methods 20
1. Mechanical disturbance rehabilitation methods: Field experiments 20
Selecting three field experimental sites 20
Rehabilitation treatments 27
Monitoring pastures 29
Classifying soil types 29
Sediment and nutrient runoff losses 30
Economics of rehabilitation 32
Photographic records 33
Land surface imagery (Spyglass) 35
Remote weather station - satellite transmission (Spyglass) 36
1.1 Survey of landholder rehabilitation experiences 36
1.2 Review of rehabilitation of degraded grazing lands 37
Literature review 37
Field rehabilitation review: Kimberley Region, Western Australia 37
Results 38
1. Mechanical disturbance rehabilitation methods: Field experiments 38
Rainfall 38
Soil types 44
Pasture production 45
Landscape function analysis (LFA) 56
Economic analyses (Spyglass and Injune) 58
Surface profile Lidar scan (Spyglass) 60
Sediment and nutrient losses 60
2. Landholder rehabilitation experiences - Survey 73
Opinions of surveyed landholders 73

Management practice survey 81
3. Review of rehabilitation of degraded grazing lands 82
Literature Review Summary 82
Field Review: Kimberley Region, Western Australia........ 83
Lessons for regeneration of grazing lands of the reef catchments of Queensland 83
Discussion 86
Field experiments, landholder survey and literature review – application of findings........ 86
Great Barrier Reef – beyond grazing lands 93
Conclusions........ 94
Future Directions: D-condition grazing land and water quality 95
References........ 97
Appendices 99
Appendix 1: Climatic data at three rehabilitation experiment sites. 99
Appendix 2: Botanical composition species identification booklet........ 100
Appendix 3. Soil types description, analysis at three rehabilitation experiment sites. 101
Appendix 4: UAV aerial 3D survey of Spyglass rehabilitation site. 120
Appendix 5. Survey: Landholder comments on their rehabilitation works........ 125
Appendix 6: Publications from Rehabilitation Project RRRD.024........ 135
Appendix 7. Photographs of rehabilitation experiment sites........ 144
Appendix 8. Gypsum experiments on sodic dermosol soil at Spyglass 163

List of Figures

Figure 1. Extent of the Great Barrier Reef off the eastern coast of Queensland Land mass contributing to runoff into the reef lagoon; and R. Map of GBR marine parks. 15
Figure 2. 'ABCD' land condition framework showing unstable D-condition requiring mechanical intervention to improve back to C-condition (FutureBeef.com.au). 16
Figure 3. L. Rehabilitation regions of Burdekin (north) and Fitzroy River (south) catchments in north-east Queensland; C. Burdekin and R. Fitzroy catchments with river systems and major towns. 17
Figure 4. Land condition mapping for the Burdekin catchment (CSIRO; Abbott 2010). 21
Figure 5. Average cover at Spyglass: the rehabilitation experiment area selected is in the bare areas in the north-east (Forage analysis, DNRM). 22
Figure 6. Site 1 Spyglass in the Burdekin catchment before rehabilitation treatments were applied to the west side of the creek (Oct. 2011) (source Google). 22
Figure 7. Rehabilitation experimental site boundary fence in the Burdekin ('Spyglass'). 23
Figure 8.Extent of eroded surfaces at Spyglass experiment site before rehabilitation (August 2011)... 23
Figure 9. Land condition (ABCD) mapping for the Fitzroy catchment (CSIRO; Abbott 2008).. 24
Figure 10. Rehabilitation experiment site (Paddock A) at Injune. 25
Figure 11. L. Un- rehabilitated Injune experiment site in a bare area in the south-west corner of the paddock (Paddock B); and R. The bare experiment site at Injune. 25
Figure 12. L. Injune site during rehabilitation in 2003; and R. Rehabilitated pasture in 2011.25
Figure 13. L. Injune site bare patches rehabilitation treatment of deep ripping and seeding (2003); and R. Patch not rehabilitated (2012). 26
Figure 14. L. Fitzroy experiment site 2 (Banana) paddock before rehabilitation; and R. Typical blade plough with roller seeder in operation. 26
Figure 15. L. Un-rehabilitated bare patches; and R. Rehabilitated sown pastures at Banana site (2012). 27
Figure 16. Rainfall simulation A-frame unit in operation at Spyglass (2012). 31
Figure 17. Fixed site photos of ripping treatment (N to S and S to N) from March to May 2012 at Spyglass. 34
Figure 18. Remote solar powered camera with satellite transmission capabilities at Spyglass. 34
Figure 19. Spyglass site images over second drought year from satellite camera (July 2012 to March 2013). 35
Figure 20. Solar powered weather station with satellite communication capabilities at Spyglass. 36
Figure 21. Southern Oscillation Index for 2011-14 period showing the wet 2011-12 and dry 2012-14 periods. 39
Figure 22. Pasture growth related to seasonal rainfall for the establishment year at Spyglass 2011-2012 and the average of the following two drought years 2012-2014 across Queensland. 40
Figure 23. Monthly rainfall and long-term mean at the Spyglass experiment site (2011-2014). 41
Figure 24. Rainfall chart over the 2012-2013 wet season at Spyglass experiment site from the automatic 'satellite' weather station. 43
Figure 25. Daily temperature range from March-June 2013 at the Spyglass experiment site.44

Figure 26. (a) Pasture dry matter yield (kg ha^{-1}), (b) total cover (%), (c) litter cover (%) and (d) LFA long-term cover (%) at three sites in 2012, 2013 and 2014. 46
Figure 27 (a, b, c, d). Change (% total DMY) in perennial native and exotic sown grasses and native and sown legumes in the deep ripping and chisel ploughing treatments between 2012 and 2014 at Spyglass. 47
Figure 28. (a) Pasture basal area (%) and (b) surface roughness rating (1-3 scale) at three sites between 2012 and 2014. 48
Figure 29. Proportion of species functional group (% of total DMY) in treatments at Spyglass in the establishment year (2012). 53
Figure 30. Total number of species per treatment and average species per quadrat in disturbance treatments at three sites between 2012 and 2014. 54
Figure 31. Treatment and soil type pasture nitrogen (%) in winter 2012 at Spyglass. 55
Figure 32. Mineral and nutrient analysis of whole plant samples of pastures in winter (2012) at three experiment sites. 55
Figure 33. Soil surface roughness rating (1-3) at three sites in 2012, 2013 and 2014. 56
Figure 34.Cover (%) levels of long-term pasture and all organic matter in all rehabilitation treatments in 2013. 57
Figure 35. LFA stability, infiltration and nutrient cycling indices at Fitzroy and Burdekin sites in 2013. 57
Figure 36. Lidar surface scans of Spyglass rehabilitation experiment: L. Hay mulch treatment, and R. Across experiment site (October 2012). 60
Figure 37. Pasture conditions at the 16 rainfall simulation plots at three sites and five soil types in July-August 2012. 62
Figure 38. Initial soil moisture (air dry) and rainfall infiltration before the commencement of runoff at three sites up to nine years after aggressive soil disturbance for pasture rehabilitation. 63
Figure 39. Water balance after runoff commenced at three sites up to nine years after aggressive soil disturbance (high) and nil disturbance for pasture rehabilitation. 63
Figure 40. Infiltration % of rainfall intensity at 87 mm hr^{-1} in good, poor and nil rehabilitation areas at the Injune experiment site in 2012. 64
Figure 41. Average rainfall at 87 mm hour^{-1} before runoff at two Fitzroy sites in good, part and nil rehabilitation plots in 2012. 64
Figure 42. Soil loss (tonnes per hectare) from degraded pasture land given aggressive and nil soil disturbance when subjected to simulated rainfall at an intensity of 87 mm hr^{-1}, one, three and nine years after treatment. 65
Figure 43. Nitrogen loss (kg ha^{-1}) from degraded pasture land given aggressive and nil soil disturbance when subjected to simulated rainfall nine months, three years and nine years after treatment. TN - total nitrogen; TNS – total nitrogen in suspended material; TND – Total nitrogen dissolved. 65
Figure 44. Initial soil moisture (air dry) and rainfall infiltration before the commencement of runoff where four soil disturbance treatments were applied nine months prior at Spyglass. 66
Figure 45. Runoff and infiltration (%) water balance after runoff commenced one year after soil disturbance for pasture rehabilitation at Spyglass. 66
Figure 46. Runoff soil loss (tonnes per hectare) measured nine months after four levels of soil disturbance were applied to two soil types for pasture rehabilitation at Spyglass. 67

Figure 47. Nitrogen loss (kg ha^{-1}) measured nine months after four levels of soil disturbance were applied to two soil types at Spyglass. TN - total nitrogen; TNS – total nitrogen in suspended material; TND – Total nitrogen dissolved. 67
Figure 48. Components of the total phosphorus runoff loss measured nine months after four levels of soil disturbance were applied to two soil types at Spyglass. 68
Figure 49. Components of the total phosphorus runoff loss measured nine months after four levels of soil disturbance were applied to two soil types at Spyglass. 68
Figure 50. VegMachine historical cover index at Spyglass experiment site relative to the mean cover (0.5) and high cover (0.95) areas from year 2000. 69
Figure 51. Long-term pasture cover index (VegMachine) in the un-rehabilitated Injune paddock – whole paddock and around D-condition areas. 69
Figure 52. Long-term cover index of Injune (Fitzroy) rehabilitation site, untreated site and average of surrounding brigalow landtype. 70
Figure 53. Long-term cover index of Banana (Fitzroy) rehabilitation paddock blade ploughed, untreated areas and average of surrounding Eucalypt woodland landtype. 70
Figure 54. Part of kangaroo population between experiment site and double dam (L) and inside fenced experiment (R) (20/03/14). 71
Figure 55. Gypsum site 3D view across chisel ploughed scalds and water courses, Spyglass December 2013. 71
Figure 56. Erosion scalds adjacent to water courses near the Spyglass experiment site A (located in NW corner of image) December 2013). 72
Figure 57. A small coastal marina relying on the GBR for tourism, recreation and commercial activities. 93
Figure 58. Aerial view of the deep blue water on the outer GBR beyond the fringes of a reef complex. 94

List of Tables

Table 1. Pasture grass and legume species sown at the three experiment sites. 27
Table 2. LFA pasture and soil surface condition parameters used to record rehabilitation treatments at three sites (2013 and 2014). 30
Table 3. Ten rainfall simulation plots at the Spyglass experiment site (August 2012). 31
Table 4. Six rainfall simulation plots at the Injune and Banana experimental sites (August 2012)... 32
Table 5. Long-term annual climate statistics for the three experiment regions. 41
Table 6. Monthly (July 2010-June 2014) and long-term (LT) rainfall (mm) near the Spyglass experiment site and long-term mean (New Moon station).. 42
Table 7. Monthly rainfall (mm) near the Injune experiment site and long-term mean (Mt Kingsley). 42
Table 8. Monthly rainfall (mm) near the Banana experiment site and long-term (LT) mean (Banana town). 43
Table 9. Soil types and brief description of soil profiles at Spyglass (4, 5, 6), Injune (61, 62, 63) and Banana (64) field experiment sites 45
Table 10. Number of species recorded at three rehabilitation sites in autumn of 2012, 2013 and 2014. 48
Table 11. Pasture species recorded in rehabilitation treatments at three sites (Burdekin and Fitzroy) in 2012, 2013 and 2014. 49
Table 12. Pasture species recorded in rehabilitation treatments at Spyglass (Burdekin) in 2012 and 2013. 50
Table 13. Pasture species recorded in rehabilitation treatments at Injune and Banana (Fitzroy) in 2012 and 2013. 51
Table 14. Pasture species functional groups dry matter yields (kg ha-1) at Spyglass in 2012, 2013 and 2014. 52
Table 15. Pasture functional groups dry matter yields (kg ha^{-1}) at two Fitzroy sites in 2012, 2013 and 2014. 54
Table 16. LFA indices for treatments at the three experiment sites and means of Burdekin and Fitzroy sites in May 2013.. 58
Table 17. Rainfall simulation plots pasture cover, basal area and dry matter yield in mechanical treatments at Spyglass (August 2012). 60
Table 18. Rainfall simulation plots pasture cover, basal area and dry matter yields at Injune site in July 2012. 61
Table 19. Rainfall simulation plots pasture cover, basal area and dry matter yields at Banana site in July 2012. 61

Abbreviations / Acronyms

ABS	Australian Bureau of Statistics
BGI	Bare ground index
BMP	Best management practice
BOM	Bureau of Meteorology
COC	Caring for Our Country
DAFF/DAF	Queensland Department of Agriculture, Fisheries and Forestry (same as QDAFF); recently changed to DAF Department of Agriculture and Fisheries
DEEDI	(now DAF) Queensland Department of Employment, Economic Development and Innovation
DERM	(now DNRM) Queensland Department of Environment and Resource Management
DMY	Dry matter yield of pasture (kg ha^{-1})
DNRM	Queensland Department of Natural Resources and Mines
DSEWPaC	Department of Sustainability, Environment, Water, Population and Community
FBA	Fitzroy Basin Association Inc. (Natural Resource Management organisation)
GBR	Great Barrier Reef
GBRL	Great Barrier Reef Lagoon
GBRMPA	Great Barrier Reef Marine Park Authority
GLM	Grazing land management (MLA EDGE network courses)
GRASP	Grass production model
IRR	Internal rate of return
LWG	Liveweight gain
MLA	Meat and Livestock Australia
NCF	Net cash flow
NPV	Net present value
NQDT	North Queensland Dry Tropics Inc. (Natural Resource Management organisation)
NRM	Natural Resource Management
NSW	New South Wales
NT	Northern Territory
PPF	Principal Profile Form (Northcote soil classification)
QDAFF	Queensland Department of Agriculture, Fisheries and Forestry (same as DAFF/DAF)
Qld	Queensland
RR2	Reef Rescue project funding Round 2 (includes this project RRRD.024)
RRRC	Reef and Rainforest Research Centre Limited
RRRD	Reef Rescue Research and Development
SOI	Southern Oscillation Index
VegMachine	Bare ground cover satellite monitoring analysis method
VRD	Victoria River District of North-Western Australia
WA	Western Australia (State)

Acknowledgements

I wish to thank the property owners for cooperating with the project team in providing field rehabilitation trial sites and associated paddock histories: Dr Brett Abbott, CSIRO, and Dr Terry Beutel from DAF VegMachine team for providing satellite imagery and BGI data to help select regions and properties to investigate for field trials and landholders to survey for their rehabilitation works; the surveyed landholders who provided information on their personal experiences in rehabilitating degraded D-condition lands on their properties; the management of DAFF/DAF for providing support for the Burdekin field trial site at the 'Spyglass Beef Research Facility', Charters Towers; the staff of DAF at 'Spyglass' for assistance in establishing and managing the field trial site; Dr Richard Silcock for preparing the literature review; Mr Tim Moravek and Ms Rebecca Gowen for conducting the economic analyses of rehabilitation treatments; the staff of the DNRM 'rainfall simulation team' for assistance in conducting the rainfall simulation sediment loss measurements at three trial sites; Mrs Kathy Delaney for developing the photograph database; Mrs Cristine Hall, Hallmark Rural Enterprises, for reviewing this report; Reef Rescue colleagues for providing reference material for our literature review; Mrs Jane Waterhouse for assistance and direction in completing the formal reporting processes during the project; the Australian Governments' Reef Rescue Research and Development program for providing operating finance to complete the project; and Queensland DAFF/DAF for managerial and financial support throughout the project.

Introduction

The Burdekin River catchment of Queensland covers over 13 million hectares, and is the second largest catchment draining into the Great Barrier Reef (GBR) lagoon after the 14.3 million hectares of the Fitzroy River catchment (Australian Bureau of Statistics (ABS) 2010). Both catchments have grazing as the dominant land use. There have been at least eight major episodic climatic events throughout the grazing history of the rangelands in northern Australia that have contributed to land degradation (McKeon *et al.* 2004). These authors described in detail eight major degradation episodes in Australia's rangelands over the last one hundred years. These serious droughts combined with continued grazing have produced some of the eroded, bare D-condition landscapes and patches that now occur throughout the landscape. Most of the rangelands have recovered between these climatic events, but not all of the bare patches that developed under the extreme conditions have done so.

The loss of surface soil as sediments and pasture-growing nutrients, particularly nitrogen and phosphorus, in runoff water from grazing lands has damaging effects on current and future productivity and profitability of the land. Sediment loss, including nutrients, also affects the quality of water entering the Great Barrier Reef (GBR) lagoon, which can have detrimental effects on the survival, growth and reproduction of the reef corals. Studies have shown soil and nutrients are lost from the hillslopes of grazing lands as well as from stream and river banks and beds. Historically, poor management of grazing by beef cattle has decreased pasture cover and soil surface protection in the reef catchments, particularly in the Burdekin and Fitzroy. Evidence from sampling on the BGR suggests sediment delivery to the reef has increased since the introduction of sheep and cattle grazing to the catchments since early European settlement from the 1860s.

The extent of the GBR down the eastern coast of Queensland from the tip of Cape York Peninsula in the north to Frazer Island in the south, and the area of land on the eastern side of the Great Dividing Ranges that contributes to runoff into the GBR lagoon, and the GBR marine parks are shown in Figure 1.

Figure 1. Extent of the Great Barrier Reef off the eastern coast of Queensland Land mass contributing to runoff into the reef lagoon; and R. Map of GBR marine parks.

Managing water, sediment and nutrient losses from grazing landscapes is equally important to the landholder, who requires sustainable and profitable beef production from these lands, as it is to the wider community who require protection of the GBR. Managing pastures to minimise soil loss from grazing properties is required for the landholders' long-term future and this has equivalent community benefits in reducing off-site impacts. The EDGE network Grazing Land Management (GLM) course (Quirk and McIvor, 2003) offered through Meat and Livestock Australia (MLA) to landholders in the reef catchments aims to improve their pasture and soil surface condition management for long-term beef production. The improved management has potential to provide carry-over benefits in reducing the historical rates of soil erosion across the catchments, and particularly in areas of degraded land condition.

The 'ABCD' land condition framework (Figure 2) definitions used in GLM workshops (FutureBeef.com.au) and the satellite imagery of long-term ground cover were used to help select the experiment sites during the field inspections. The D-condition land selected was bare and eroded, excluding areas in the wider definition that can include woody weed cover or severe gullying.

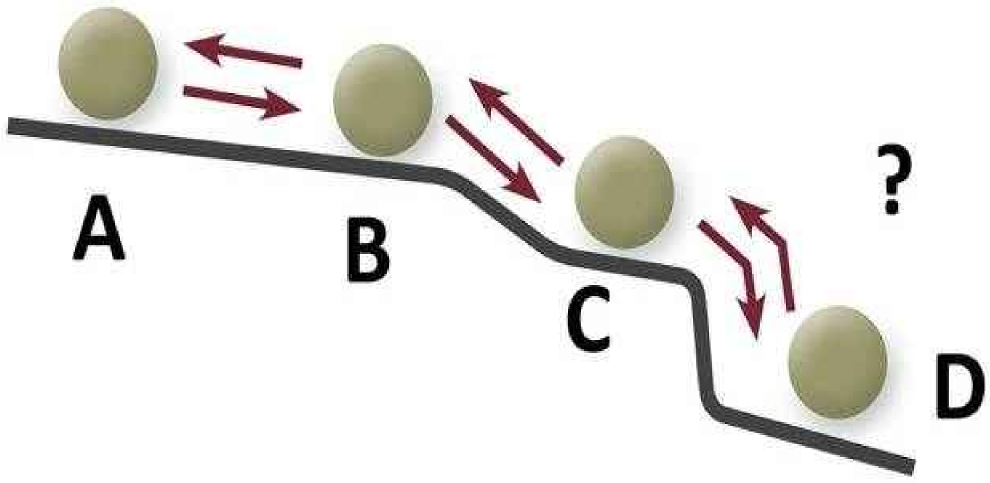


Figure 2. 'ABCD' land condition framework showing unstable D-condition requiring mechanical intervention to improve back to C-condition (FutureBeef.com.au).

There are grazing and resting management strategies to change pastures between the more stable A, B and C land condition states. However, by the time land is in the less stable D-condition it has lost productive capacity, and requires a high degree of time and energy inputs, such as mechanical and/or chemical disturbance and pasture seeding, to revert back to at least C-condition. The disturbance may be insufficient if soil losses and condition have been too severely degraded. There are areas of grazing lands throughout Queensland that have been degraded to varying extents. These areas have been identified and defined by Tothill and Gillies (1992).

Land condition can deteriorate rapidly from C to D-condition by a combination of drought and continued stocking, especially with heavy grazing pressure or during the severe episodic drought events. These circumstances can also lead to a failure of rehabilitation attempts. Equally, the post-drought grazing and spelling management of rehabilitation sites is critical to land condition improvement as is its management during the drought. Additionally strategic spelling and timely weed and woody regrowth control are necessary following a drought, irrespective of rehabilitation or land condition.

Fraser (2013) suggests that total above-ground biomass (i.e. pasture standing biomass plus grass and tree litter) is the best indicator of infiltration capacity in rangeland pastures. Also surface soil texture is an important factor in determining infiltration capacity when above-ground biomass is low. Therefore, improving the standing pasture and ground cover on bare patches of D-condition grazing land, known as 'scalds', will reduce soil, water and nutrient losses. However, by definition of D-condition scalds it requires mechanical intervention to commence the process of developing pasture biomass.

The land condition scale of 'ABCD' as defined by the GLM program is the method used to describe the range of grazing land conditions. The most cost-effective mechanical treatments or the levels of reduction in erosion and nutrient loss are not well defined or quantified. Grazing management strategies are available to continue improvement from C-condition to B- and

A-condition. This project aims to identify and quantify the effectiveness of mechanical interventions and review landholder attempts at rehabilitation of bare D-condition land in the Great Barrier Reef (GBR) catchments of the Burdekin and Fitzroy Rivers. Results from this project will compliment concurrent research on gully and stream bank erosion in the Reef catchments. Quantified data will support other reef recovery projects on the social and economic aspects of improving land management.

This project (RRRD.024) provides information for landholders and Reef Rescue (RR2) on mechanical methods, and social and economic issues on rehabilitating degraded, bare D-condition grazing lands in the Burdekin and Fitzroy River catchments of north eastern Queensland. These degraded landscapes have been caused by high grazing pressure, particularly in selected favourable environments and exacerbated by re-occurring extended drought periods.

The project regions cover the two largest river catchments flowing into the GBR lagoon, the Burdekin and Fitzroy Rivers, in north-east Queensland. Their adjacent location on the Queensland coast and catchment details relative to the GBR are shown in Figure 3 (L, C and R).

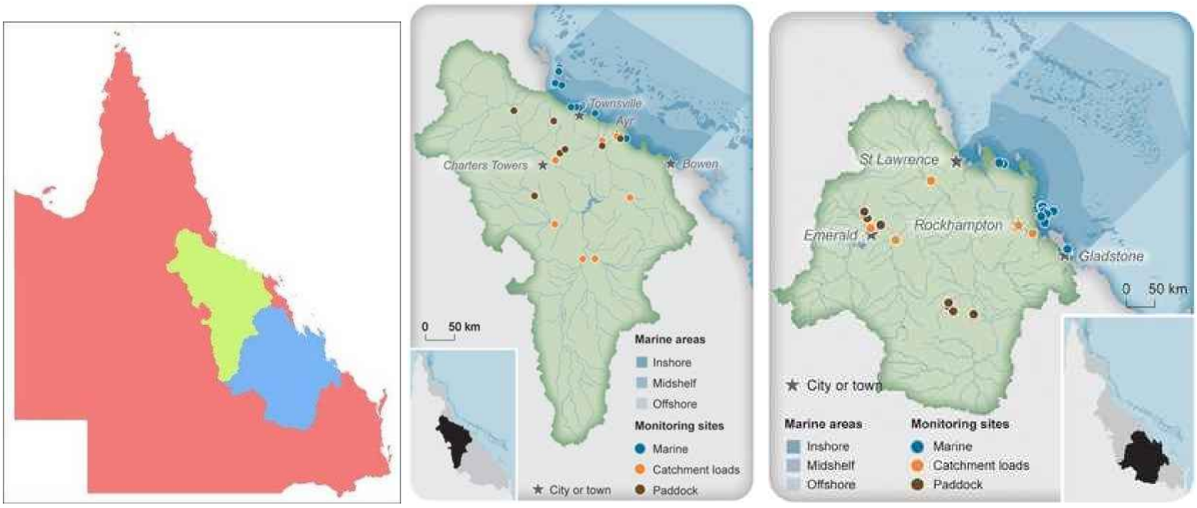


Figure 3. L. Rehabilitation regions of Burdekin (north) and Fitzroy River (south) catchments in north-east Queensland; C. Burdekin and R. Fitzroy catchments with river systems and major towns.

The six key project objectives were to evaluate mechanical rehabilitation treatments for bare patches of D-condition grazing land, to reduce erosion losses of soil, water and nutrients, to improve water quality of runoff into the Great Barrier Reef; to quantify the rate of cover improvement from mechanical intervention; to estimate the costs of rehabilitation treatments; to identify barriers of adoption of proven mechanical treatments; and to estimate rehabilitation costs and incentives required to encourage landholders to implement mechanical treatments of D-condition land on their properties. The main GBR issue investigated in the project included identifying the widespread areas of degraded D-condition land patches across the grazing zones of the Burdekin and Fitzroy catchments and assessing commercially available methods of rehabilitation. Although individual patches may be small in area, they contribute a disproportionate amount of erosion sediment materials to the GBR lagoon. This project addressed mechanical disturbance approaches to improve regeneration methodologies, their costs, benefits and landholder barriers.

The research approach was to establish mechanical disturbance field experiments and to investigate methods implemented by landholders to rehabilitate bare degraded D-condition grazing lands. The experiments had different levels of cultivation/disturbance treatments across different soil types (in the Fitzroy and Burdekin catchments) with grazing managed to assist establishment and production of the sown pastures. All sites and treatments were seeded and mechanical treatments ranged in disturbance levels from nil to high (e.g., blade ploughing and deep ripping). Measurements addressed the pastures, soil surface conditions, sediment losses and costs.

Beyond the results of the mechanical methods evaluated, the project objectives were achieved through: a review of previous demonstration sites, landholder experiences of rehabilitation attempts and reviewing literature and on rehabilitating degraded grazing lands across northern Australia, including in the Fitzroy and Burdekin river catchments, and by reviewing successful large-scale rehabilitation in the Kimberley of Western Australia (WA). Due to paucity of collected quantitative D-condition land rehabilitation data this involved the selective collection of pasture condition data and the collation of experiential learnings of the producers and agencies involved via one-on-one interview surveys. These sites included North Queensland Dry Tropics (NQDT) and Fitzroy Basin Association (FBA) funded landholders who had rehabilitated degraded pastures, Landcare group sites, research experiments and other relevant commercial sites.

The landholder surveys, and literature and regeneration site reviews were included to provide subjective information from different sources to complement the objective data measured at field experimental sites to cover the six objectives.

The ecological and financial results from the experiments were extrapolated across the landscape. This component of the project is linked with associated Reef Rescue projects, such as: the “Getting ground cover right” (RRRD.027) and “Integrated assessment of BMP cost-effectiveness” (RRRD.039) with emphasis on the grazing lands, and with Queensland Department of Natural Resources and Mines (DNRM, formerly DERM) rainfall simulator and runoff/erosion work. Quantified data on soil, runoff and pasture data is available to key research users for extrapolating results, for example, via GRASP (a Grass Production Model that simulates grass production and predicts outcomes of management decisions about soil water, pasture growth and animal grazing) (Littleboy and McKeon 1997), long-term carrying capacity calculations, and economic case studies.

The project aims are consistent with targets and Caring for Our Country outcomes. It provides practical regeneration methodologies with associated costs and benefits, which can be linked to incentives, leading to an ability to improve the pasture and ground cover management of degraded grazing land in the GBR catchments.

The project is delivering against Caring for our Country 2011-12 Business Plan target for ‘Great Barrier Reef water quality research and development’. This study forms part of the Reef Rescue Research and Development program and is a component of Sub-program 1: Adoption and development of sustainable practices that have water quality benefits - Grazing Practices.

Project Objectives

There were six objectives of the project:

1. *to identify social and economic drivers that motivate land managers to rehabilitate degraded grazing lands*
2. *to identify the barriers to rehabilitating degraded grazing lands*
3. *to validate the effectiveness of mechanical approaches to initiating the rehabilitation of degraded grazing lands on improving water quality*
4. *to assess the effectiveness of maintaining different levels of groundcover and soil surface condition on managing erosion*
5. *to estimate the costs and benefits of rehabilitating degraded grazing lands and the likely level of incentives required to accelerate the adoption practices to improve the condition of degraded grazing lands*
6. *to quantify the time-lag between mechanical intervention and improved pasture condition, soil condition and animal production.*

Methods

Three main research approaches were developed in the regional project investigating the rehabilitation of bare, D-condition grazing lands in the Burdekin and Fitzroy catchments of north-east Queensland to address the six previously-set RRRD objectives.

The three, complementary approaches were:

1. mechanical disturbance rehabilitation methods field experiments at three sites
2. a survey of landholder rehabilitation experiences
3. a literature and field review of rehabilitation of D-condition grazing lands.

Within the mechanical disturbance rehabilitation experiments, multiple aspects were explored. These included: disturbance methods, grass and legume species selection, seasons (years) of rehabilitation, pasture performance parameters, soil surface conditions, sediment and nutrient runoff losses, costs of rehabilitation and potential returns from grazing treated sites.

1. Mechanical disturbance rehabilitation methods: Field experiments

Selecting three field experimental sites

A bare ground index (BGI) analysis of the long-term Landsat imagery of grazing lands in the Burdekin River (Abbott 2010) and Fitzroy River (Abbott 2008) catchments identified areas of consistently low cover or bare ground. Some areas were shown to be bare, eroded scalds in D-condition, the type of landscapes suitable for rehabilitation. These areas were overlaid onto land title maps of eastern Queensland to identify suitable properties for potential field experiment sites within the Burdekin and Fitzroy catchments, and possible landholders for the rehabilitation survey interviews (pers. comm. Dr Abbott CSIRO 2011).

After discussions with several property owners and on-ground inspections, three field experiment sites were selected:

Site 1: ‘Spyglass’ Beef Research Facility (19.3366^{0}S; 145.8154^{0}E) (DAF) in the Burdekin catchment
Site 2: ‘Injune’, north of the town of Injune (25.3184^{0}S; 148.8772^{0}E) in the Fitzroy catchment
Site 3: ‘Banana’ north-east of the town of Banana (24.4510^{0}S; 150.1745^{0}E) also in the Fitzroy catchment.

Burdekin catchment

The extensive low-cover areas that include bare D-condition grazing land in the centre and southern part of the Burdekin catchment are shown as red in Figure 4.

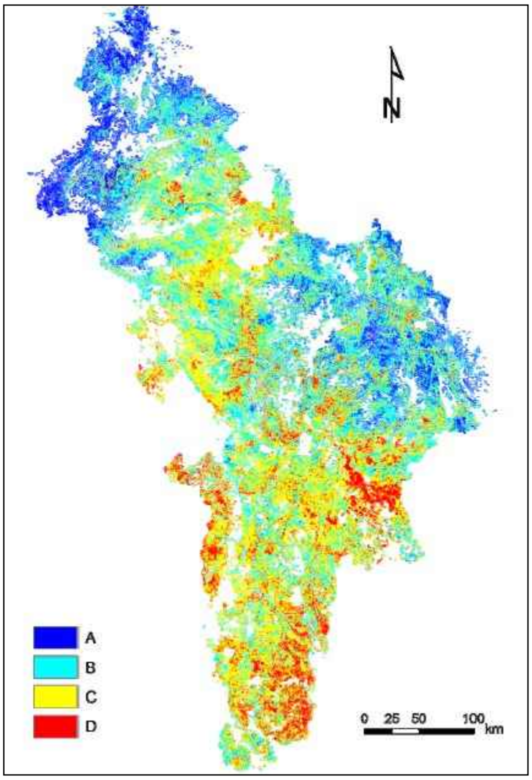


Figure 4. Land condition mapping for the Burdekin catchment (CSIRO; Abbott 2010).

Spyglass was shown to have typical D-condition bare country, representative of a range of eroded-frontage soil types suffering severe soil loss in the Burdekin catchment. As a DAF research facility, Spyglass was chosen as a field experiment site so the project had control and management of the land, rehabilitation treatments, and grazing during the project period. After the initial RR2 project is complete, the Spyglass site could be maintained and monitored for longer-term results of mechanical rehabilitation and management requirements over a longer time-frame into the future.

Site 1: Spyglass (Charters Towers)

A suitable D-condition 10 hectare (ha) experimental site was selected on Spyglass from an on-ground inspection of potential locations, confirmed by a DNRM Forage analysis (Queensland Government) that uses the same long-term Landsat imagery of grazing lands as the BGI analysis. The below-average forage (including pasture) cover at Spyglass is shown as brown in Figure 5. The experimental area selected is towards the north-east corner of the property in the extensive dark brown area on the image. After on-ground site inspections, the experiment site selected was along a creek frontage, 2 km west of the Burdekin River, and is some 120 km north of Charters Towers and a similar distance west of Townsville.

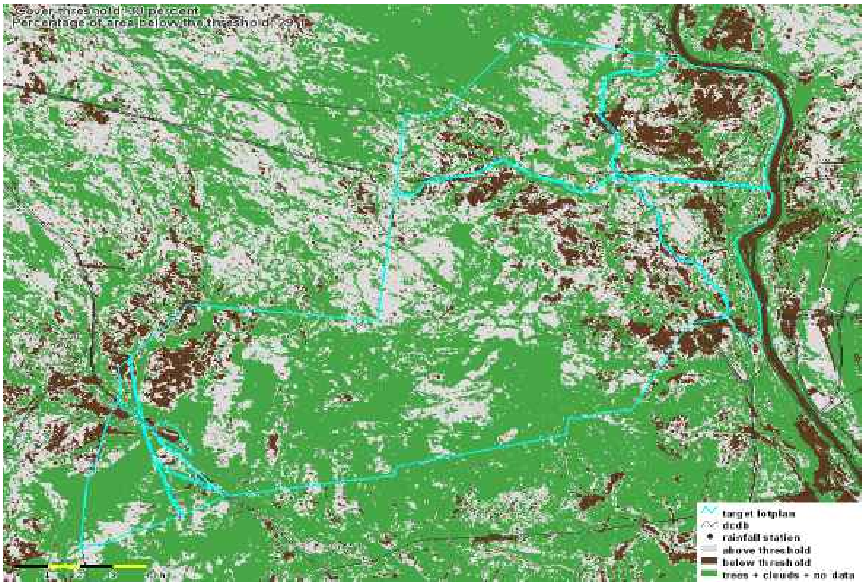


Figure 5. Average cover at Spyglass: the rehabilitation experiment area selected is in the bare areas in the north-east (Forage analysis, DNRM).

A satellite image (World View) of the Spyglass experimental site was captured, before the rehabilitation treatments were applied in October 2011. The extent of eroded D-condition surfaces on both sides of the creek is clearly shown. The eroded creek frontages selected for the rehabilitation experiment is on the west side of the creek and is clearly shown in Figure 6.

Figure 6. Site 1 Spyglass in the Burdekin catchment before rehabilitation treatments were applied to the west side of the creek (Oct. 2011) (source Google).

A map of the fenced experimental site at Spyglass is shown overlaying the satellite image of the eroded creek frontages after the treatments were applied (Figure 7).

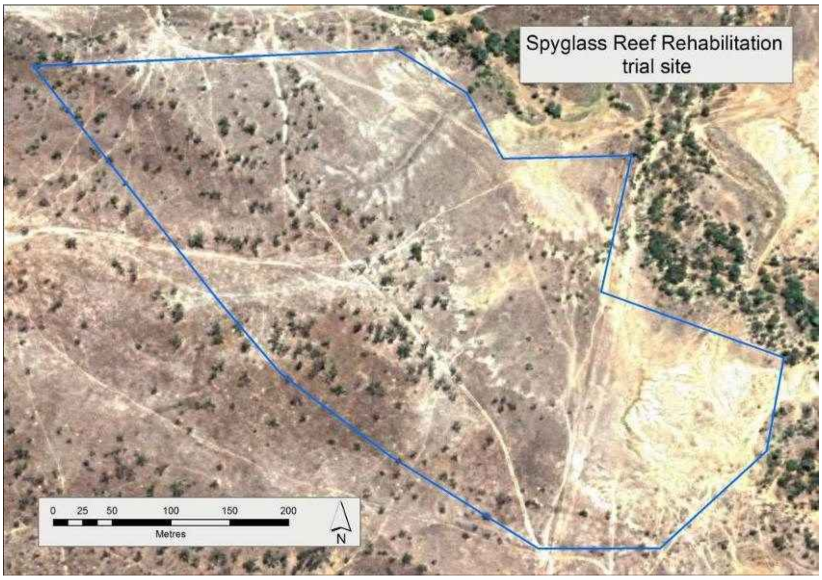


Figure 7. Rehabilitation experimental site boundary fence in the Burdekin ('Spyglass').

The 10 ha of rehabilitation treatments extends across the bare area on the eastern half of the experiment site into the treeline. A strip of land in the trees down the western part of the fenced site was not treated and remained as native pasture.

The extent of erosion across the Spyglass experiment site in 2011 is shown in Figure 8, with extensive sheet eroded areas and more deeply eroded patches.

Figure 8.Extent of eroded surfaces at Spyglass experiment site before rehabilitation (August 2011).

The elevated logs (right photograph) suggest serious erosion has occurred in recent decades. There was an average of 40-50 cm of topsoil lost from across most of the site and a two metre depth of soil lost from the eroded gully at the south of the fenced experiment site. The head of this gully was chosen to evaluate one of the mechanical disturbance rehabilitation treatments: pasture seeding and hay mulch cover on a battered gully head.

Fitzroy catchment

The bare, eroded, D-condition grazing lands of the Fitzroy catchment are predominantly through the centre and to the west of the catchment, shown as purple in Figure 9.

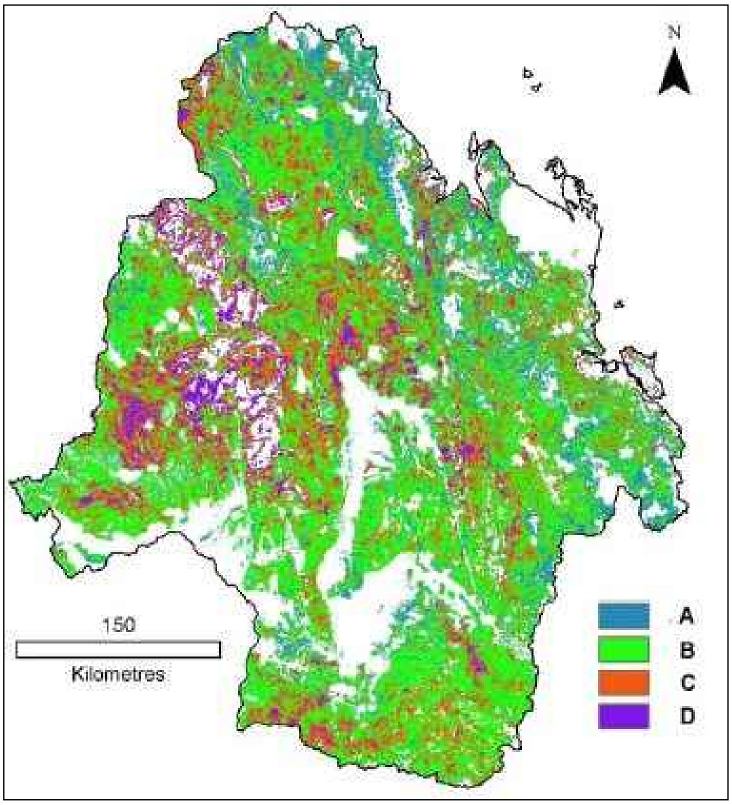


Figure 9. Land condition (ABCD) mapping for the Fitzroy catchment (CSIRO; Abbott 2008).

When investigating potential field experimental sites in the Fitzroy catchment, properties were located where the landholders had done their own rehabilitation work and had developed successful methods. Two of these properties were selected as Site 2 Injune and Site 3 Banana, on two different soil types, rehabilitated with two different disturbance methods, and managed over two different time frames. The two established sites were selected to provide the project with additional, comparative rehabilitation data starting in 2011 as Year 1 at Spyglass, Year 3 at Banana, and Year 9 at Injune. All three sites were monitored for pasture performance, soil surface conditions, and sediment and nutrient runoff during the three-year project period (2011-2014).

Site 2: Injune

The Injune experiment site was in two comparable paddocks (A and B) of approximately 90 and 110 ha in cleared brigalow country. Paddock A had been rehabilitated by deep ripping and pasture seeding over bare, scalded, surface patches in 2003 (
Figure 10) as part of an externally funded program, and Paddock B, on the same landtype, had not been rehabilitated and retained similar bare patches Figure 11 (L and R).

Figure 10. Rehabilitation experiment site (Paddock A) at Injune.

Figure 11. L. Un- rehabilitated Injune experiment site in a bare area in the south-west corner of the paddock (Paddock B); and R. The bare experiment site at Injune.

In Paddock A, the visible bare patches indicate the extent of D-condition patches prior to the deep ripping and seeding treatment in 2003 (Figure 12 L). The subsequent established pasture in 2011 reflects the success of the deep ripping rehabilitation treatment over an eight-year period (Figure 12 R).

Figure 12. L. Injune site during rehabilitation in 2003; and R. Rehabilitated pasture in 2011.

Controlled grazing management, using extended rest periods (cell grazing system), was practiced during the initial rehabilitation period (2003-2007) and continuing through the project monitoring phase (2011 to 2013). For the first four years after rehabilitation treatments the grazing pressure in Paddock A was consistently less than in the non-rehabilitated Paddock B, where the rest periods were of a much shorter duration during this 2003-2007 period.

Paddock B, the un-rehabilitated site, had patches of bare soil surfaces within a buffel grass pasture on the same cleared brigalow land type (Figure 13 R) as the rehabilitated paddock.

Figure 13. L. Injune site bare patches rehabilitation treatment of deep ripping and seeding (2003); and R. Patch not rehabilitated (2012).

Site 3 – Banana

The Banana experiment site had extensive bare D-condition patches over the whole paddock (Figure 14. L), and especially in the mid-slope position. The rehabilitation method was to blade plough the whole paddock and reseed it all with a grass and legume pasture mix in 2009 (Figure 14 R).

Figure 14. L. Fitzroy experiment site 2 (Banana) paddock before rehabilitation; and R. Typical blade plough with roller seeder in operation.

This rehabilitation work was self-funded with no input from sponsored programs. Grazing was managed each year by the landholder to allow the new pasture to establish, develop and seed, and the same management continued during the project monitoring period of 2011 to 2014. Bare patches at the Banana site, similar to those before rehabilitation, and pastures that established after the blade ploughing and seeding rehabilitation treatment in 2009 are shown in Figure 15.

Figure 15. L. Un-rehabilitated bare patches; and R. Rehabilitated sown pastures at Banana site (2012).

Rehabilitation treatments

At all three sites, a mechanical disturbance rehabilitation treatment is considered to be a combination of a mechanical disturbance of various 'aggressive' levels, followed by pasture grass and legume seeding.

Pasture seeding

As D-condition bare areas are by definition seriously eroded and scalded surfaces, they will not have a surviving pasture seed supply, so the most adapted tropical grasses and legumes for the soil type and climatic environment were selected and sown in all treatments at the three experiment sites (Table 1).

Table 1. Pasture grass and legume species sown at the three experiment sites.

Spyglass (Burdekin)	Injune (Fitzroy)	Banana (Fitzroy)
Angleton bluegrass (cv. Floren)	Buffel grass (cv. Biloela)	Bambatsi panic
Bambatsi panic	Buffel grass (cv. Gayndah)	Buffel grass (cv. Biloela)
Buffel grass (cv. Gayndah)#	Caatinga stylo (cvv. Primar/Unica)	Butterfly pea (cv. Milgarra)
Burgundy bean*	Rhodes grass	Caribbean stylo (cv. Verano)
Butterfly pea cv. Milgarra (Clitoria)*	Seca shrubby stylo	Green panic
Caatinga stylo (cvv. Primar/Unica)	Siratro	Sabi grass (Urochloa)
Caribbean stylo (cvv. Amiga /Verano)	Silk sorghum	Siratro
Creeping bluegrass (cv. Bisset)		Silk sorghum
Desmanthus (cv. Progardes)*		
Indian bluegrass (cv. Keppel#)		
Rhodes grass (cv. Katambora)		
Sabi grass (perennial Urochloa)		
Shrubby stylo (cv. Seca)		

Spyglass site: # Uncoated grass seed; * Uncoated legume seed.

A different sown pasture species mix was used at each site. The main species sown reflect the three environments and were aimed at providing rapid first year surface cover and a long-term permanent grass-legume pasture. The aim of the final pasture was to provide good surface cover and erosion protection, as well as be a productive grazing pasture for cattle. A commercial pasture mix will have fewer species included than was used in these experimental sites.

Mechanical disturbance

The mechanical disturbance treatments evaluated at Spyglass were selected to be practical and more cost effective for landholders to implement if successful, and the two methods at Injune and Banana were developed by the landholders. The types of machinery available to landholders, and their practical operation in the landscapes to be rehabilitated were considered in selecting a range of potential methods from low to high input in both energy and financial costs. Different disturbance methods were used at the three experiment sites.

Spyglass (Burdekin)

Mechanical disturbance treatments at this site were:

1. Deep ripping (high disturbance)
2. Chisel ploughing (medium disturbance)
3. Pitting using a 'crocodile plough seeder' (low disturbance)
4. Hay mulch cover on a battered gully head (high disturbance)
5. Control – bare (D-condition, no disturbance)
6. Control – silt (C-condition, no disturbance and with deep ripping disturbance).

All treatments, including the controls, were seeded with a mix of pasture grass and legume species (Table 1). A 3-point linkage fertilizer spinner spread all larger uncoated seed across all treatments and the smaller coated seed on the two control treatments. The small coated seed lines were distributed via the crocodile plough seeder in the disturbed treatments. The light fluffy, uncoated, grass seed (buffel grass and Indian bluegrass) was hand broadcast on a grid pattern over the whole site. No fertilizer was applied. All treatments were established on hot, dry soil surfaces between 6 and 13 October 2011.

Additional treatment: Gypsum experiment

After an analysis of the first two years results at Spyglass where there was no successful rehabilitation on one soil type, the sodic dermosol, a gypsum experiment was established on this soil type. The experimental plots were within the fenced experiment area and on other eroded loam and heavy clay surfaces in an adjacent paddock. The rates of gypsum tested were two and three tonnes per hectare, surface-spread after chisel ploughing and reseeding with the same pasture seed mix. The treatments were applied in early December 2013.

The summer after establishing the gypsum experiments was a drought year 2013-2014 and pasture establishment was poor and inconsistent within and between plots. These experiments need to be repeated to evaluate the potential of gypsum aiding pasture establishment on the sodic dermosol soil. Results of the gypsum experiments are summarised in Appendix 8.

Injune (Fitzroy)

There was one main rehabilitation method used on selected bare surface-scalded patches only, not on the whole paddock. The site was deep ripped and seeded with a grass and legume pasture mixture (Table 1). Only the bare scalded sites were rehabilitated within the paddock which was closed to grazing and subsequent grazing was managed, particularly during the early drought years, as the pasture developed over the next seven years.

Banana (Fitzroy)

The Banana paddock included extensive bare scalded patches in a native pasture on cleared undulating Eucalypt country. The scalds were predominantly across the lower hill slopes. The rehabilitation method was to blade plough and reseed (Table 1) the whole paddock. The scalds and native grass areas were all improved at the one time. Grazing could be managed in one large paddock over the initial establishment years, allowing both the originally bare patches and grassy areas to improve in ground cover. The blade ploughing left a rough surface increasing water infiltration and erosion control, and produced a productive exotic species pasture for beef cattle production.

Monitoring pastures

Measurements addressed pasture establishment (Spyglass only), pasture production, ground cover, litter; soil surface and landscape condition; and losses of soil, water and nutrients; and treatment costs at the three sites.

The species composition, frequency and dry matter yield, pasture total dry matter yield, total ground cover and litter cover, reproduction status of the legumes and surface roughness were recorded at the three experimental sites in autumn (April) of 2012, 2013 and 2014, after the summer growing season (e.g., Year 1 at Spyglass is 2011-2012). The Botanal method (Tothill *et. al*. 1992) was the pasture recording technique used in all years (2012-2014) with 30 to 92 quadrats of 0.25 m^2 per treatment recorded on each occasion, on a grid pattern over all treatments at the three sites. A photographic booklet (33 pages) of over 60 potential herbaceous species (grasses, legumes and forbs) at the three sites was produced prior to monitoring pasture composition, to assist in consistent species identification by Botanal recording staff (Appendix 2).

Classifying soil types

There were seven soil types identified at the three field sites by DNRM soil surveyors. Selected profiles of the three soil types at Spyglass were mapped using 1-2 m deep profile cores. There were variations of red and brown dermosol soils at Injune and a brown vertosol at Banana. These soils were described, classified and analysed for chemical and physical properties. The details are included in Appendix 3.

Soil surface conditions

Soil surface roughness was recorded using a 1-3 rating scale (1-smooth, 2-uneven, and 3-rough) in conjunction with all Botanal pasture recording quadrats at the three sites over three years (2012-2014). In addition, soil surface conditions in all treatments were measured by the Landscape Function Analysis (LFA) method (Tongway and Hindley 2005) in all pasture recording quadrats at the three sites after summer in 2013 and 2014. The LFA parameters (Table 2) were used to calculate indices of stability, infiltration and nutrient cycling for each treatment.

Table 2. LFA pasture and soil surface condition parameters used to record rehabilitation treatments at three sites (2013 and 2014).

No.	Parameter	Data form	Data values
1	Dominant Species name/number	Code no.	0 - 86
2	Dominant Species contribution	%	0 - 99
3	Dry Matter Yield	rating	0 - 99
4	Utilisation % (grazing)	range	1 - 4
5	Woody regrowth cover (10 radius)	%	0 - 99
6	Basal area pasture	%	0 - 10
7	Tree and shrub cover	%	0 - 99
8	Total ground cover	%	0 - 99
9	Organic matter cover	%	0 - 99
10	LFA cover (excludes litter)	%	0 - 99
11	Litter cover	%	0 - 99
12	Litter origin/source	Code	1 - 2
13	Litter decomposition	Code	1 - 4
14	Cryptogam cover	Code	0 - 4
15	Crust broken-ness	Code	0 - 4
16	Erosion type	Code	1 - 5
17	Erosion severity	Code	1 - 4
18	Deposits (amount * cover)	Code	1 - 4
19	Surface roughness	Code	1 - 5
20	Surface nature (brittle/hardness)	Code	1 - 5
21	Soil texture class (infiltration)	Code	1 - 4
22	Slake test	Number	0 - 4

Sediment and nutrient runoff losses

Sediment and nutrient losses were measured in the disturbance treatments and in partly rehabilitated and un-rehabilitated sites at the three experimental sites in July-August 2012 by a rainfall simulation method (managed by the DNRM rainfall simulation team). This provided runoff loss measurements after one (Spyglass), three (Banana) and nine years (Injune) after mechanical disturbance and reseeding treatments had been applied.

Infiltration and runoff rates, and losses of sediment and nutrients (nitrogen and phosphorus), were measured using a rainfall simulation machine based on the A-frame design of Loch *et al.* (2001). There were three downward spraying Veejet 80100 nozzles (Lock and Donnollan, 1983) delivering an average 87 mm per hour in a flat spray pattern with a fan angle of 80^o (Figure 16). Adjacent paired plots (replications), each 1.7 m long by 1.0 m wide, received simulated rainfall until runoff commenced and then continued for a further 30 minutes.

Runoff water samples were collected from each of the paired plots at five minute intervals during the event to determine infiltration and runoff rates, and the sediment and nutrient concentrations in the runoff. More details of this rainfall simulation methodology are available in the Reef Paddock to Reef programme: *Paddock scale water quality monitoring and modelling to measure effectiveness of management practices*, a Queensland DNRM project.

Figure 16. Rainfall simulation A-frame unit in operation at Spyglass (2012).

Site 1: Spyglass (Burdekin)

Rainfall simulation measurements were conducted on two soil types (heavy clay/vertosol and loam/sodosol surfaces) which had four disturbance treatments (deep ripping, chisel ploughing, crocodile plough seeding and a control-bare) (Table 3).

Table 3. Ten rainfall simulation plots at the Spyglass experiment site (August 2012).

Mechanical treatment	Disturbance level	Surface soil type
Ripping	high	heavy clay and loam
Chisel ploughing	medium	heavy clay and loam
Crocodile plough seeder	low	heavy clay and loam
Control - bare	nil	heavy clay and loam
Control - bare	nil	loam – low cover
Native pasture (undisturbed)	nil	loam surface duplex

In addition, there was a control-bare loam soil site in a negligible cover area of the experiment, and a site on an un-eroded area of native pasture in the Eucalypt woodland on the loam-surfaced sodosol soil type adjacent to the experimental site (Table 3). There were a total of ten rainfall simulation locations across the Spyglass site.

The mechanical treatments were carried out in October 2011, ten months prior to rainfall simulation measurements (August 2012). Simulation rainfall was applied at an average of 87.4 mm per hour.

Sites 2 and 3 - Injune and Banana (Fitzroy)

In the Fitzroy catchment, at both the Injune and Banana experimental sites, six rainfall simulation plots were installed on three areas, selected as good, poor and nil rehabilitation sites, from the original treatments previously applied nine years (deep ripping) and three years (blade ploughing) earlier respectively (Table 4). The same rainfall simulation equipment, methods and paired plot design to that used at Spyglass was used at these six locations.

At both sites, the selected successful rehabilitation plots retained high surface roughness, ground cover and pasture DM yields. However, the nil rehabilitated plots had <5% ground cover and negligible surface roughness and pasture dry matter yield. The poor rehabilitation plots were between these levels for all parameters, but had been treated the same as the good rehabilitation sites originally.

Table 4. Six rainfall simulation plots at the Injune and Banana experimental sites (August 2012).

Site	Mechanical treatment	Disturbance level	Surface soil type
Injune	Ripping – good rehabilitation	high	clay loam
	Ripping – partial rehabilitation	high	clay loam
	Undisturbed – no rehabilitation	nil	clay loam
Banana	Blade plough – good rehabilitation	high	heavy clay
	Blade plough – partial rehabilitation	high	heavy clay
	Undisturbed – no rehabilitation	nil	heavy clay

Economics of rehabilitation

The economic costs and benefits of the rehabilitation disturbance with reseeding treatments used at the three experiment sites were analysed from actual operations, their commercial costs and subsequent pastures produced over the following 3-4 years. These results were then extrapolated forward over a 20-year period. An additional economic analysis of the potential beef production, using a steer trading enterprise, from the Spyglass rehabilitation treatments was conducted. This analysis was based on the measured pasture grass/legume composition and dry matter production from the good rainfall establishment year (2011-12) and the following two poor, drought years (2012-13 and 2013-14). The significant decline in pasture performance between these years affected the potential financial returns. The economic analysis takes account of the relative decrease in grass yield (*Bothriochloa pertusa* predominantly) representing declining pasture quantity, and the increase in perennial legume yield (cvv. Milgarra butterfly pea, Seca stylo and Progardes desmanthus) representing improving pasture quality, between the good and poor years.

To determine the economic viability of land rehabilitation in the Burdekin for a steer trading enterprise, a partial discounted cashflow analysis was used to calculate a Net Present Value (NPV) of each treatment. In this analysis, the NPV is the sum of the difference between the discounted net cash flows of each type of investment in land rehabilitation and the control. Therefore the net cashflow of the control scenario (*A*) was subtracted from that of a rehabilitation scenario (*B*). A range of discount rates were applied. Further, since all treatments incurred different levels of capital expenditure, an Internal Rate of Return (IRR) was calculated to determine the return on each additional dollar invested in rehabilitation. The IRR is defined as the discount factor required for the NPV to be zero. A discount factor of 10% was chosen due to potential returns on an alternative use of funds, such as debt reduction or stock investment. The initial cost of performing rehabilitation was treated as a tax deduction at the 30% marginal tax rate at the beginning of the project.

A Land Reclamation Economics Tool (Moravek 2013; DAF, FutureBeef.com.au) was developed to assist landholders calculate their own costs and benefits of rehabilitation works. The Excel® spreadsheet-based program calculates returns without and with rehabilitation works, the total capital outlay, and labour costs. The difference in returns between with and without rehabilitation identifies if the work will produce a positive or negative cash flow over time. The analysis assumes that the D-condition land patches will not expand if left untreated. Public financial benefits such as from reduced sediment, nutrient losses, or any biodiversity improvement, are not included in the calculations.

Photographic records

The three field experiment sites and pastures were photographed regularly by various means during the project (Appendix 7). There were fixed photo sites established in the Spyglass treatments that were recorded monthly, a permanent camera with satellite capabilities recording a daily photograph, and photos at pasture recording periods and also irregular photos on experiment site inspections. Opportunistic photographs were taken of the Injune and Banana sites at data recording and inspection visits.

Fixed-site photos (Spyglass only)

Permanent photo sites were installed at Spyglass with two steel posts 10 m apart on a north-south axis in the six treatments (chisel plough, ripping, crocodile plough, hay mulch, control-bare and control-silt). A photograph was taken at these sites in both directions (N to S and S to N) in the middle of each month. These photographs are stored in a DAF server database. An example of these photographs for the ripping treatment (Figure 17) shows the dramatic seasonal maturity changes over three months in the establishment year.

2012 March: 1. Ripping N-S **2. Ripping S-N**

2012 April: 1. Ripping N-S **2. Ripping S-N**

2012 May: 1. Ripping N-S **2. Ripping S-N**

Figure 17. Fixed site photos of ripping treatment (N to S and S to N) from March to May 2012 at Spyglass.

Daily site photograph sent via satellite (Spyglass)

A solar powered camera with capabilities of sending photos via satellite to a remote server on request was installed at the Spyglass experiment site and set to take a photograph daily at 1:00 pm across the ripping and chisel ploughing treatments (Figure 18).

Figure 18. Remote solar powered camera with satellite transmission capabilities at Spyglass.

The photographs can be accessed remotely via the web. An example of the daily photos over the second summer, a drought year, from July 2012 to March 2013 is shown in Figure 19.

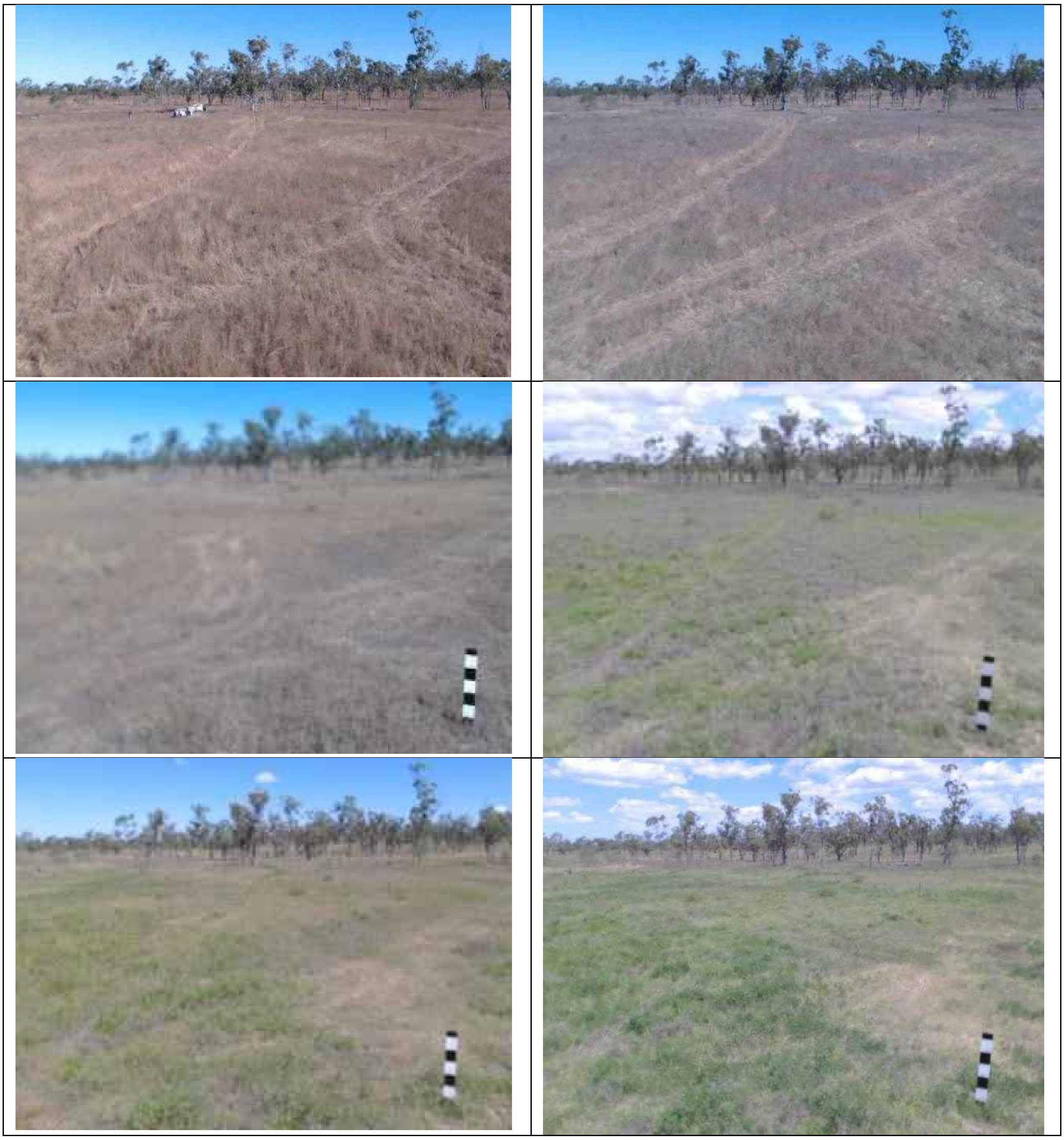


Figure 19. Spyglass site images over second drought year from satellite camera (July 2012 to March 2013).

Land surface imagery (Spyglass)

During the Spyglass experiment, there were two land surface imagery methods used to provide detailed surface imagery. They were a fixed-point Lidar scan conducted in 2012 (an example of imagery is shown in the Results section), and an aerial UAV detailed 3-D photographic surface imagery system in 2013 (results are shown in Appendix 4). These systems complimented the detailed World-View satellite imagery conducted across the site on 1 October 2011, immediately before the treatments were established.

Remote weather station - satellite transmission (Spyglass)

Rainfall and Temperature

A weather station recording rainfall, air temperature, relative humidity and dew point was installed in the centre of the experiment at Spyglass, in the rehabilitation ripping treatment (Figure 20).

Figure 20. Solar powered weather station with satellite communication capabilities at Spyglass.

This unit has capability of transferring data hourly to a remote server via satellite communication and the data can be accessed remotely via the web. The data can be graphed automatically for any time period.

1.1 Survey of landholder rehabilitation experiences

An interview survey protocol was designed with semi-structured questions (Kvale, 2007) guided by the six previously-identified project objectives to capture the thoughts of landholders on their experiences in rehabilitating D-condition land. Landholders with long-term, low cover areas (D-condition land) identified by the BGI analysis, or those who had previously attempted rehabilitation methods were considered potential survey participants.

A target participant group of landholders was listed from discussions with regional Queensland DAF extension specialists, and suggestions from other landholders who were contacted as part of the selection process (snowballing). Over 50 landholders in the Burdekin and Fitzroy catchments were identified as having an interest, or had participated in D-condition land rehabilitation work.

From the group of 50, 20 landholders were asked to participate in a detailed, semi-structured telephone interview over 30-60 minutes, talking about their rehabilitation experiences. The six project objectives used as a discussion guide were: *social and economic drivers; barriers;*

mechanical approaches; groundcover and soil surface conditions; costs and benefits; and time-lag after rehabilitation. Speaking with landowners (rather than landholders) was preferred where possible because it was their finances that were directly at risk in undertaking any rehabilitation work.

The landholders were located across different landtypes, in different regions of the Burdekin and Fitzroy catchments, and had conducted rehabilitation work, both with and without external financial assistance and input from Landcare or Catchment NRM organisations. Direct quotes and comments from these landholders on their rehabilitation experiences were recorded and are summarised for reporting in the Results section and detailed in Appendix 5.

1.2 Review of rehabilitation of degraded grazing lands

Two reviews were conducted on the rehabilitation of grazing lands: first a desktop review of the relevant, international literature on land rehabilitation, and second, a field inspection and review of the land rehabilitation in the Kimberley region of Australia.

Literature review

A literature review of published information on rehabilitation of degraded grazing lands, with emphasis on reef catchments, was prepared. A systematic search of potential references from many published sources, including research papers, reports, fact sheets and websites was conducted. Also information from colleagues involved in water quality and grazing management research was assessed for sites with rehabilitating D-condition grazing lands. Researchers and extension staff involved in reef management and gully erosion also provided sources of information. More than 230 potential reference sources were located. This literature was evaluated for specific information related to the six project objectives. A table of the six objectives and specific relevant information was developed to identify recurrent issues and themes. The executive summary is included in the Results section of this report and the full review is included as Part II (Silcock and Hall 2014).

Field rehabilitation review: Kimberley Region, Western Australia

A field inspection and review was conducted of the largest successful rehabilitation works in northern Australia, in the Ord River catchment of the Kimberley Region of Western Australia. The work was a Government financed and conducted program on grazing land that had been resumed from the pastoralists and destocked through the 1980s. This review was to provide first-hand information on the rehabilitation from the original extensive D-condition landscapes in the early 1960s, and what mechanical rehabilitation was successful and how grazing management was conducted over 50-plus years to produce an eventual successful exotic species pasture cover. The Ord River Regeneration Reserve is now grazing-free and managed as a national park.

A second region inspected was the rehabilitation works conducted on private properties in the Fitzroy River catchment of the Kimberley Region, WA, since 2009. Multiple shallow ponding rehabilitation sites were inspected and evaluated on three properties. A report on these two rehabilitation programs and their relevance to the rehabilitation of D-condition grazing land in the Burdekin and Fitzroy catchments is published in Part IV.

Results

The results from the three research approaches; the field experiments, landholder surveys and reviews of literature and field works, are reported here with additional details included in the Appendices and Parts II, III and IV.

1. Mechanical disturbance rehabilitation methods: Field experiments

Rehabilitation success requires suitable rainfall amounts and seasonal distribution for pasture establishment where the subsequent pasture growth provides soil surface cover. During the project period (2011-2014), there were some average or above-average rainfall years at the three sites. However, at the Spyglass and Injune sites, there was also below-average rainfall resulting in an extended drought from 2012-2014. As expected, the rainfall received at each of the three field experiment sites affected the level of pasture establishment and subsequent percentage of soil surface cover required for successful rehabilitation.

Rainfall

Southern Oscillation Index

The Southern Oscillation Index (SOI) (Troup 1965) is an indicator of potential above-average or below-average rainfall in tropical Queensland Bureau of Meteorology (BOM). The strongly positive index indicated the good rainfall establishment season (for Spyglass) of 2011-12 in the reef catchments, and the contrasting dry to drought summers of 2012 to 2014 indicated by the negative index (Figure 21). Prior to commencing the project there had been good rainfall years between 2007 and 2009, and a dry summer in 2009-2010. These wet and dry cycles are typical for the reef catchments.

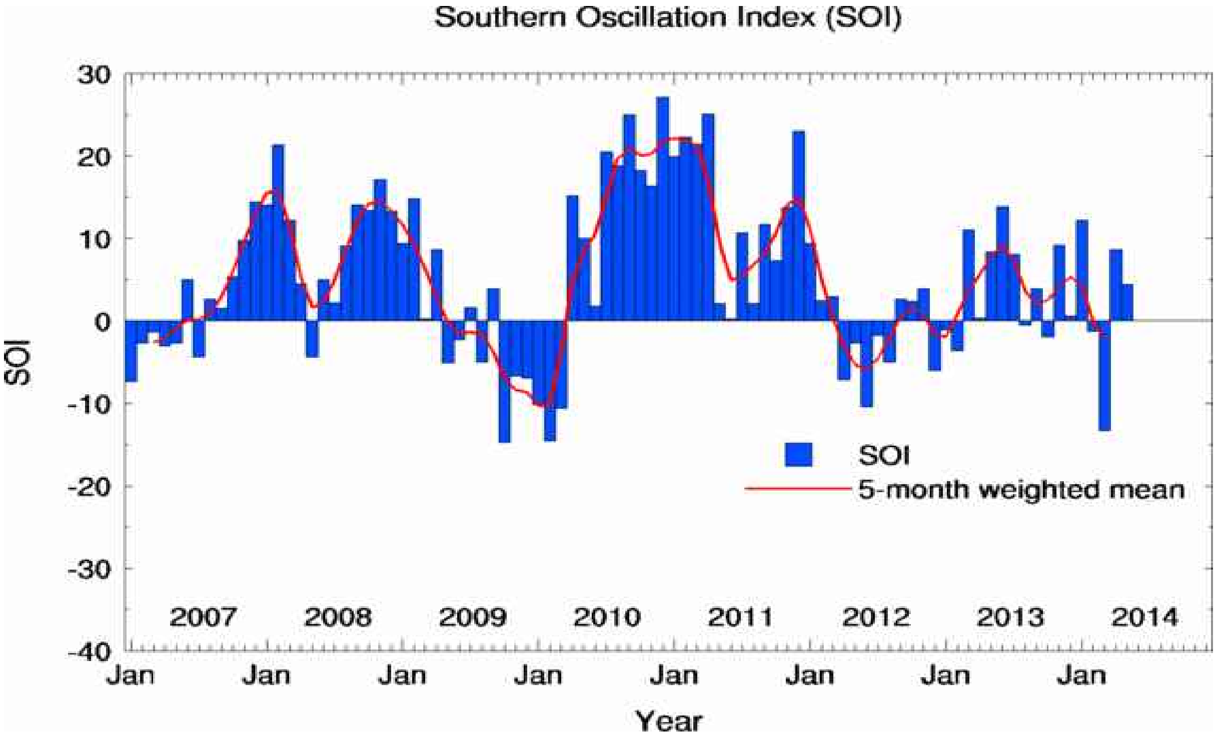


Figure 21. Southern Oscillation Index for 2011-14 period showing the wet 2011-12 and dry 2012-14 periods.

(Source: Bureau of Meteorology)

These two, contrasting summer rainfall seasons affected pasture establishment (2011-2012) at Spyglass, and pasture growth at all three experiment sites. The first-year pasture that established at Spyglass was most susceptible to plant deaths in the following two drought years (2012-2014) due to shallow root systems of new plants.

Long-term pasture growth modelling

GRASP is a long-term pasture growth model developed for landtypes (Whish 2011) across Queensland by DNRM (LongPaddock.com.au). Using this model, annual pasture growth is predicted for Queensland. The average and above average rainfall seasons and pasture growth conditions for the establishment year (Year 1) at Spyglass (2011-2012), and the well-below average pasture growth over the following two drought years across Queensland (2012-2014) are shown in Figure 22. Pasture growth related to seasonal rainfall for the establishment year at Spyglass 2011-2012 and the average of the following two drought years 2012-2014 across Queensland.(Figure 22 a. and b. respectively).

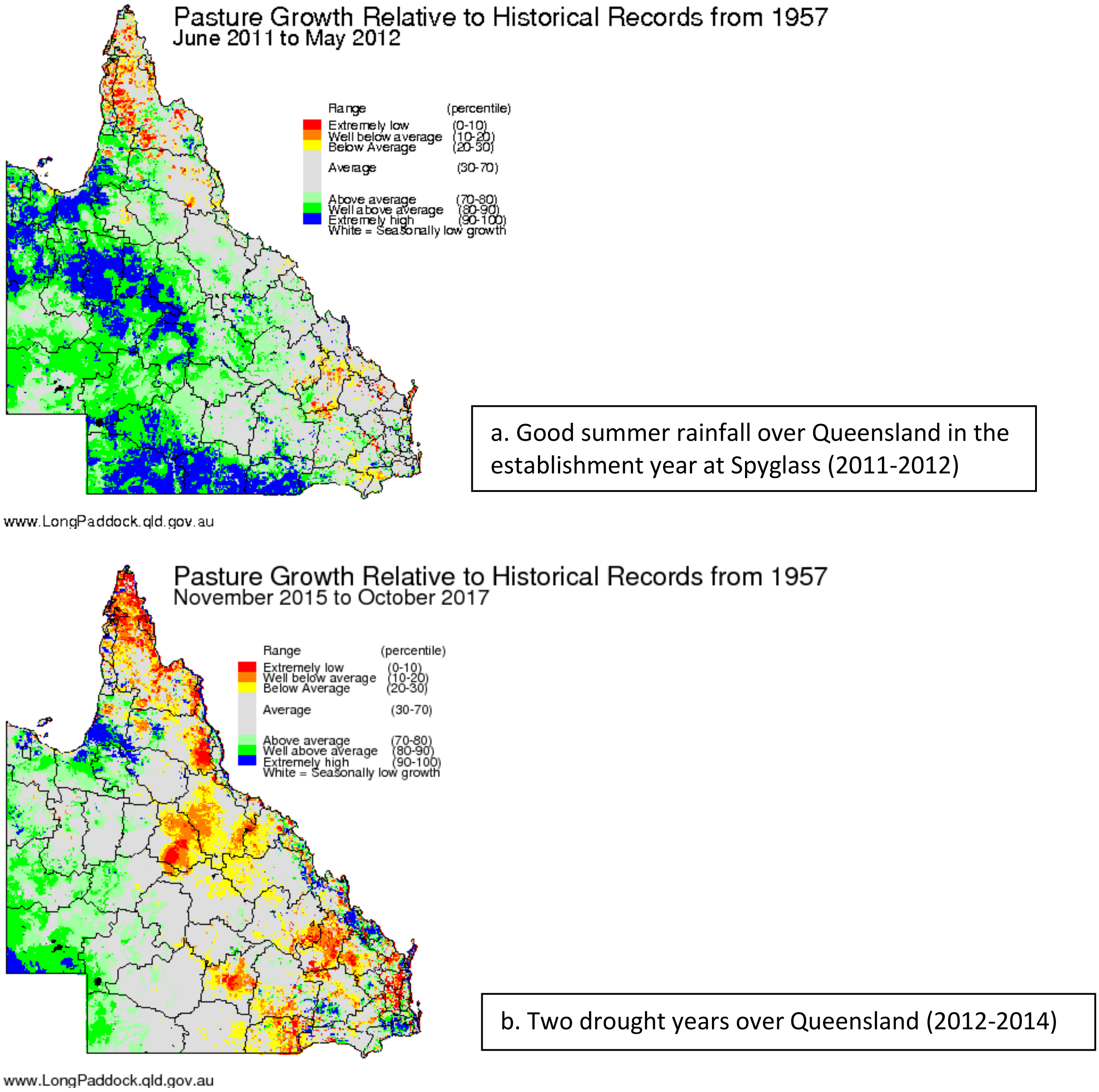


Figure 22. Pasture growth related to seasonal rainfall for the establishment year at Spyglass 2011-2012 and the average of the following two drought years 2012-2014 across Queensland.

The average to good growth conditions for establishing the Spyglass experiment in the establishment year, over the first summer (2011-2012), was sufficient to develop a dense high-yielding grass-based pasture. However, the pasture did not survive well during the following two drought years (2012-2014). This extended drought caused a decline in production from the well-established pastures at the Injune and Banana sites, but to a lesser extent than occurred at Spyglass.

Long-term climatic conditions

Mean annual climatic statistics from the three experimental site regions (nearest main towns; BOM data) shows similar rainfall, however, temperatures, both mean maximum and mean minimum, are higher in the Burdekin than at the Fitzroy sites (Table 5.) which may make pasture establishment more difficult. Detailed mean monthly climatic data from the three experimental sites is shown in Appendix 1.

Table 5. Long-term annual climate statistics for the three experiment regions.

Statistics	Charters Towers	Injune	Banana
Rainfall mean (mm)	659	638	684
Median rainfall (mm)	645	631	685
Rain days (no.)	47	53	55
Clear days (no.)	156	144	
Cloud days (no.)	66	68	
Max Temp (°C)	30.2	27.5	28.4
Min Temp (°C)	17.1	11.8	12.9
Sunshine (hrs)			8.2
Temperature 9am (°C)	23.2	19.9	21.4
Relative Humidity 9am (%)	65	61	64
Wind speed (km h^{-1})	7	8.7	8.8

Rainfall at field experiment sites

Daily rainfall was recorded at the Spyglass experiment site over the project period (2011-2014). The long-term (LT) rainfall data from the Bureau of Meteorology (BOM) recording stations within four kilometres (km) of the Spyglass (New Moon station), Injune (Mt. Kingsley) and Banana (Banana township) field experiment sites were used.

Site 1: Rainfall at Spyglass

The monthly rainfall at Spyglass shows the good distribution and above-average rainfall in the first year of the project period, (2011-2012), the pasture establishment year, and the following two poor rainfall years of 2012-14, known as the pasture growth years. Months of above and below average rainfall are shown in Figure 23.

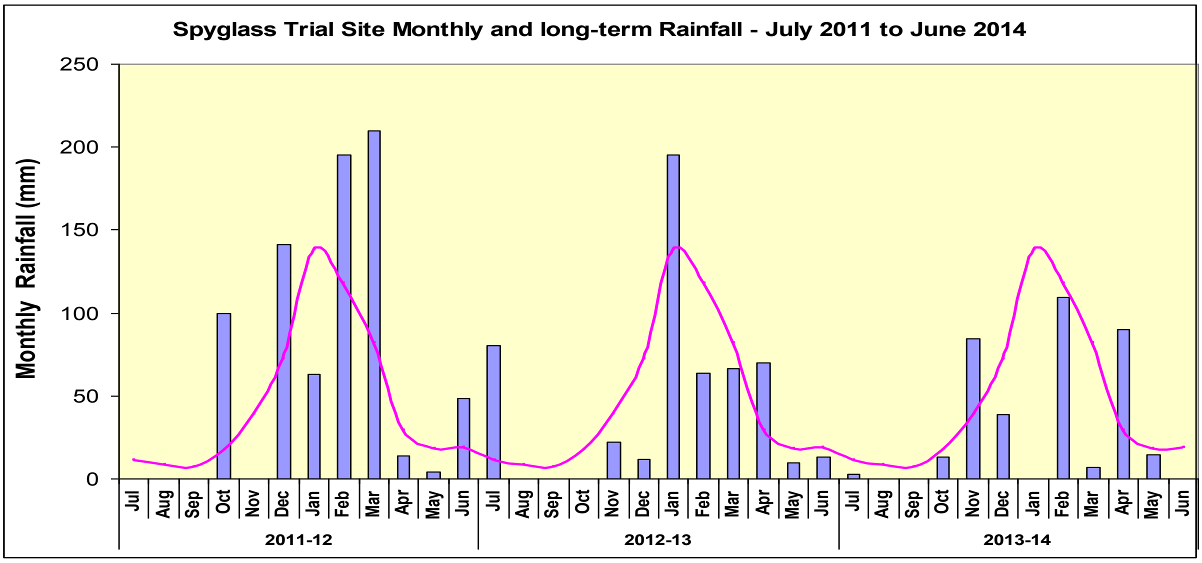


Figure 23. Monthly rainfall and long-term mean at the Spyglass experiment site (2011-2014).

The high rainfall in February 2012 was from a cyclone and low pressure system influences. There was an extended dry season through spring and into summer of the second year (2012-2013). The drought continued through 2013-2014 with no consistent periods of average to above average rainfall. The first summer of the project (2011-2012) produced a good initial pasture establishment, pasture growth, and soil surface cover. However, in the subsequent dry seasons and drought years, survival of the pasture plants, especially the grasses, was affected and there was negligible establishment of a new pasture in the second or third years. Most of the first year grasses died and became litter, while there was good survival of grasses in the more favourable locations and of the deep-rooted perennial sown legumes. Results of the pasture production are detailed in a later section.

The annual rainfall from Spyglass in both the year preceding establishment (1176 mm in 2010-2011), and the establishment year (707 mm in 2011-2012) was above average when compared with the Spyglass mean (501 mm in 2011-2014) and the long-term (LT) mean of 605 mm at New Moon Station, south of Spyglass (Table 6).

Table 6. Monthly (July 2010-June 2014) and long-term (LT) rainfall (mm) near the Spyglass experiment site and long-term mean (New Moon station).

Hillgrove	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual
2010-11	3	86	0	30	147	412	139	169	136	31	1	21	1,176
2011-12	3	36	0	28	6	86	207	113	163	10	41	15	707
2012-13	112	0	5	0	23	12	140	35	28	64	16	0	434
2013-14	3	0	0	13	85	39	0	110	7	90	15	0	362
Trial mean 2011-14	39	12	2	14	39	46	116	86	66	55	24	5	501
LT mean	14	9	8	14	62	84	140	121	81	35	22	12	605

The low rainfall summer of 2012-13 with 238 mm from October to March reflects the drought conditions experienced. The drought continued through 2013-14 producing storm rains in November (85 mm) and February (110 mm), with hot dry periods in the months between and following.

Both summer growing seasons (2012-2014) were poor for establishing new pasture seedlings. The poor rainfall, associated with high temperatures, affected the pastures' survival and new growth in all rehabilitation treatments throughout the two-year drought, which continued through to the end of the recording period (June 2014). The 112 mm of out-of-season rainfall in July 2012 did not assist first year plant survival, as there were frosts, no follow-up rainfall, and an unusually hot and dry spring and early summer period followed.

Site 2: Rainfall at Injune

At Injune, rainfall was well-above average in the 2010-2011 year (1068 mm); however, it was below to well-below the average (605 mm) in the three years of measuring pastures during the project period (2011-2014) (Table 7).

Table 7. Monthly rainfall (mm) near the Injune experiment site and long-term mean (Mt Kingsley).

Injune	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual
2010-11	20	0	0	28	143	567	103	76	0	86	36	9	1,068
2011-12	9	26	21	85	82	94	107	45	30	32	52	0	583
2012-13	0	0	24	44	13	26	81	22	57	0	14	0	281
2013-14	4	4	0	39	76	20	15	36	127	39	7	0	367
Trial mean 2011-14	4	10	15	56	57	47	68	34	71	24	24	0	410
LT mean	26	28	25	50	74	94	93	74	44	40	35	27	575

There was a drought in the second year of the project (2012-2013) with only 243 mm of summer rain (from October to March) compared with a long-term average of 429 mm over the six month period. Good autumn rainfall of 127 mm in March 2014, followed by resting the pasture, produced good growth by May when the pasture was recorded.

Site 3: Rainfall at Banana

At Banana, the rainfall was well-above average in the 2010-11 year (942 mm), and it was near average (665 mm) in the three years of measuring pastures during the project (Table 8).

Table 8. Monthly rainfall (mm) near the Banana experiment site and long-term (LT) mean (Banana town).

Banana	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual
2010-11	0	89	0	71	89	298	74	76	145	43	49	9	943
2011-12	9	51	0	28	0	143	142	102	105	0	18	73	671
2012-13	6	32	15	0	66	12	228	81	157	17	42	0	656
2013-14	0	0	0	16	198	39	37	0	116	20	7	10	443
Trial mean 2011-14	5	28	5	15	88	65	136	61	126	12	22	28	590
LT mean	30	23	29	54	68	93	96	96	70	34	36	38	665

The Banana site did not experience the drought that occurred in the latter two years of the project at the other two experiment sites.

Rainfall distribution

Rainfall distribution has a strong impact on pasture establishment and production. Data from the remote weather station at Spyglass shows the short duration and poor rainfall season with few main rainfall events over the 2012-2013 summer (Figure 24).

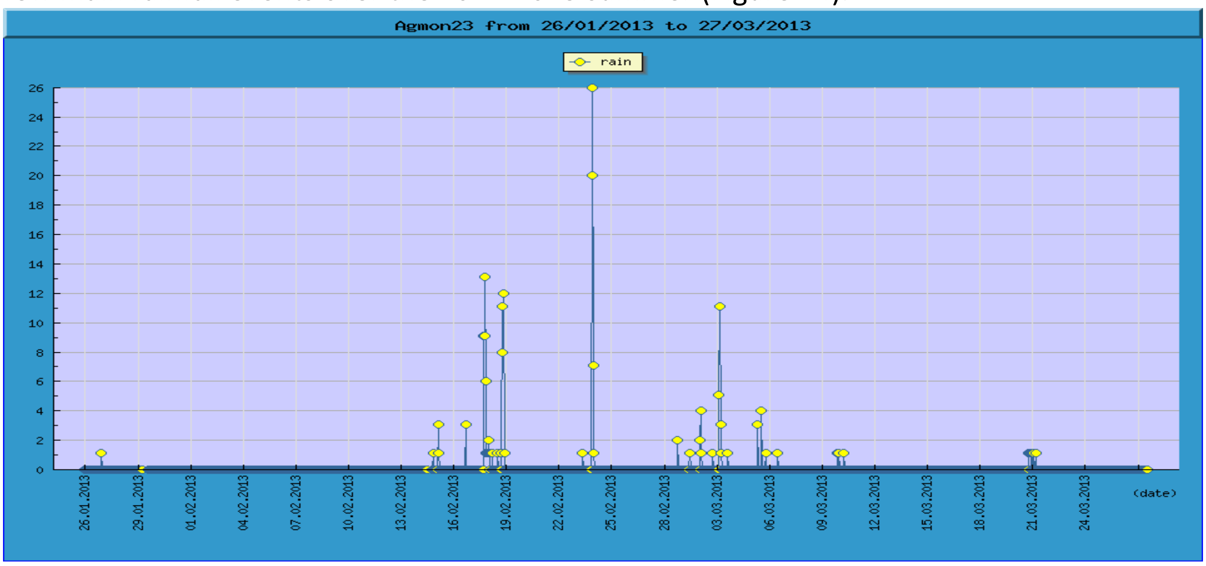


Figure 24. Rainfall chart over the 2012-2013 wet season at Spyglass experiment site from the automatic 'satellite' weather station.

Distribution was similarly poor at the Injune site and less so at Banana although there was a three month period over the 2013-2014 summer when only 76 mm of rain fell.

Daily temperature

The daily temperature range from March to June 2013 at Spyglass (Figure 25) shows the extended periods of high daily temperatures during the dry autumn (>30^{0}C) and periods of cold (<5^{0}C) and dry conditions during winter at the Spyglass experiment site. Frosts can occur at this site some years.

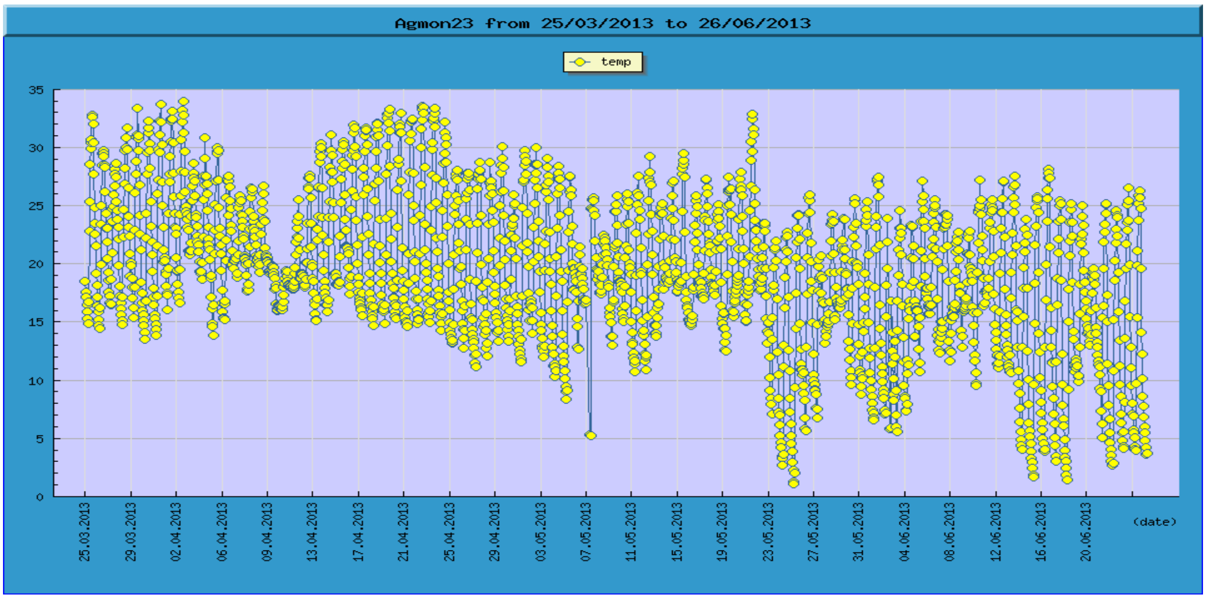


Figure 25. Daily temperature range from March-June 2013 at the Spyglass experiment site.

There were a series of frosts which killed tops of pasture plants across the experiment site in the winter of 2012. Most of these plants subsequently died during the following dry and hot spring and early summer of 2012-2013.

Soil types

Three soil types were identified in the rehabilitation treatments at Spyglass as a sodic brown dermosol, a grey sodosol, and a black vertosol. There were three variations of soil types in the rehabilitation and un-rehabilitated paddocks at Injune, red and brown dermosols, and one soil type at Banana, a brown vertosol. Representative profiles of the seven soils were
and are briefly described in

Table 9. (Detailed descriptions and analyses are reported in Appendix 3).

Table 9. Soil types and brief description of soil profiles at Spyglass (4, 5, 6), Injune (61, 62, 63) and Banana (64) field experiment sites

Profile no.	Soil type	PPF
4	**Brown dermosol (sodic)**	Uf6.41
	Sodic, eutrophic, brown clay, Dermosol, non-gravelly, clayey	
5	**Grey sodosol – yellow duplex**	Dy3.13
	Eutrophic, subnatric, grey, Sodosol, medium, non-gravelly, clay loamy, clayey, very deep	
6	**Black vertisol – cracking grey clay**	Ug5.15
	Crusty, black, Vertosol, non-gravelly, medium fine, very deep	
61	**Red dermosol**	Gn3.13
good rehabilitation	surface: red brown fine sandy clay loam	
63	**Red dermosol**	Gn3.12
control bare	surface: dark brown silty clay loam	
62	**Brown dermosol**	Gn3.22
pasture near control	surface: dark brown sandy clay loam	
64	**Brown vertosol**	Ug5.34
	surface: dark brown medium clay	

The chemical analysis of the subsoil of the three soils indicates sufficiently high levels of salinity (Chloride 1900 mg/kg at 50 cm depth) and sodicity (ESP >21% at 20 cm depth) to detrimentally affect pasture root development. These levels were found at different depths: on the surface of the dermosol, at 30 cm in the sodosol and below 40 cm in the vertosol. The three soils have high alkalinity down the profile from the surface (dermosol and vertosol), or near the surface (sodosol), which will reduce nutrient availability for pastures. A detailed profile description and chemical analysis of the three soil types are shown in Appendix 3.

Pasture production

Dry matter yield (DMY)

The above-average rainfall year of 2011-2012 with two periods of 100 mm produced good pasture establishment, growth and cover in all disturbed treatments in year one at Spyglass. However, the pasture responses were less in the lower rainfall, continuing drought, of the second and third years (2012-2014). The dry matter yields (DMY) of the treatments at the Injune site were also higher in 2012 than in the subsequent years of 2012-2014, while at the Banana site there was no difference between years (2011-2014) (Figure 26a).

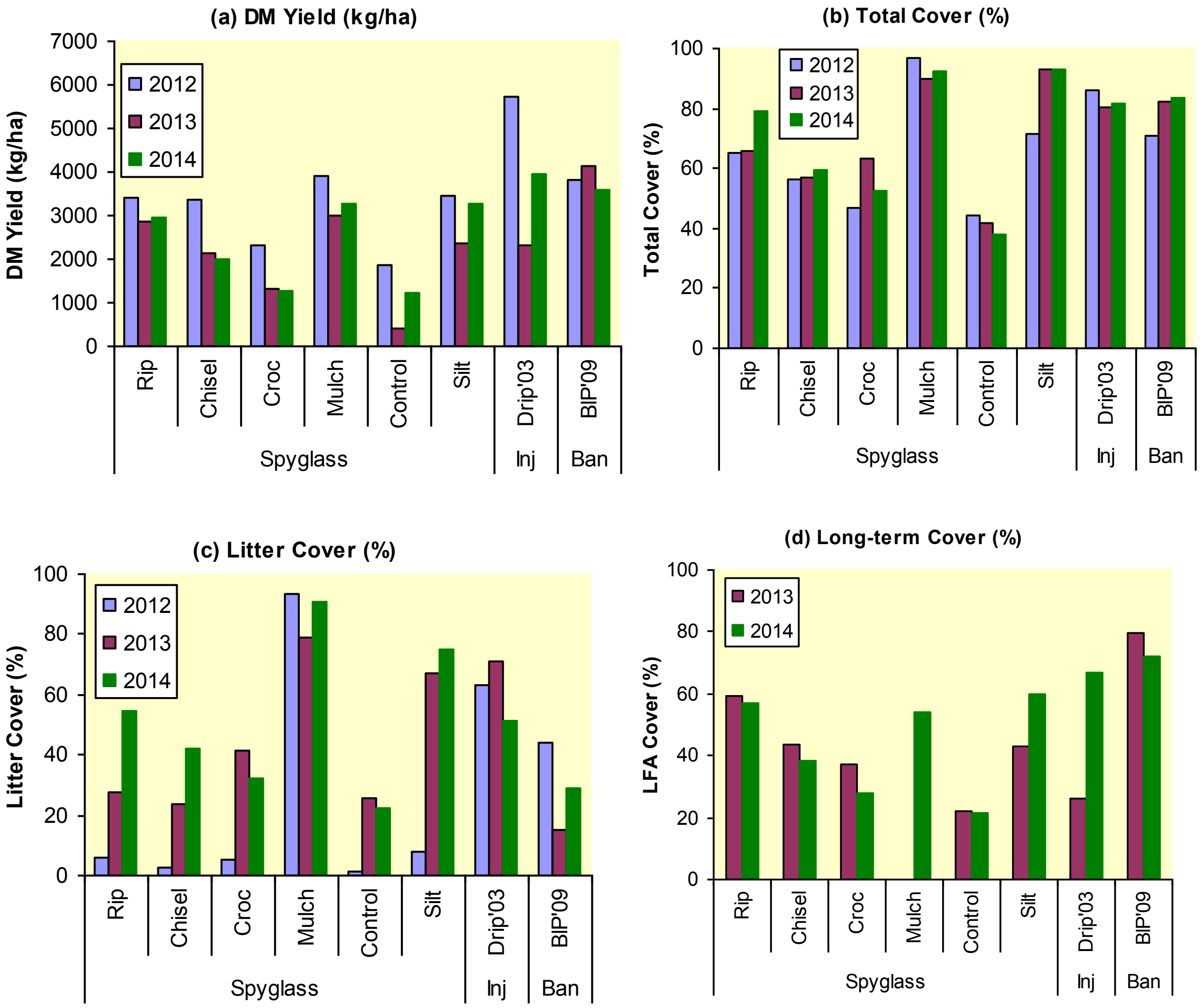


Figure 26. (a) Pasture dry matter yield (kg ha^{-1}), (b) total cover (%), (c) litter cover (%) and (d) LFA long-term cover (%) at three sites in 2012, 2013 and 2014.

Pasture dry matter yield. The production changes after summer between the first two years were greatest in the crocodile plough seeding (-43%) and control-bare (-77%) treatments at Spyglass, and in the deep rip treatment at Injune (-59%) (Figure 26(a)). Both of these sites experienced a drought over the 2012-2013 year. There were extensive grass plant deaths across all treatments at Spyglass between these two April recordings.

Total cover. Mean total ground cover in treatments at Spyglass was similar in 2012 (62%) and 2013 (64%) (Figure 26(b)), however, in the latter year cover included litter and dead plants from the drought over summer. Ground cover was higher at both Fitzroy sites in both years, between 71-86%.

Litter cover. Pasture litter cover in the six treatments at Spyglass in 2012 and 2013 show the insignificant litter at the end of the first summer (average 4% excluding the hay mulch treatment) and a significant increase in the second year (average 30%). This occurred after the extended dry season with a late start to poor summer rainfall in late January 2013 (Figure 26c). A high death rate in first-year grass plants contributed to the litter cover. The long-term cover, as defined by the LFA method, was less variable than either the total cover or litter cover at

Spyglass (Figure 26d). The greatest difference in long-term cover between 2013 and 2014 was at the Injune site.

Change in pasture production (Spyglass only)

Changes in total pasture yields in the ripping and chisel ploughing treatments at Spyglass (2012-2014) were moderated by the increasing yield from the sown perennial legumes, mainly Milgarra butterfly pea, Seca stylo and Progardes desmanthus. The increase in the legume pasture production compensated for the declining contribution by deaths of the perennial sown grasses. These relative changes (% of total DMY) in the perennial native and exotic sown grasses, and in the native and sown legumes in both the ripping and chisel ploughing treatments at Spyglass are shown in Figure 27 (a, b, c, and d).

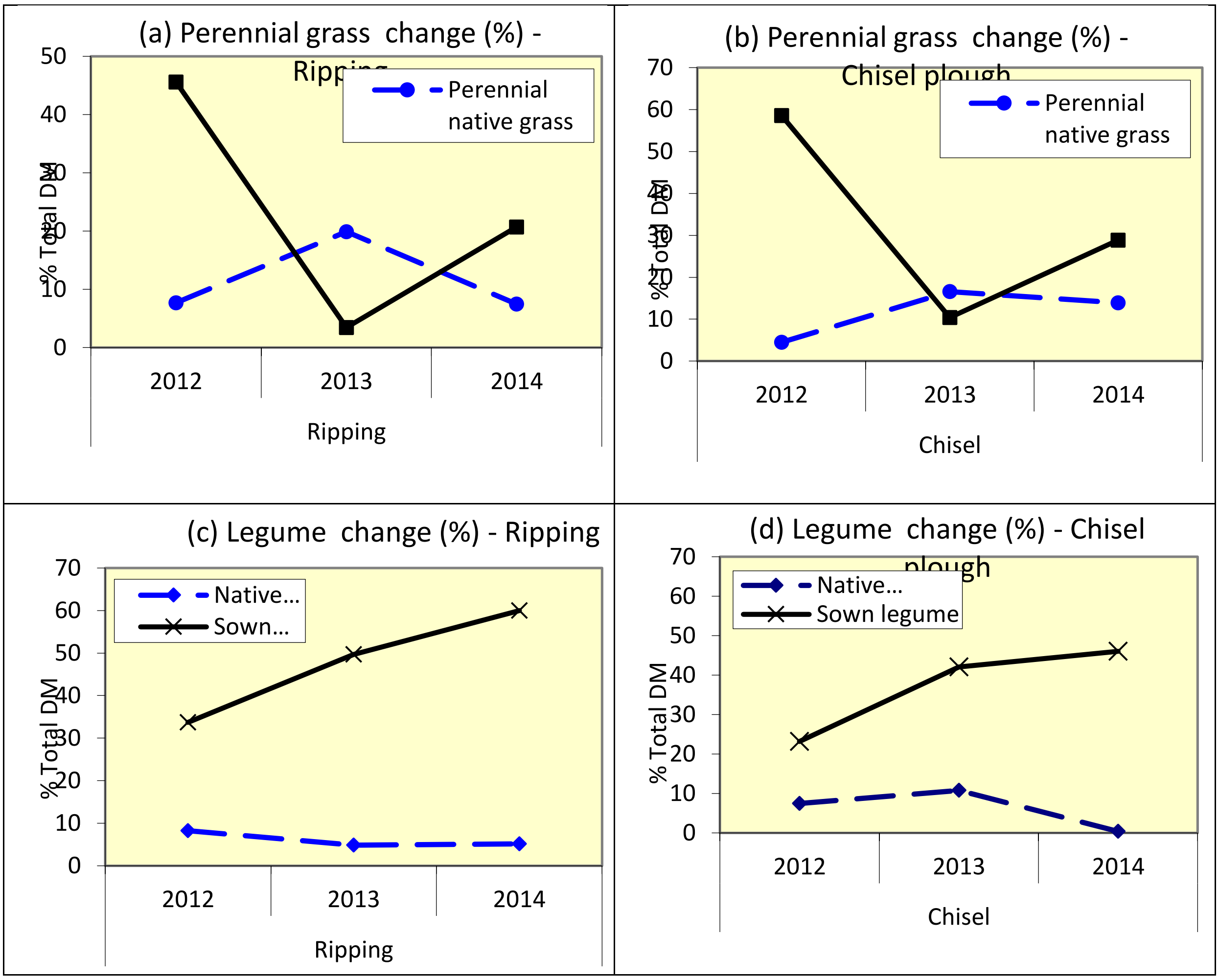


Figure 27 (a, b, c, d). Change (% total DMY) in perennial native and exotic sown grasses and native and sown legumes in the deep ripping and chisel ploughing treatments between 2012 and 2014 at Spyglass.

The distribution of the pasture became more-patchy as the years progressed. The perennial legumes increased in population and size in the more favourable moisture areas within the treatments, such as in hollows and micro-depressions, and grasses continued dying off in the micro-elevated, drier patches.

Pasture basal area (Spyglass only) and surface roughness

Pasture basal area at Spyglass remained low, less than 3.2% in all treatments for the three years (2012-2014) and remained at similar levels. Basal area, in association with composition, is a good indicator of the condition of a pasture and relates to its capacity to regrow when moisture and temperatures are suitable. There was a decline in basal area between 2012 and 2013 in the crocodile plough seeder treatment by 44% to 0.9% and in the control 'bare' treatment by 70% to 0.3% (Figure 28(a)). There was a small increase in the basal area in the mulch treatment due to an increase in size of surviving tussock grasses, particularly the buffel grass tussocks.

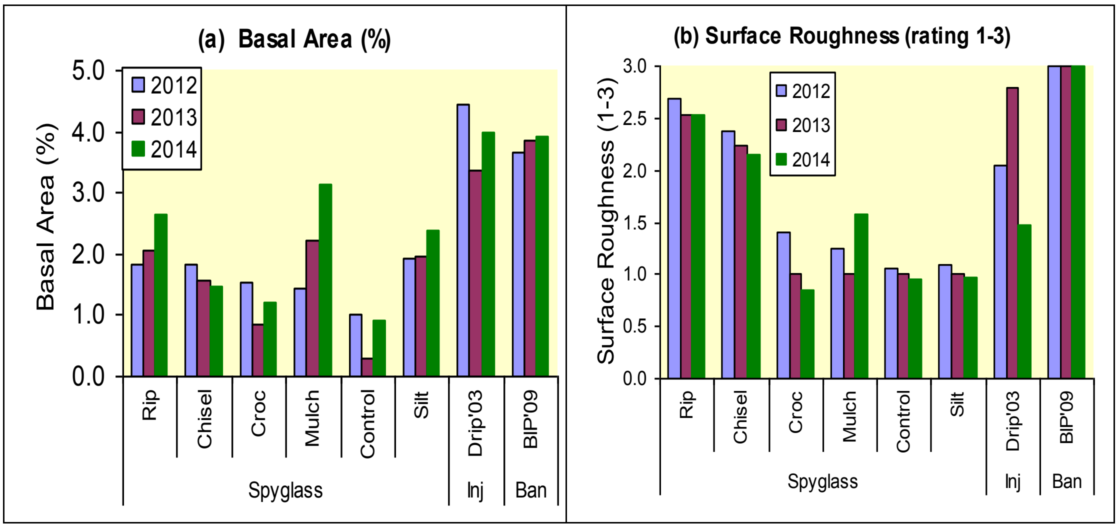


Figure 28. (a) Pasture basal area (%) and (b) surface roughness rating (1-3 scale) at three sites between 2012 and 2014.

Soil surfaced roughness ratings (Figure 28(b)) show the higher disturbance levels from the initial treatments remaining through the three year monitoring period (2012-2014). Surface roughness is related to the time water is held on the surface allowing infiltration after rainfall events. The final two poor rainfall years would have contributed to the surfaces retaining a similar degree of roughness. The Spyglass crocodile plough seeder treatment started with a low degree of surface roughness and became less-rough over the three years, with little water retention capacity. The Banana blade ploughed site retained the roughest surface every year (rating 3).

Botanical composition

The pasture botanical composition recording in autumn of 2012, 2013 and 2014 identified a declining number of species at Spyglass (from 44 to 33), and at Injune (from 11 to 8), over this period as the good first growing season deteriorated into two drought years (Table 10).

Table 10. Number of species recorded at three rehabilitation sites in autumn of 2012, 2013 and 2014.

Year	Spyglass	Injune	Banana	Total species
2012	44	11	16	52
2013	40	8	14	50
2014	34	8	17	44

There was a similar number of species recorded (16-17), at Banana over the three years. The total number of different species recorded at all sites over the three years declined from 52 to 44.

There were 26 species present in all three years of recording (in autumns of 2012-2014) (Table 11). These included native perennial and annual grasses, sown exotic grasses, native and sown exotic legumes, and native forbs.

Table 11. Pasture species recorded in rehabilitation treatments at three sites (Burdekin and Fitzroy) in 2012, 2013 and 2014.

Genus	species	Common name
Bothriochloa	*bladhii*	forest bluegrass
Bothriochloa	*pertusa*	Indian couch
Brachyachne	*convergens*	native couch
Cenchrus	*ciliaris*	buffel cv. Gayndah
Chloris	*gayana*	Rhodes grass
Chrysopogon	*fallax*	golden bead grass
Clitoria	*ternatea*	Butterfly pea cv. Milgarra
Dactyloctenium	*radulans*	button grass
Desmanthus	*early flowering*	Marc type - green
Desmanthus	*late flowering*	Uman type – red cv. Progardes
Desmodium	spp.	Desmodium
Digitaria	*ciliaris*	summer grass
Echinochloa	spp.	barn yard grass
Indigofera	spp.	Indigofera
Iseilema	spp.	Flinders grass
Neptunia	spp.	sensitive weed
Portulaca	*oleracea*	pigweed
Rhynchosia	*minima*	rhyncosia
Sida	*Malvaceae*	sida - flannel weeds
Sporobolus	*actinocladus*	Katoora
Sporobolus	*caroli*	fairy grass
Stylosanthes	*hamata*	cvv. Amiga/Verano
Stylosanthes	*scabra*	Seca stylo
Stylosanthes	*seabrana*	Caatinga stylo
Unidentified	forb	Unid. forbs
Urochloa	*mosambicensis*	Sabi grass

The botanical composition recorded at Spyglass in 2012 (good rainfall) and 2013 (poor rainfall) identified 36 species common to both years, 11 species only in 2012 and 5 only in 2013 (Table 12). There were between 30 and 382 quadrats of 0.25 m^2 recorded along a grid across the treatments at the sites each year. There was a mix of the sown exotic species and some natives in the treatments. Not all sown species were recorded in the quadrats, for example Floren bluegrass, which is known to favour heavy textured soil types such as the black vertosol. There was negligible sown species present on the sodic dermosol soiltype irrespective of disturbance technique. The native species *Portulaca* and *Sporobolus* were the only common species on this difficult soil.

Table 12. Pasture species recorded in rehabilitation treatments at Spyglass (Burdekin) in 2012 and 2013.

Present	Genus	species	Common name
2012-13	*Bothriochloa*	*bladhii*	forest bluegrass
36 species	*Bothriochloa*	*ewartiana*	desert bluegrass
	Chloris	*divaricata*	windmill grass
	Chrysopogon	*fallax*	goldenbeard grass
	Eriochloa	spp.	summer grass
	Panicum	spp.	Panicum
	Unidentified	native grass	Unid. native per grasses
	Bothriochloa	*pertusa*	Indian couch
	Cenchrus	*ciliaris*	buffel cv. Gayndah
	Chloris	*gayana*	Rhodes grass
	Urochloa	*mosambicensis*	Sabi grass
	Unidentified	exotic grass	Unid. exotic per grasses
	Desmodium	spp.	Desmodium
	Glycine	spp.	glycine
	Indigofera	spp.	Indigofera
	Neptunia	spp.	sensitive weed
	Rhynchosia	*minima*	rhyncosia
	Sesbania	spp.	horse bean
	Clitoria	ternatea	Butterfly pea (cv. Milgarra)
	Desmanthus	early flowering	Marc type - green
	Desmanthus	late flowering	Uman type – red (cv. Progardes)
	Macroptilium	*bracteatum*	burgundy bean
	Stylosanthes	*hamata*	cvv. Amiga/Verano
	Stylosanthes	*scabra*	Seca stylo
	Stylosanthes	*seabrana*	Caatinga stylo
	Brachyachne	*convergens*	native couch
	Dactyloctenium	*radulans*	button grass
	Digitaria	*ciliaris*	summer grass
	Iseilema	spp.	Flinders grass
	Sporobolus	*actinocladus*	Katoora
	Sporobolus	*caroli*	fairy grass
	Echinochloa	spp.	barn yard grass
	Portulaca	*oleracea*	pigweed
	Sida	Malvaceae	sida - flannel weeds
	Unidentified	forb	Unid. forbs
	Fimbristylis	spp.	sedge
2012 only	*Aristida*	*calycina*	branched wire grass
11 species	*Aristida*	unidentified	Unid. Aristida spp.
	Bothriochloa	*decipiens*	pitted bluegrass
	Cymbopogon	spp.	barb wire grass
	Dichanthium	*sericeum*	Qld bluegrass
	Eragrostis	spp.	love grass
	Heteropogon	*contortus*	black spear grass

Present	Genus	species	Common name
	Tripogon	*loliiformis*	5-minute grass
	Unidentified	native legume	Unid. native legumes
	Macroptilium	atropurpureum	siratro
	Unidentified	annual grass	Unid. annual grasses
2013 only	*Aristida*	*pruinosa*	gulf wiregrass
5 species	*Astrebla*	*lappacea*	curly Mitchell
	Eulalia	*aurea*	silky browntop
	Melinis	*repens*	red Natal grass
	Cyperus	spp.	nut grass

There were 16 pasture species recorded at the two Fitzroy sites in both 2012 and 2013, with an additional 7 species present in the higher rainfall first year. An additional native legume occurred only in 2013 (Table 13). There was a mix of the treatment sown species, native grass species and naturalised exotic grass species present at the sites.

Table 13. Pasture species recorded in rehabilitation treatments at Injune and Banana (Fitzroy) in 2012 and 2013.

Present	Genus	species	Common name	Site
2012-13	*Bothriochloa*	*bladhii*	forest bluegrass	B
16 species	*Bothriochloa*	*insculpta*	creeping blue grass	I
	Bothriochloa	*pertusa*	Indian couch	B
	Cenchrus	*ciliaris*	buffel cv. Gayndah	I, B
	Cenchrus	*ciliaris*	buffel cv. Biloela	I, B
	Chloris	spp.	windmill grass	B
	Clitoria	*ternatea*	butterfly pea (cv. Milgarra)	I, B
	Dichanthium	*sericeum*	Qld bluegrass	I, B
	Heteropogon	*contortus*	black spear grass	B
	Macroptilium	*atropurpureum*	siratro	I, B
	Melinis	*repens*	red Natal	B
	Panicum	*maximum*	green panic	B
	Sida	Malvaceae	sida flannel weeds	I, B
	Sorghum	hybrid	Silk sorghum	I, B
	Unidentified	forb	Unid. forbs	I, B
	Urochloa	*mosambicensis*	Sabi grass	B
2012 only	*Chloris*	*gayana*	Rhodes grass	I
7 species	*Panicum*	*coloratum*	Bambatsi panic	B
	Rhynchosia	*minima*	Rhyncosia	B
	Sclerolaena	spp.	burrs	B
	Stylosanthes	*hamata*	Caribbean Amiga/Verano	I, B
	Stylosanthes	*scabra*	Seca shrubby stylo	I
	Stylosanthes	*seabrana*	Caatinga (Primar/Unica)	B
2013 only	Unidentified	native legume	Unid. native legumes	B

The pasture species recorded at each site and year were divided in to seven functional groups. The dry matter yields of pastures within these groups at Spyglass (Table 14) indicates a significant decline in the sown (exotic) perennial grasses between 2012 and 2013, with a small increase following good autumn rainfall in 2014.

Table 14. Pasture species functional groups dry matter yields (kg ha-1) at Spyglass in 2012, 2013 and 2014.

Species groups	Deep Ripping			Chisel Ploughing			Crocodile plough seeder			Hay Mulch			Control			Silt (run-on hollow)		
	2012	**2013**	**2014**	**2012**	**2013**	**2014**	**2012**	**2013**	**2014**	**2012**	**2013**	**2014**	**2012**	**2013**	**2014**	**2012**	**2013**	**2014**
Perennial native grass	264	570	222	150	355	280	296	222	289	184	4	30	9	155	19	422	491	165
Perennial sown grass	1559	99	614	1963	222	579	1762	36	658	2853	1224	2333	1406	12	425	2559	113	711
Native legume	281	138	151	249	230	7	42	128	45	0	460	0	47	8	0	106	173	92
Sown legume	1151	1421	1778	776	899	923	126	599	177	298	661	312	148	133	96	291	1067	2094
Annual grass	97	597	54	187	360	109	60	305	50	459	545	61	213	94	46	48	444	2
Forbs	63	12	146	26	65	108	17	8	71	112	124	53	25	7	37	12	0	193
Sedges	3	23	0	0	8	0	1	8	0	0	0	0	0	11	0	0	69	0
Total	**3420**	**2860**	**2965**	**3352**	**2139**	**2007**	**2304**	**1306**	**1289**	**3907**	**3017**	**2774**	**1848**	**420**	**622**	**3437**	**2357**	**3256**

Native perennial and annual grasses were consistently low yielding in all treatments over this period. Sown legumes increased in yield, especially in the ripping and silt treatments, predominantly from Butterfly pea and Seca stylo, and the native legumes remained consistently low yielding (to 460 kg ha^{-1}). Forbs and sedges remained insignificant (<200 kg ha^{-1}). Regeneration in the control was patchy with bare areas remaining and patches of grass establishing. Most grass was buffel grass establishing in silt washed down from the hay mulch treatment

In the establishment year (2011-2012) at Spyglass there was no consistency between the proportions of total species functional group dry matter yields, expressed as a percent of total treatment DM yield (Figure 29).

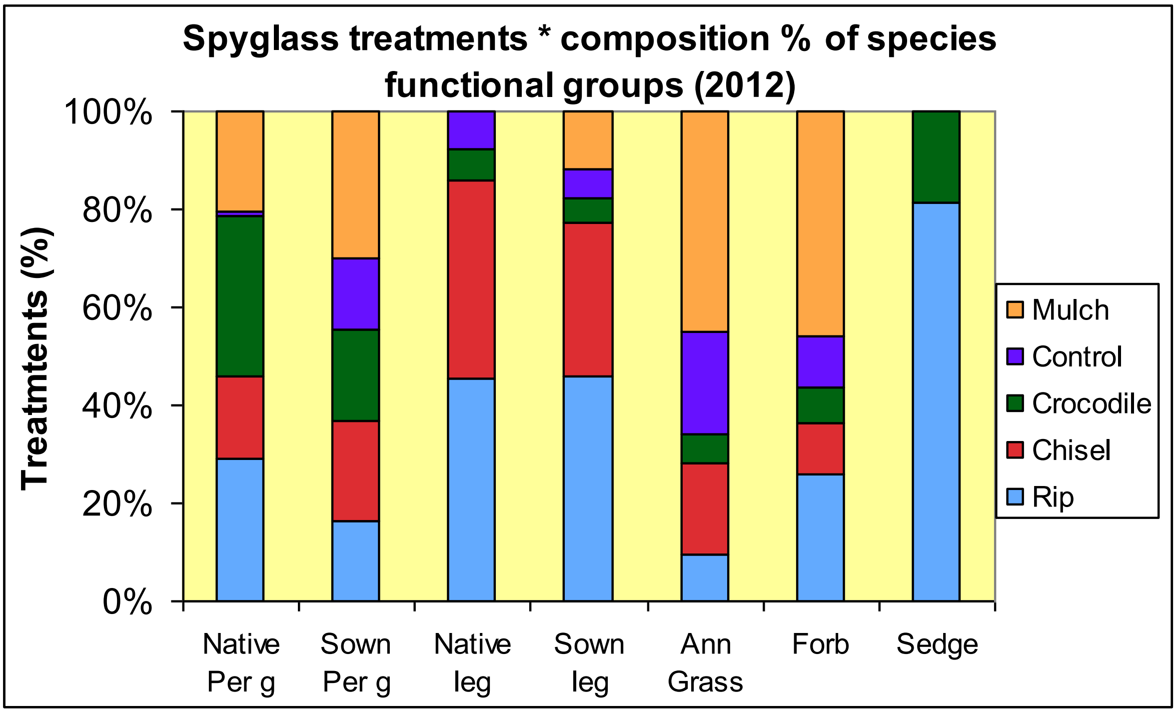


Figure 29. Proportion of species functional group (% of total DMY) in treatments at Spyglass in the establishment year (2012).

The ripping and chisel ploughing treatments had the highest proportion of native and sown legumes; sedges only occurred in the ripping and crocodile treatments; the mulch treatment had the highest proportion of annual grasses and forbs; and the sown perennial grasses occurred in similar proportions in all treatments, although was highest in the mulch.

Although the species composition on the three soil types at Spyglass were not differentiated in the field, it was obvious the only common species on the sodic dermosol soil type were pigweed (*Portulaca* spp.) and acid or fairy grass (*Sporobolus* spp.). However, after deep ripping and chisel ploughing across this soil type, there were patches of buffel grass and Sabi grass establishing in silty patches in the bottom of hollows by autumn 2014.

At the two Fitzroy sites sown perennial grasses dominated the pasture, 79-97%, at both sites with over 2200 kg ha^{-1} in all years (

Table 15).

Table 15. Pasture functional groups dry matter yields (kg ha^{-1}) at two Fitzroy sites in 2012, 2013 and 2014.

Species groups	Deep rip 03			Blade plough 09		
	2012	**2013**	**2014**	**2012**	**2013**	**2014**
Perennial native grass	44	0	0	101	581	307
Perennial sown grass	4885	2243	3661	3273	3355	2826
Native legume	0	0	0	3	1	32
Sown legume	299	31	202	157	188	375
Annual grass	474	0	0	208	0	0
Forbs	14	45	86	87	11	42
Sedges	0	0	0	0	0	0
Total	**5716**	**2319**	**3949**	**3829**	**4136**	**3582**

There was an increase in native perennial grasses at the blade ploughed site, while at the deep ripped site annual grasses and sown legumes declined between 2012 and 2013, but improved with the late rain in 2014. Forbs were negligible and there were no sedges at either site. The deep ripped site had not been grazed since early summer, before the rain that grew the pasture in late summer and autumn.

Pasture species numbers

There was a more diverse species population at Spyglass than at the two Fitzroy sites. Species number was lowest at the deep ripped Injune site and highest in the deep ripped Spyglass treatment. The number of species in the disturbed treatments at Spyglass declined over the three years between 2012 and 2014 (Figure 30(a)).

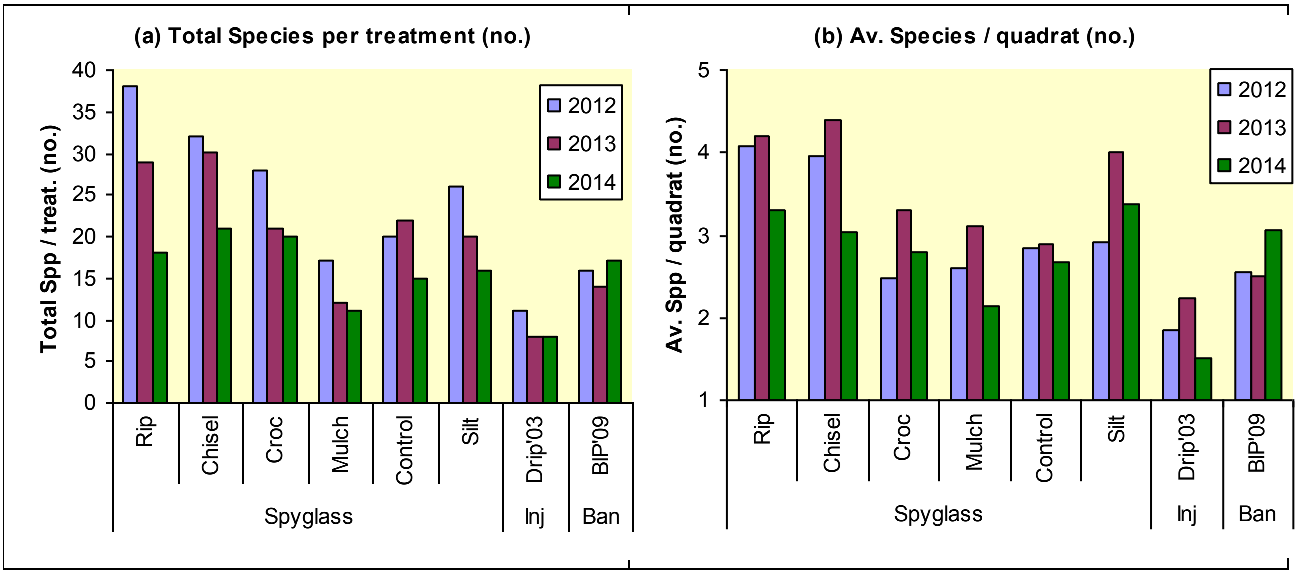


Figure 30. Total number of species per treatment and average species per quadrat in disturbance treatments at three sites between 2012 and 2014.

This species diversity is reflected in the average number of species per quadrat recorded in the treatments, with the deep ripping and chisel ploughing at Spyglass having consistently high (>3) species recorded per quadrat (Figure 30(b)). The nine year established Injune treatment had the least number of species per quadrat.

Pasture nutrient concentrations

Between treatments at Spyglass in winter of 2012, there was a marginally higher nitrogen concentration in the whole plant tops of the pasture samples in the ripping treatment (0.60%) than in other treatments (0.40%) (Figure 31).

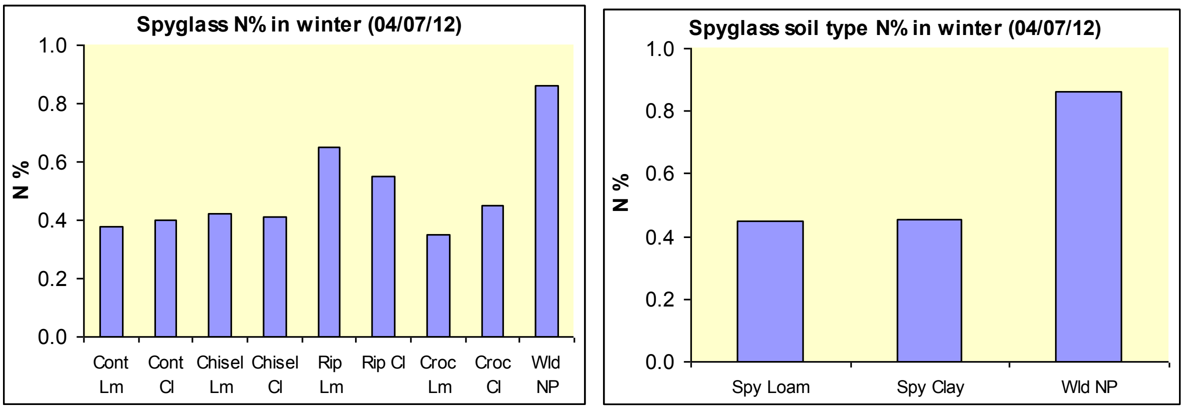


Figure 31. Treatment and soil type pasture nitrogen (%) in winter 2012 at Spyglass.

However, all treatments had lower concentrations than the native pasture in the un-eroded woodland (0.86%), some 100 m from the rehabilitation treatments. There was no difference between the clay and loam surfaced soils in pasture nitrogen concentration in winter (average 0.45%).

Whole plant tops of pasture samples from winter (July) 2012 were analysed for minerals and nutrients from the three experiment sites, including two soil types from Spyglass (Figure 32).

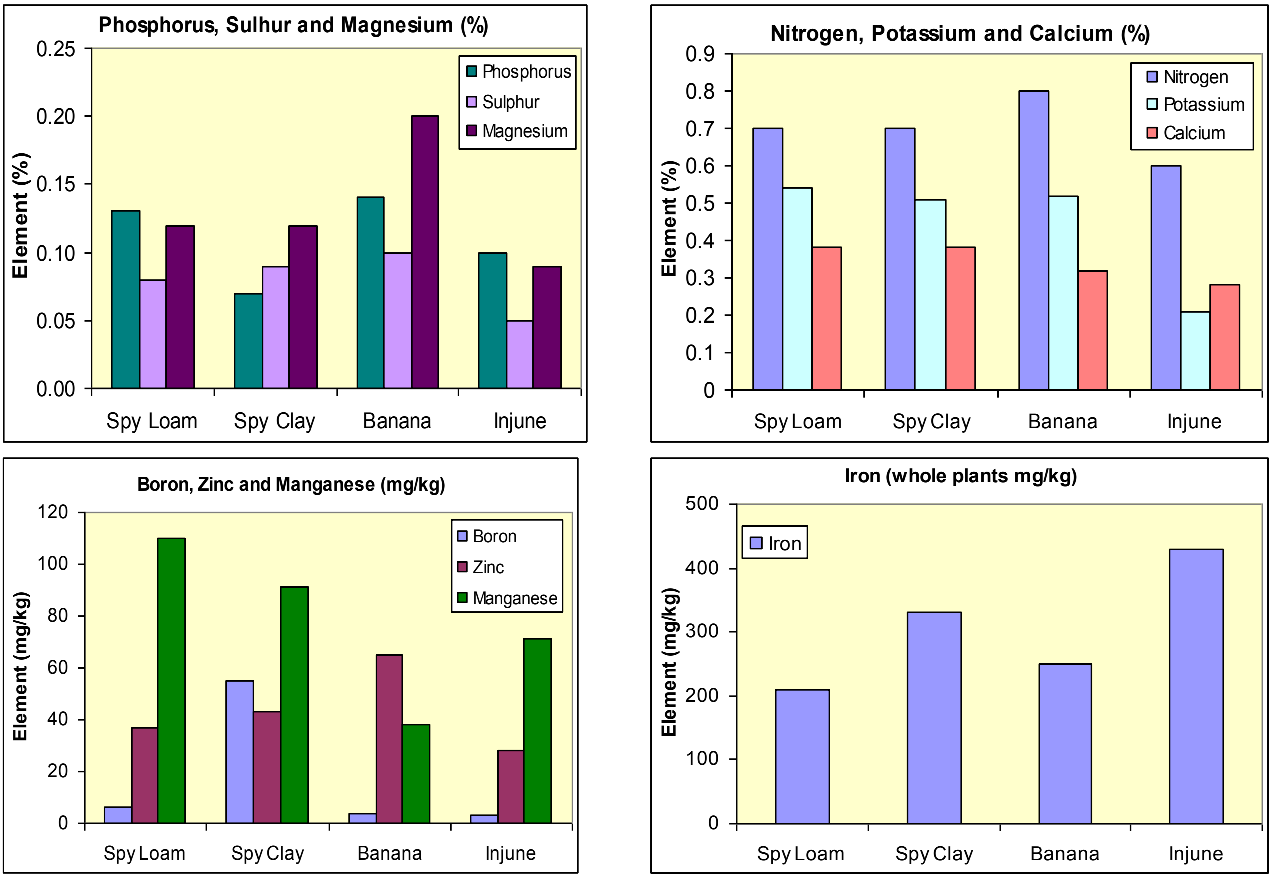


Figure 32. Mineral and nutrient analysis of whole plant samples of pastures in winter (2012) at three experiment sites.

Pastures at the Banana site had the highest phosphorus, nitrogen, sulphur and magnesium, while the Injune site tended to have marginally lower values in most elements except for iron, which was highest at this site. These samples reflect the potential quality of the rehabilitated pastures for grazing value at the time the pasture could have been opened for grazing for the first time. A light graze in winter of the first year, after a good establishment growing-season, would have a minimal effect on pasture recovery in the following wet season.

Landscape function analysis (LFA)

Blade ploughing (Banana site) provided the most rough surface and it maintained the highest roughness rating after three years compared with all other treatments (Figure 33).

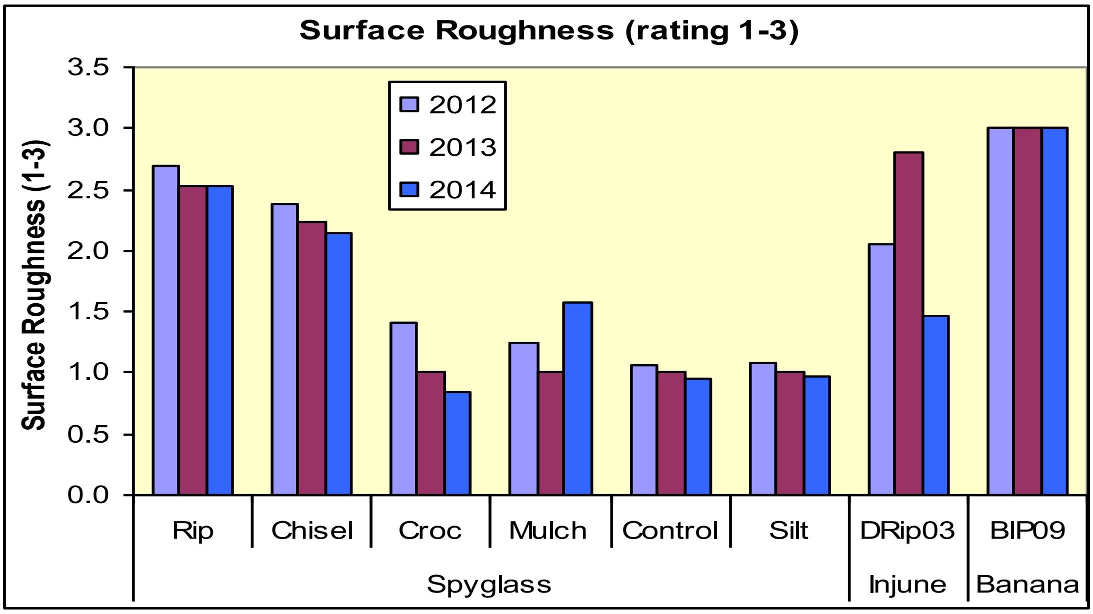


Figure 33. Soil surface roughness rating (1-3) at three sites in 2012, 2013 and 2014.

The next most- rough surfaces were produced by deep ripping and then chisel ploughing (at Spyglass). This measure is highly correlated with water holding capacity on the surface. The crocodile plough seeder on dry soil in October did not provide a rough surface after the first good rainfall summer and its' roughness rating was equivalent to the untreated control surfaces after the second summer.

By 2013 the two Fitzroy sites had rehabilitated to the extent of maintaining high organic matter soil surface cover (>80%) after four and nine years respectively (Figure 34).

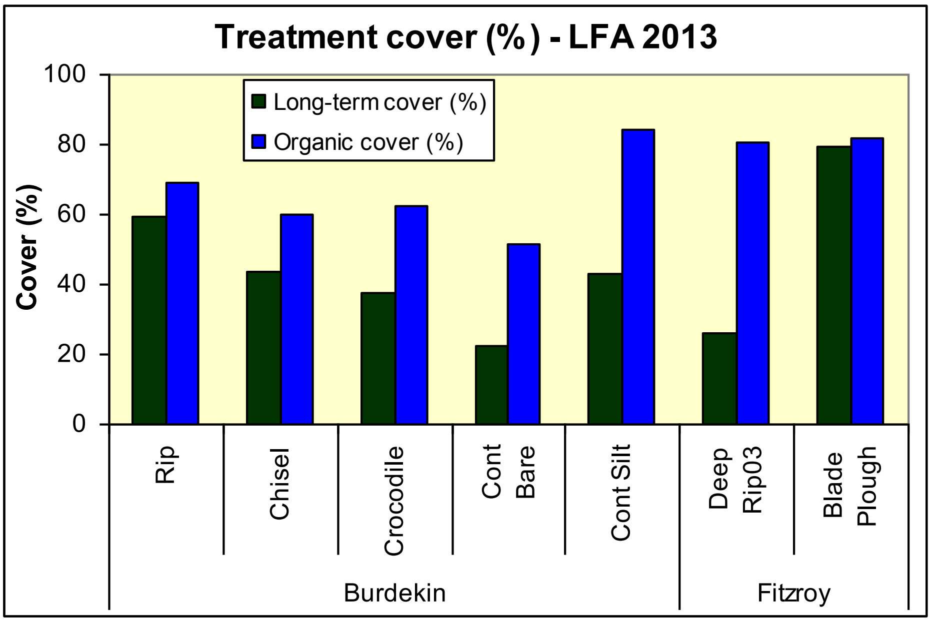


Figure 34.Cover (%) levels of long-term pasture and all organic matter in all rehabilitation treatments in 2013.

There was similar cover in the control silt (C-condition) treatment at Spyglass. The new rehabilitation treatments at Spyglass had declining levels of long-term cover between treatments with ripping producing almost 60% compared with 20% in the control. In the Fitzroy, the blade ploughing (Banana) had 80% long-term cover in 2013 compared with 26% in the deep ripping (Injune) treatment, reflecting the different soil types as well as good rainfall and drought conditions over the previous summer respectively.

Soil surface conditions, recorded by the landscape function analysis (LFA) method in all treatments at the three sites after the summer of 2013 (first drought year), show nutrient cycling had the least variation between treatments and sites (range 22.2 to 27.4) (Figure 35).

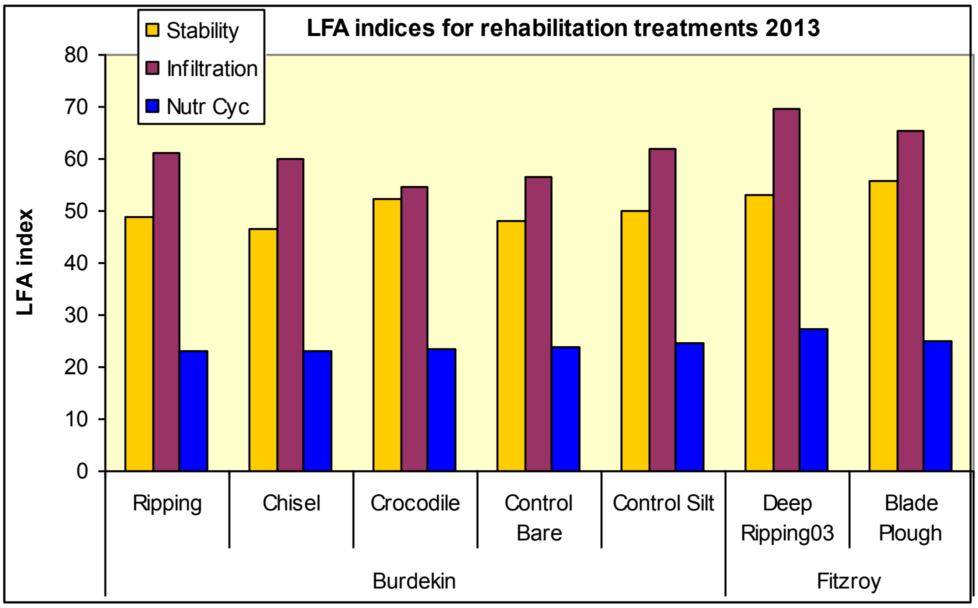


Figure 35. LFA stability, infiltration and nutrient cycling indices at Fitzroy and Burdekin sites in 2013.

However, the deep ripping treatment in the Fitzroy had the highest nutrient cycling index, mainly due to its' high litter cover. The deep ripping in 2003 and blade ploughing in 2009 treatments at the two Fitzroy sites had the highest infiltration index (mean 68), and a marginally higher stability index (mean 55), compared with the second year treatments at Spyglass in the Burdekin (mean 59 and 49 respectively).

The mean LFA indices across all treatments in May 2013 (Table 16.) show higher levels for the three parameters, stability, infiltration and nutrient cycling at the four and nine year rehabilitated Fitzroy sites than at the second year of rehabilitation treatments at the Burdekin site.

Table 16. LFA indices for treatments at the three experiment sites and means of Burdekin and Fitzroy sites in May 2013.

	LFA Indices		
Sites	**Stability**	**Infiltration**	**Nutrient Cycling**
Burdekin Mean	49.2	58.9	23.7
Fitzroy Mean	54.5	67.6	26.3
Mean of three experiment sites	**50.7**	**61.4**	**24.5**

Economic analyses (Spyglass and Injune)

The economic analysis of treatments at the Spyglass and Injune experiment sites is based on the actual field results, while there have been generic analysis of the economics of blade ploughing, similar to the Banana rehabilitation program. A detailed report on the economics of the Spyglass rehabilitation treatments is published in Part III.

Spyglass experiment treatments. Based on a steer trading enterprise and the actual field experiment pasture results at Spyglass, none of the three mechanical rehabilitation plus pasture seeding treatments produced a positive economic result. The analysis included the differences in pasture production and composition between the treatments; however, there were small economic differences. The sensitivity analysis showed that at the lowest discount factor, 5%, and default cattle price levels, no projects obtained a positive NPV. An increase in the value of cattle is reflected uniformly across the treatments and does little to change the outcome; however, at the highest prices and productivity levels, as well as the lowest discount factor, crocodile plough seeding and chisel ploughing returned positive NPVs.

This economic analysis demonstrates that D-condition land improvement can be achieved through mechanical intervention and seeding, but it is unlikely to be an acceptable investment for landholders in the situation represented by the Spyglass experiment site. This includes the good and poor summer rainfall years and favourable and unfavourable soil types, typical of the normal circumstances faced by landholders in this region. In order for the investment to become profitable, on a pure financial basis, the productivity gains would have to higher than was achieved over the 2011-2014 years at the Spyglass site. For landholders to break-even on investing in rehabilitation works, based on the Spyglass situation as measured and the default economic parameters, they would require an external subsidy of 57% for deep ripping, 54% for the chisel ploughing and 50% for crocodile plough seeding.

For beef producers in the Burdekin catchment to widely participate in D-condition land rehabilitation programs, significant external financial assistance with upfront capital costs would be required. This support means that producers could conduct D-condition land rehabilitation works and avoid the potential financial losses, while providing wider public benefits such as reducing sediment and nutrient runoff losses into the GBR Lagoon and possibly increased biodiversity in their pastures.

Costs of rehabilitation treatments (Spyglass, October 2011):

The estimated cost of machinery time if the work was done at a commercial area scale:

- Contour bank (600m) @ $4/m = $2400
- Diversion bank (300m) @ $4/m = $1200
- Deep ripping $100 - $250/ha
- Chisel ploughing $70 - $100/ha
- Crocodile plough seeding $40/ha
- Blade plowing* $200/ha
- Pasture seed $30 - $60/ha.

*The estimated costs of blade ploughing similar to that conducted at Banana.

Injune deep ripping. The results of rehabilitating the bare patches at Injune were used for an economic analysis of deep ripping in the Fitzroy catchment. The area was cleared brigalow scrub country sown to buffel grass pastures in the 1960s and some areas subsequently became degraded with bare, scalded D-condition patches by 2003. The rehabilitation treatment was:

- In October 2003, a 35ha paddock was fenced and the scalded patches were deep ripped and seeded to tropical pasture species:
  - Milgarra butterfly pea, burgundy bean, siratro, Bisset creeping bluegrass and silk sorghum,
  - Buffel grass had been sown decades earlier and occurred around the scalded sites providing a seed source.
- The paddock was shut up excluding cattle grazing for the first 2 years,
- Conservative grazing management was practised in subsequent years (including throughout the experimental period) with extended rest periods every year,
- The site rehabilitated to C-condition by September 2007 (four years) and B-condition by 2010 after two high rainfall years (further improvement was recorded in 2012).

Summarised economic analysis:
- Seasonal conditions were dry (below average summer rainfall) during the first three years of the initial establishment period,
- NPV = $14,046 discounted at 6% over 20 years (with growing cattle).

With average or higher summer rainfall conditions over the first three years, the estimated economic returns from the deep ripping rehabilitation was:

- NPV (with sensitivity) = potentially $16,782 discounted at 6% over 20 years.

This example is from a site on fertile brigalow soils in a favourable summer rainfall environment with the capacity to produce high dry matter yields of over 4000 kg ha^{-1} of exotic grass pasture. Results from lower fertility soil types are expected to be much less profitable, even unprofitable, in a similar environment.

The details of this economic analysis of the Injune deep ripping rehabilitation site are reported by Gowen *et al*. (2012). Deep ripping and blade ploughing economic analysis in the Fitzroy catchment has been reported by Star *et al*. (2011). Actual financial data was not obtained from the Banana site. A more detailed economic analysis of the Spyglass rehabilitation treatments compared with the control is published in Part III (Moravek and Hall 2014).

Surface profile Lidar scan (Spyglass)

The surface of the Spyglass experiment site was scanned with a ground-based Lidar machine in October 2012, one year after rehabilitation treatments were applied. The circular eroded break-away gully head of the hay mulch treatment is clearly seen in (Figure 36-L) and the uneven surface across the site is shown in (Figure 36-R). These scan locations are marked and located by a differential GPS so the same scans can be re-checked in the future to measure any surface changes.

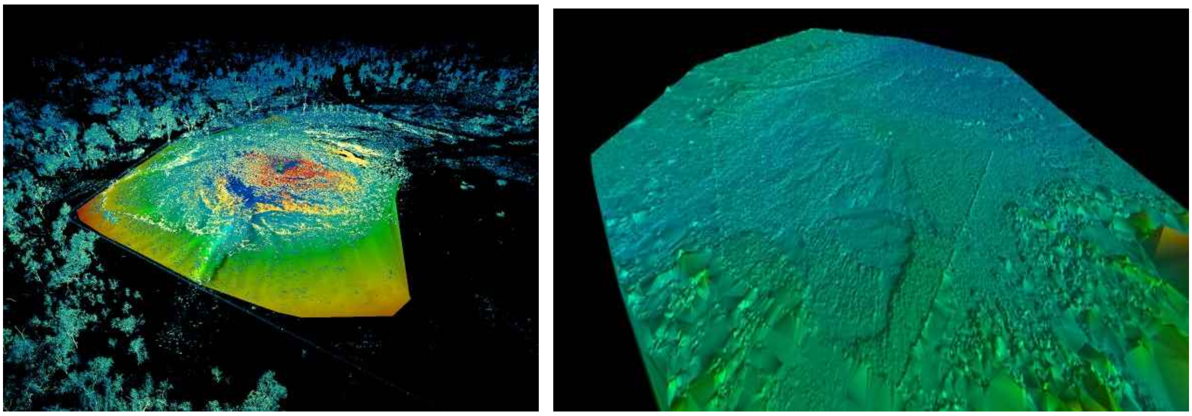


Figure 36. Lidar surface scans of Spyglass rehabilitation experiment: L. Hay mulch treatment, and R. Across experiment site (October 2012).

Sediment and nutrient losses

The sediment and nutrient losses in the treatments at the three experiment sites were measured by a rainfall simulation method by the Queensland Government DNRM rainfall simulation team of Bruce Cowie, Wendy Tang, Luke Daveson and Dale Heiner and DAF staff. Measurements in the Burdekin were at 10 locations across the Spyglass experiment site treatments (August 2012), and in the Fitzroy at three locations each at the experiment sites at both Injune and Banana (July 2012).

Site 1. Spyglass (Burdekin)

The ground cover, basal area and dry matter yield of pasture adjacent to each runoff plot site on both loam (grey sodosol) and clay (black vertosol) soil types was measured (Table 17). Ground cover ranged from 20% to 95%, basal area was from 1% to 3.3% on the loam soil and 4.0% in the native woodland, and pasture dry matter yield ranged from 270 kg ha^{-1} in the control-bare (sodic dermosol soil) to 3060 kg ha^{-1} on the clay soil of the chisel plough treatment.

Table 17. Rainfall simulation plots pasture cover, basal area and dry matter yield in mechanical treatments at Spyglass (August 2012).

Site	Rehabilitation Spyglass	Soil type	Ground cover (%)	Basal area (%)	DM Yield (kg ha^{-1})
1	Ripping	Loam	83	2.5	2920
2	Ripping	Clay	70	2.2	2500
3	Chisel plough	Loam	92	3.3	3060
4	Chisel plough	Clay	67	2.7	2040
5	Crocodile plough	Loam	82	2.8	2130
6	Crocodile plough	Clay	73	2.3	2130
7	Control	Loam	82	2.8	1550
8	Control	Clay	73	2.7	1480
9	Control - Bare	Loam	20	<1.0	270
10	Woodland	Loam	95	4.0	2670

Although basal area was lower in the more highly disturbed loam soil treatments (ripping and chisel ploughing), the cover was similar and pasture yields were higher in the first year of rehabilitation than in the native pasture in an adjacent, not degraded, open Eucalypt (brown box and narrow leaved ironbark) woodland.

Site 2: Injune (Fitzroy)

The pasture cover, basal area and dry matter yields at the rainfall simulation plots at Injune (Table 18) show the 'good' rehabilitation plot had almost complete ground cover and a dry matter yield over 4400 kg ha^{-1}.

Table 18. Rainfall simulation plots pasture cover, basal area and dry matter yields at Injune site in July 2012.

Plot	Rehabilitation Level (deep ripping 2003)	Ground Cover (%)	Basal area (%)	DM Yield (kg ha^{-1})
1	Good	95	4.2	4460
2	Poor	35	2.8	1500
3	Nil	0	0	0

The 'poor' pasture rehabilitation plot was at 35% cover and 1500 kg ha^{-1} DMY, while the un-rehabilitated plot was bare of pasture.

Site 3: Banana (Fitzroy)

The pasture cover, basal area and dry matter yields at the rainfall simulation plots (Table 19) show the 'good' rehabilitation plot had over 5000 kg ha^{-1} dry matter and good ground cover and a strong basal area.

Table 19. Rainfall simulation plots pasture cover, basal area and dry matter yields at Banana site in July 2012.

Plot	Rehabilitation Level (blade ploughing 2009)	Ground Cover (%)	Basal area (%)	DM Yield (kg ha^{-1})
1	Good	73	5.7	5300
2	Poor	50	2.7	2080
3	Nil	0	0	0

The 'poor' pasture rehabilitation plot was still in a relatively strong condition with 50% cover and over 2000 kg ha^{-1} DM yield. The un-rehabilitated plot remained bare and had no established pasture.

A comparison of the pastures at the 16 rainfall simulation plots measured at the three sites (Figure 37a, b, c) shows the wide range of pasture conditions in DM yield (range 270-5300 kg ha^{-1}), ground cover (0-95%) and basal area (0-5.7%). The yield and basal area were higher at the two established pastures at the Fitzroy sites than in the first-year pasture of the Spyglass treatments in the Burdekin.

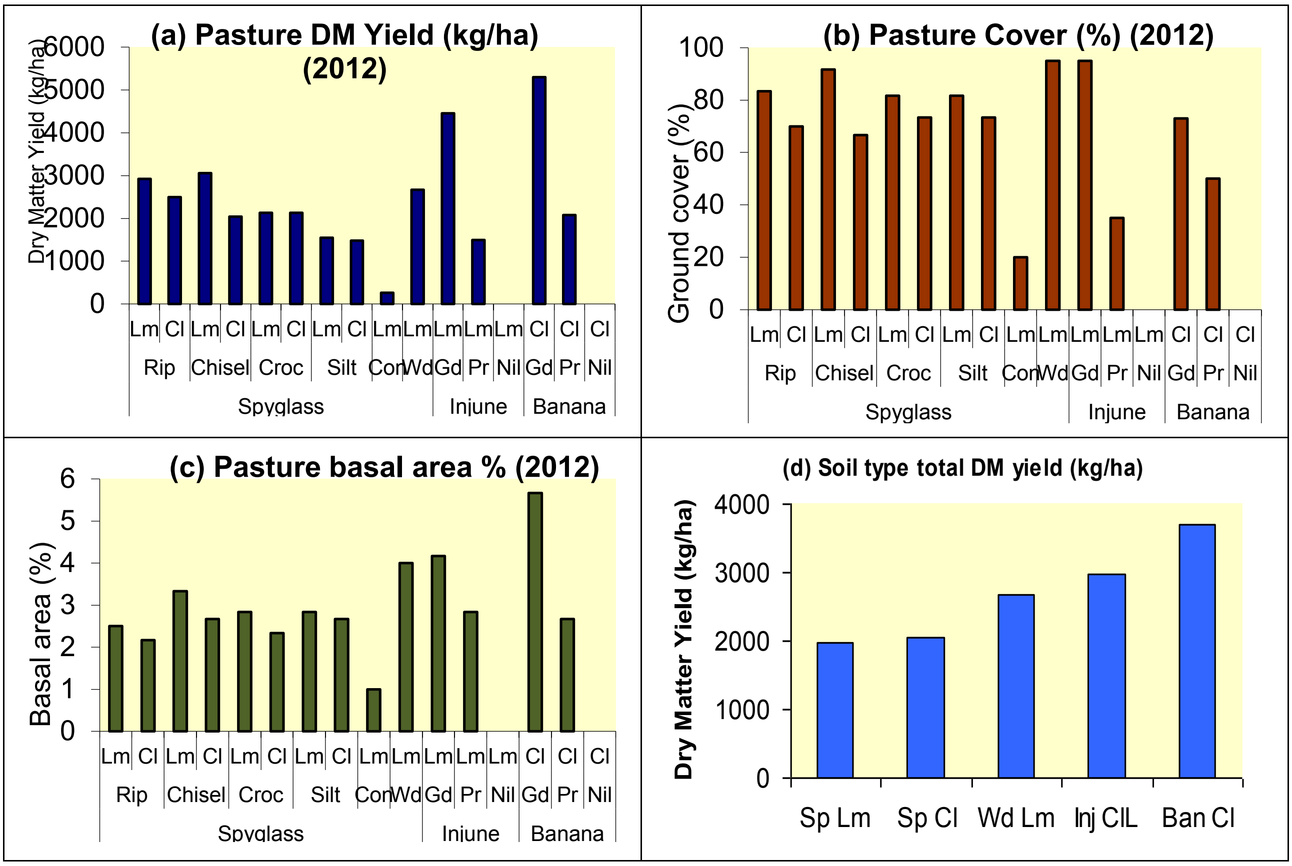


Figure 37. Pasture conditions at the 16 rainfall simulation plots at three sites and five soil types in July-August 2012.

The soil type by average treatment dry matter yield shows similar yields from the clay (Cl) and loam (Lm) soil types at Spyglass, however, these yields were lower than the Spyglass natural woodland (Wd) loam soil site or the Injune clay loam (ClL) and Banana clay (Cl) soils (Figure 37d).

Rainfall simulation runoff measurements

The effects of mechanical soil disturbance treatments of ripping and blade ploughing compared with no disturbance on two soil types at the three sites (Figure 38) shows that these aggressive soil disturbance methods increased surface (0-2.5 cm) soil moisture up to nine years after the deep ripping treatment (Injune). Also these aggressive soil disturbance methods increased the initial infiltration before the commencement of runoff at all times and on all soil types.

The more aggressive disturbance methods also increased the initial infiltration rate despite similar or higher soil moisture levels and this higher infiltration occurred irrespective of soil type. At Spyglass after one year, the mean of the ripping and chisel ploughing disturbance treatments high (input disturbance methods) on the heavy clay soil (vertosol) had higher infiltration than the corresponding treatments on the loam soil (sodosol). The natural deep cracking in the vertosol would have facilitated this higher infiltration rate.

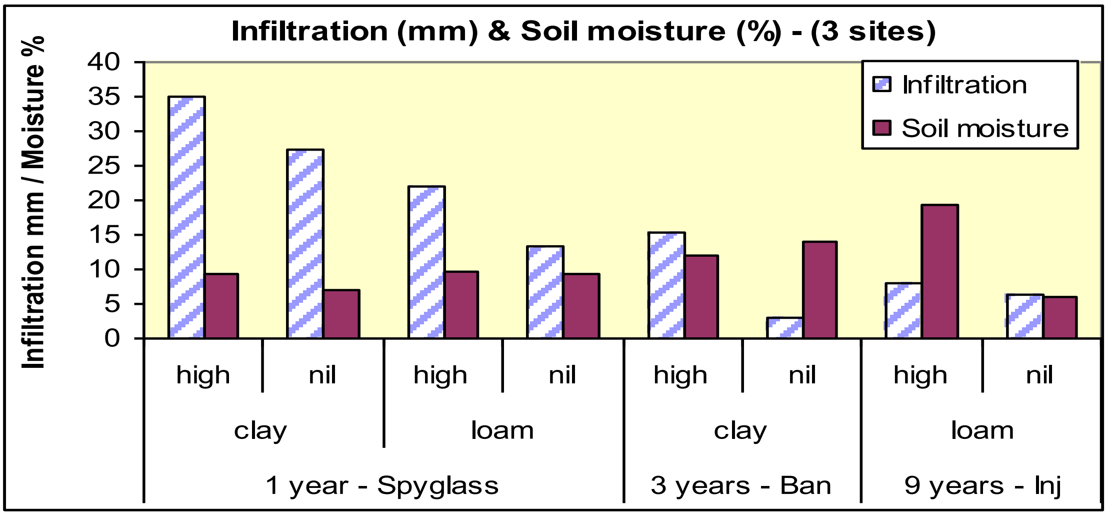


Figure 38. Initial soil moisture (air dry) and rainfall infiltration before the commencement of runoff at three sites up to nine years after aggressive soil disturbance for pasture rehabilitation.

A comparison of runoff to infiltration rates during the first 30 minutes after runoff commenced showed that the aggressive soil disturbance methods had no consistent effect on the runoff:infiltration ratio (Figure 39). On a clay soil three years after blade ploughing (Banana) there was still a significant increase in infiltration (>60%), while on the loam soil (Injune) there was only a small increase (10%) after nine years.

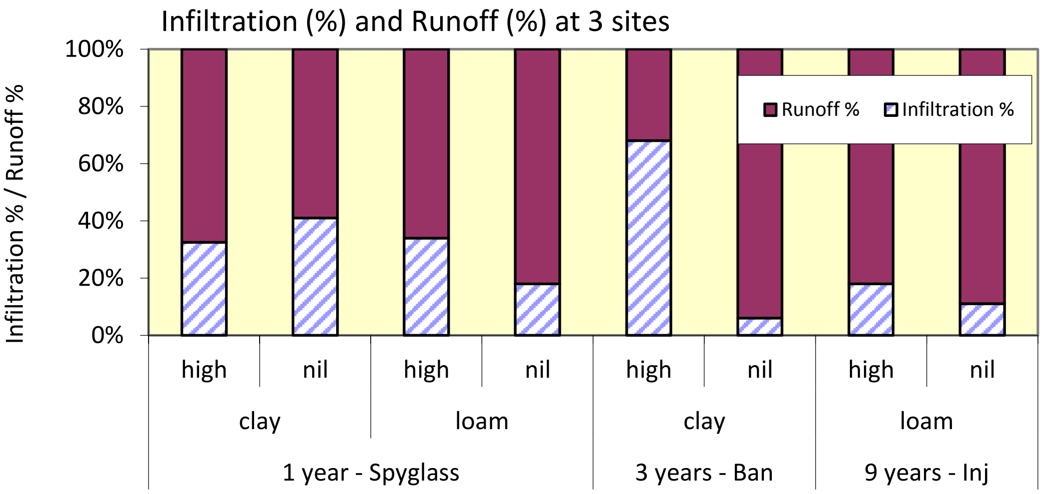


Figure 39. Water balance after runoff commenced at three sites up to nine years after aggressive soil disturbance (high) and nil disturbance for pasture rehabilitation.

The rate of infiltration declined more rapidly in the un-rehabilitated plots compared with the good and partly rehabilitated plots at the Injune site (Figure 40). After 10 minutes of simulated rainfall at 87 mm hr^{-1}, there was no difference in infiltration between the poor and nil rehabilitated plots, while the good rehabilitation plots maintained the same infiltration rate for 25 minutes at this rainfall intensity.

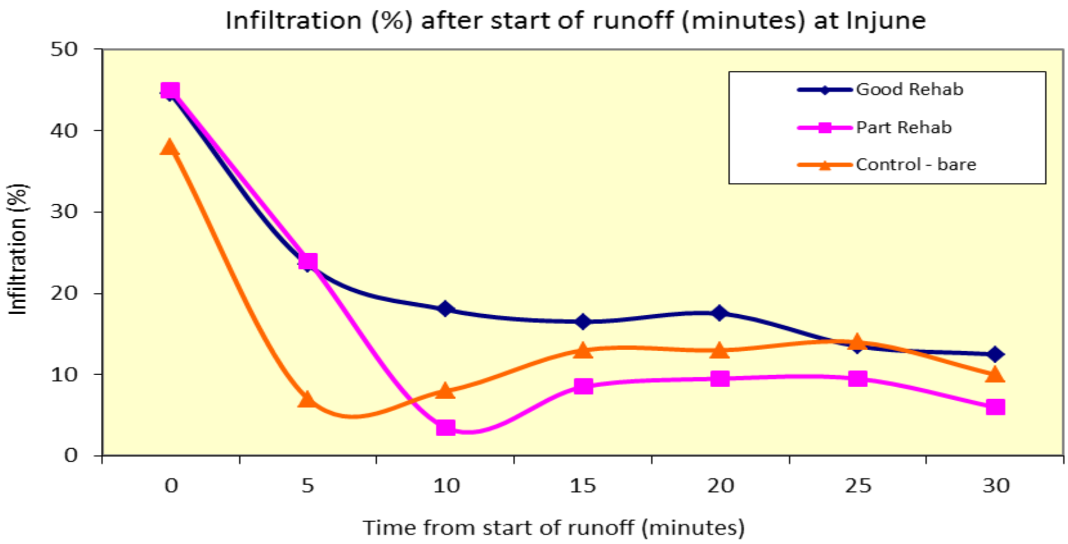


Figure 40. Infiltration % of rainfall intensity at 87 mm hr^{-1} in good, poor and nil rehabilitation areas at the Injune experiment site in 2012.

At the two Fitzroy sites there was an increasing trend in amount of rainfall absorbed in the soil at an intensity of 87 mm hr^{-1} as the success of the rehabilitation treatment increased (Figure 41). This occurred after the deep ripping (Injune) and blade ploughing (Banana) even nine years after the treatments were applied. The 'good' rehabilitation pasture absorbed more than twice as much rain before runoff compared with the un-rehabilitated plots.

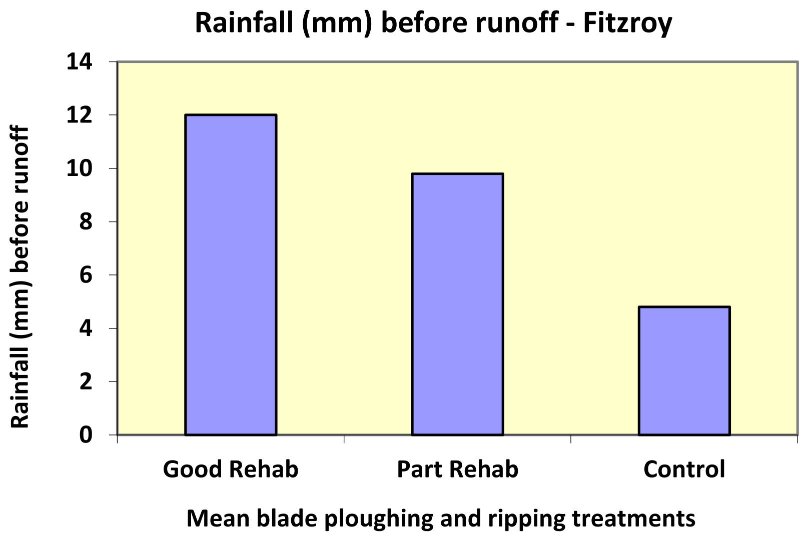


Figure 41. Average rainfall at 87 mm hour^{-1} before runoff at two Fitzroy sites in good, part and nil rehabilitation plots in 2012.

There were significant differences between treatments at the three sites in the amount of soil lost during the first 30 minutes after runoff commenced (Figure 42). At the Injune and Banana sites after aggressive disturbance treatments (nine and three years later respectively) soil loss was negligible compared to the un-rehabilitated soil surfaces. There was >2 t ha^{-1} difference on the clay soil at Banana.

At all sites, the aggressive disturbance treatments had high surface roughness, good pasture ground cover and adequate pasture dry matter yields (see Figure 33; Figure 37).

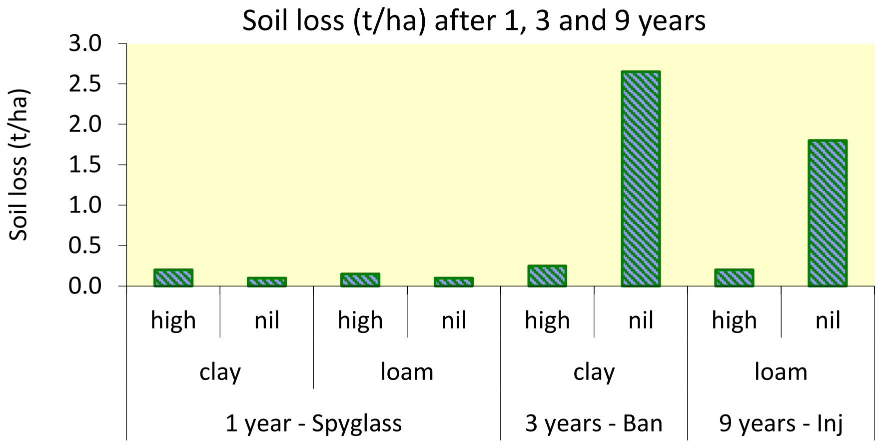


Figure 42. Soil loss (tonnes per hectare) from degraded pasture land given aggressive and nil soil disturbance when subjected to simulated rainfall at an intensity of 87 mm hr^{-1}, one, three and nine years after treatment.

The aggressive mechanical disturbance at the two Fitzroy sites (deep ripping and blade ploughing) greatly reduced losses of all forms of nitrogen compared with the untreated soil surfaces (Figure 43). There was a five-fold reduction in total nitrogen losses three years after blade ploughing on the clay soil (Banana) and an eight-fold reduction nine years after deep ripping on the loam soil (Injune). The nitrogen loss in runoff water was dominated by the suspended nitrogen component at both sites. Cattle grazing had been well managed to develop and maintain the sown pasture during the intervening periods at both sites.

After the first summer at Spyglass there were negligible nitrogen losses on the two low fertility soils irrespective of disturbance level (Figure 43).

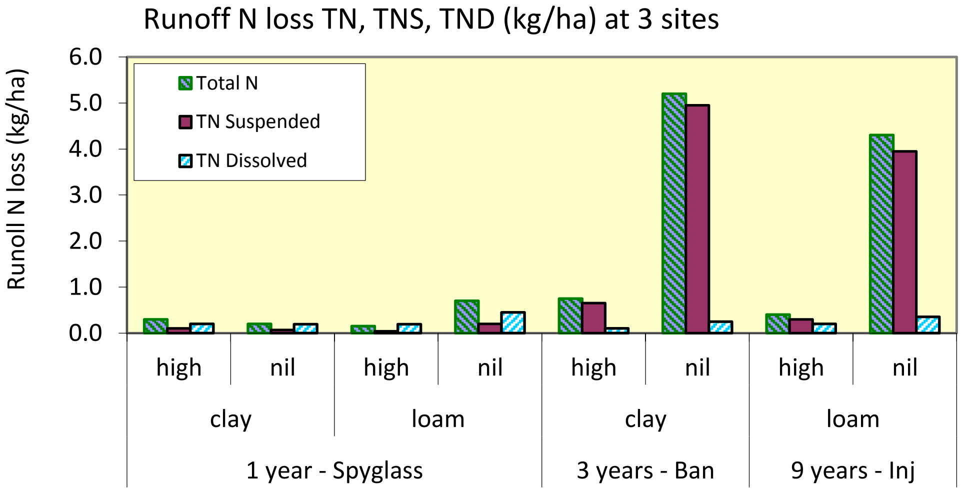


Figure 43. Nitrogen loss (kg ha^{-1}) from degraded pasture land given aggressive and nil soil disturbance when subjected to simulated rainfall nine months, three years and nine years after treatment. TN - total nitrogen; TNS – total nitrogen in suspended material; TND – Total nitrogen dissolved.

At Spyglass a comparison infiltration and soil moisture across the main treatments and two soil types reflects the short-term (after one summer) effects of different levels of mechanical disturbance (Figure 44). On the 'loam' (hard setting clay loam) soil there was no relationship between the aggressiveness of the treatment and the initial soil (0-2.5 cm) moisture. There was a trend for increased initial infiltration before runoff commenced on the two more aggressive treatments.

On the clay soil (a heavy textured, cracking clay) there was also no relationship between treatment aggressiveness and initial soil surface (0-2.5 cm) moisture and there was an inconsistent relationship between treatment aggressiveness and initial infiltration. With the rainfall simulation method, there is reduced confidence in the hydrological results on cracking clay soils. The sediment and nutrient loss estimates may be affected by the potential for some infiltration out of the plot borders through soil cracks. However, at Spyglass all soils were saturated some four weeks prior to conducting rainfall simulation measurements which would have maintained sub-soil moisture levels, reducing potential losses through dry cracks.

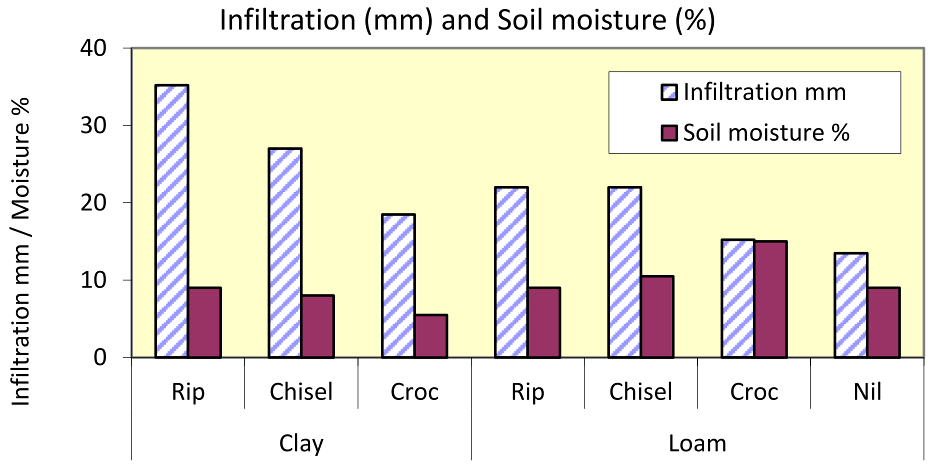


Figure 44. Initial soil moisture (air dry) and rainfall infiltration before the commencement of runoff where four soil disturbance treatments were applied nine months prior at Spyglass.

At Spyglass the ratio of infiltration to runoff in treatments on the clay (heavy cracking clay)and loam (a hard setting clay loam) soil types (Figure 45) show that on the loam there was a trend for increased infiltration, and reduced runoff, with the more aggressive soil disturbance treatments. On the clay soil there was no clear relationship between treatment aggressiveness and infiltration.

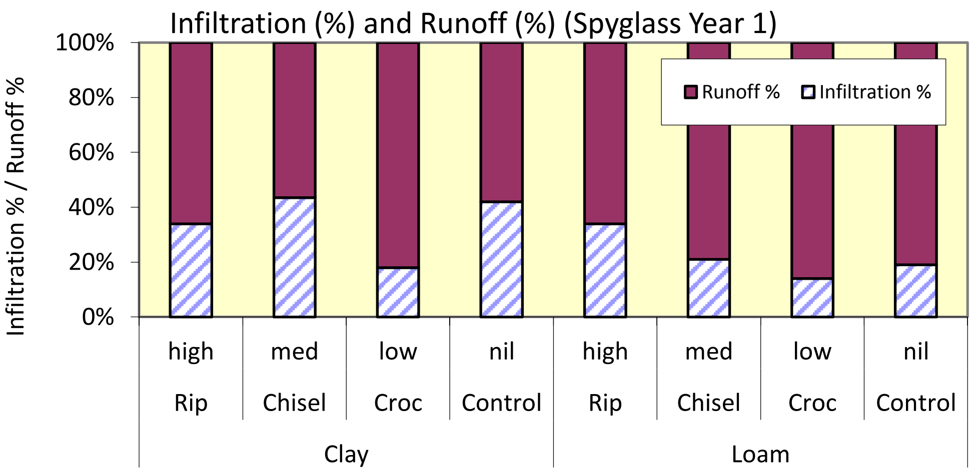


Figure 45. Runoff and infiltration (%) water balance after runoff commenced one year after soil disturbance for pasture rehabilitation at Spyglass.

At Spyglass on the loam soil there was no consistent relationship between treatment aggressiveness of soil disturbance methods and runoff soil sediment loss after the first summer (Figure 46). However, on the clay soil runoff soil sediment loss increased with increasing aggressiveness of the soil disturbance method.

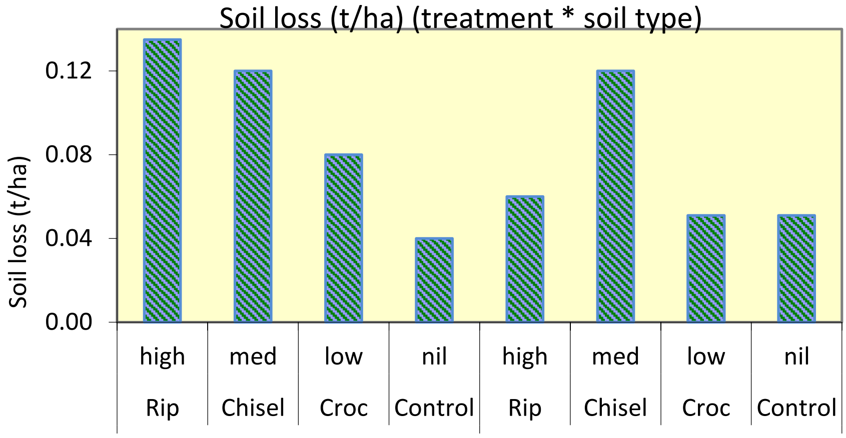


Figure 46. Runoff soil loss (tonnes per hectare) measured nine months after four levels of soil disturbance were applied to two soil types for pasture rehabilitation at Spyglass.

At Spyglass the runoff total nitrogen loss from both soil types, the loam and clay soil, showed a marginal trend to decrease with the more aggressive disturbance methods (Figure 47). These low levels of nitrogen loss are close to the limit of resolution for this rainfall simulation methodology.

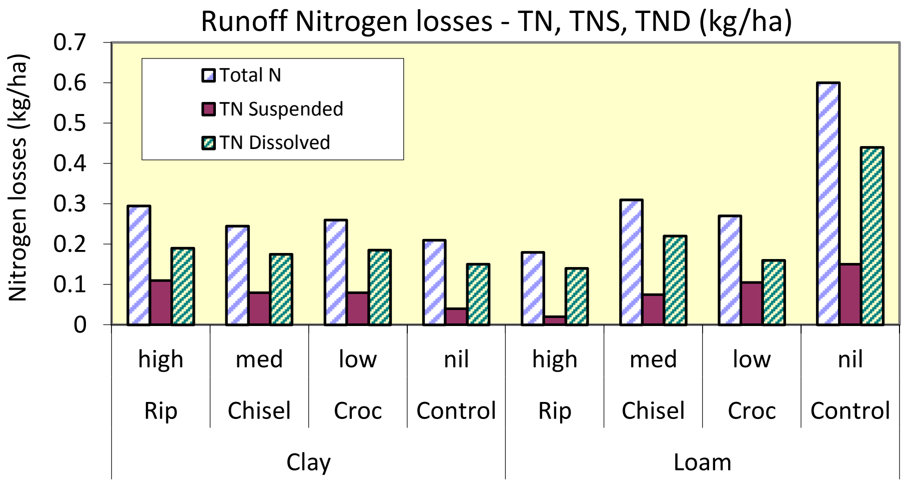


Figure 47. Nitrogen loss (kg ha^{-1}) measured nine months after four levels of soil disturbance were applied to two soil types at Spyglass. TN - total nitrogen; TNS – total nitrogen in suspended material; TND – Total nitrogen dissolved.

At Spyglass total phosphorus (dissolved and suspended) in runoff from both the clay and loam soil types showed a marginal trend to decrease with increased aggressiveness of soil disturbance (Figure 48). Runoff total phosphorus loss was higher from the loam soil than from the clay, and highest losses were from the loam soil without soil disturbance.

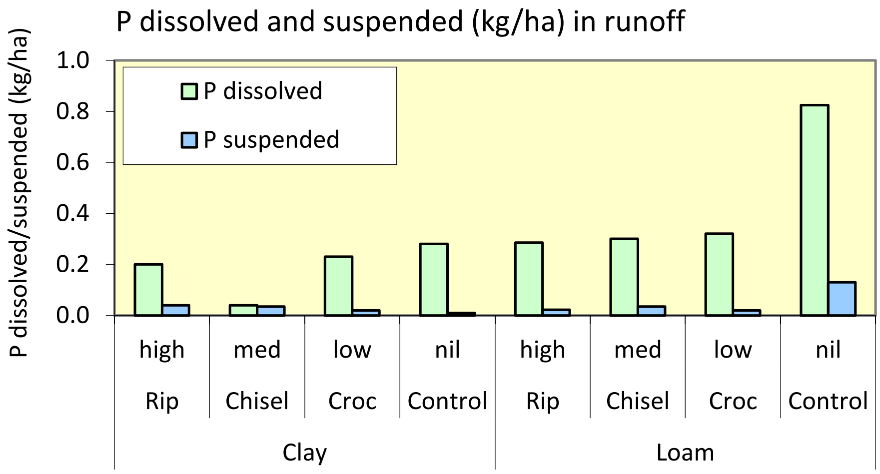


Figure 48. Components of the total phosphorus runoff loss measured nine months after four levels of soil disturbance were applied to two soil types at Spyglass.

Available soil phosphorus loss in runoff water at Spyglass had no clear relationship to soil disturbance methods or soil types, however, the most aggressive disturbance had the highest BSES soil phosphorus loss on both soil types. The lower levels of Colwell phosphorus did not show the same response to disturbance methods (Figure 49).

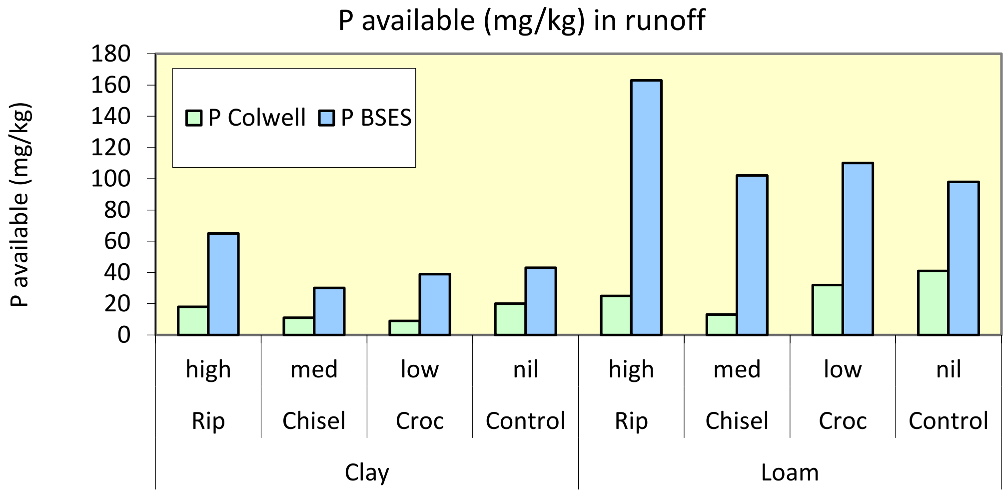


Figure 49. Components of the total phosphorus runoff loss measured nine months after four levels of soil disturbance were applied to two soil types at Spyglass.

Long-term pasture cover (VegMachine)

The long-term cover index calculated by VegMachine analysis of the three experiment sites from 1987 is shown in the following figures. At Spyglass, the experiment site history of low cover relative to the surrounding open narrow leaved ironbark woodlands (Figure 50) at long-term 50% and 95% cover ranges shows the consistently poor site cover, and that in the 2002 to 2006 period it was exceptionally low cover.

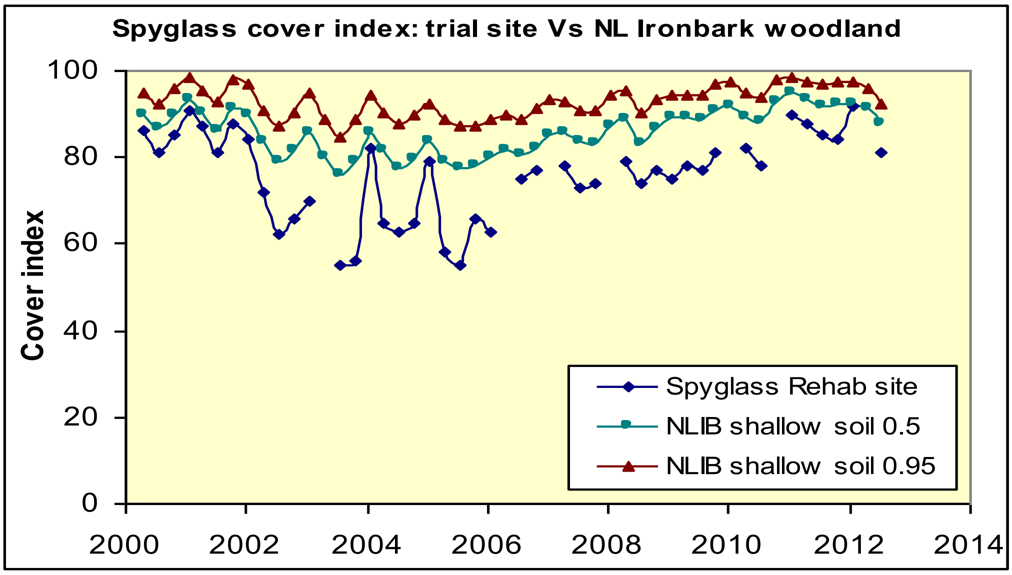


Figure 50. VegMachine historical cover index at Spyglass experiment site relative to the mean cover (0.5) and high cover (0.95) areas from year 2000.

The ground cover surrounding the un-rehabilitated Injune experiment site shows a marginally lower average cover surrounding the experiment site compared with the whole paddock average. There is a similar brigalow (cleared) landtype across the whole paddock (Figure 51).

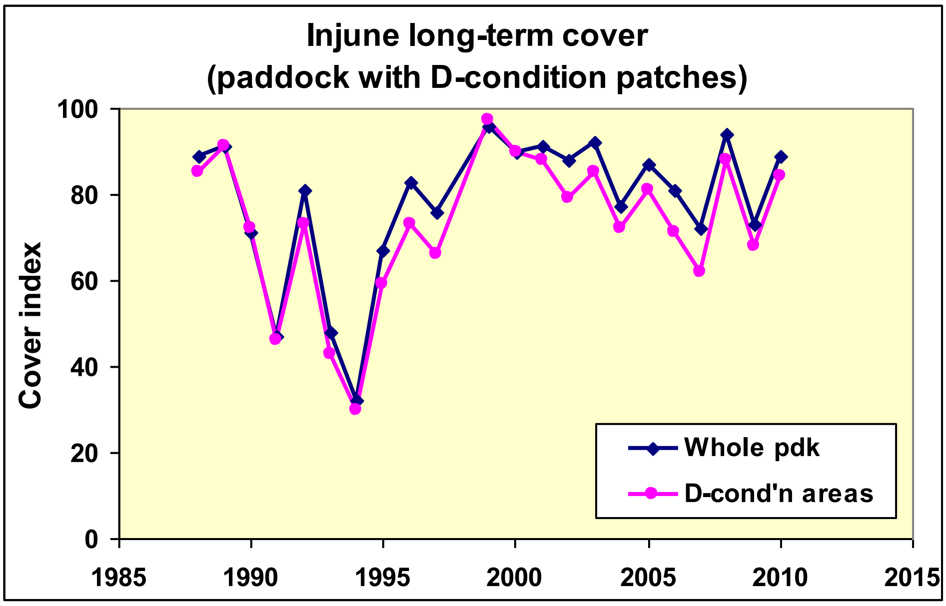


Figure 51. Long-term pasture cover index (VegMachine) in the un-rehabilitated Injune paddock – whole paddock and around D-condition areas.

The long-term cover index of the Injune rehabilitation experiment site paddock has been consistently higher than the untreated site paddock. Both paddocks are cleared and developed to buffel grass pasture and have a consistently lower cover than the average of the surrounding brigalow landtype until recent years (Figure 52).

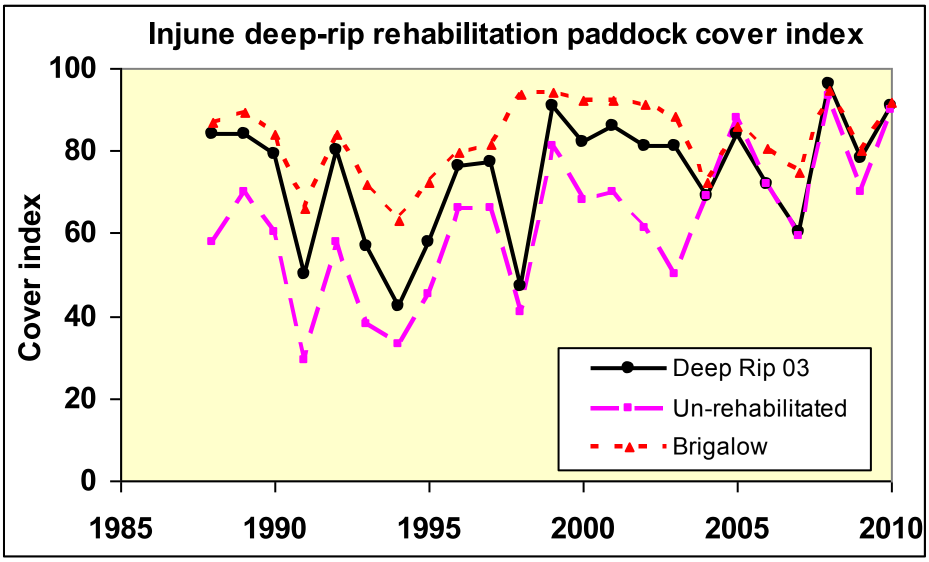


Figure 52. Long-term cover index of Injune (Fitzroy) rehabilitation site, untreated site and average of surrounding brigalow landtype.

At the Banana site the long-term cover (VegMachine) shows the experiment paddock blade ploughed in 2009 had a lower cover than similar woodland country since 1999 (Figure 53). All sites improved in cover after blade ploughing between 2009 and 2010.

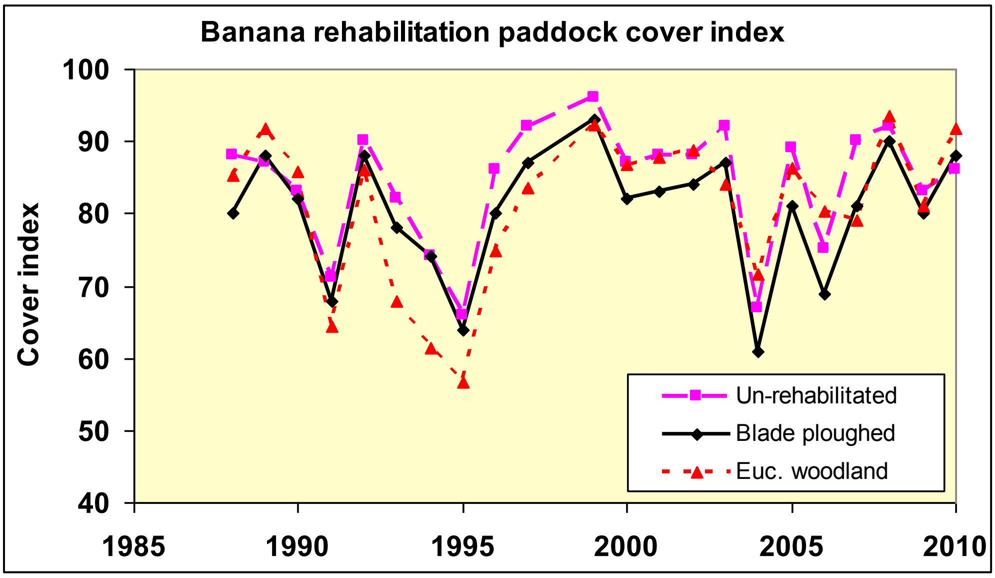


Figure 53. Long-term cover index of Banana (Fitzroy) rehabilitation paddock blade ploughed, untreated areas and average of surrounding Eucalypt woodland landtype.

Marsupials

Kangaroos and wallabies can be a serious problem in establishing seedlings of a new pasture across most of Queensland, especially on frontage country near major water courses. At Spyglass there was a high kangaroo population on and around the experiment site over the 2013-2014 summer when the surrounding paddock was being spelled from cattle grazing. For example, there were 48 kangaroos present around the site and near double dam within 1 km of the site on one afternoon in March 2014, after some late season (autumn) rainfall (Figure 54). There was a high density of kangaroo dung of ~1 m^{-2} across much the experiment site at this time. This kangaroo population would have prevented most sown grass seedlings from establishing if they did germinate over this low rainfall summer.

Figure 54. Part of kangaroo population between experiment site and double dam (L) and inside fenced experiment (R) (20/03/14).

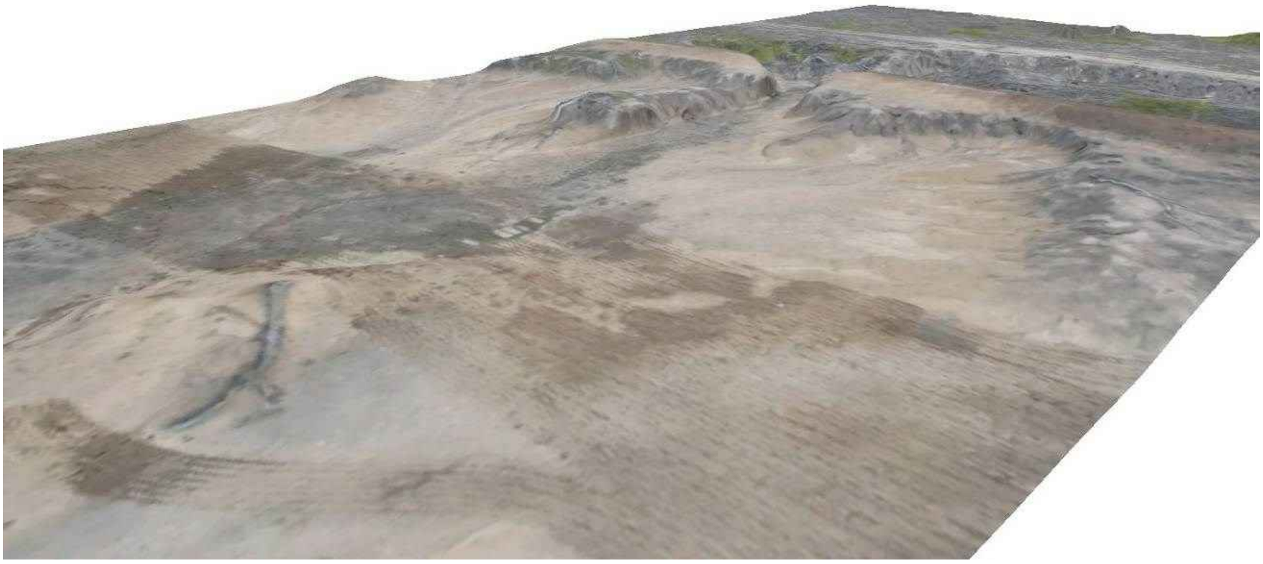


Figure 55. Gypsum site 3D view across chisel ploughed scalds and water courses, Spyglass December 2013.

Figure 56. Erosion scalds adjacent to water courses near the Spyglass experiment site A (located in NW corner of image) December 2013).

2. Landholder rehabilitation experiences - Survey

Twenty landholders were interviewed about their experiences in the rehabilitation of scalds on D-condition grazing land and subsequent management, guided by the six project objectives. The report includes an abbreviation of some of the landholder quotes and discussions related to their rehabilitation experiences and the project objectives. Additional comments are included in Appendix 5.

Opinions of surveyed landholders

The effect of rehabilitation works on off-site water quality was generally not discussed during the interviews, probably because landholders focus on operations on their own properties, and thus have little knowledge of down-stream responses. However, there is an implicit acknowledgement that runoff from D-condition land is a source of sediment downstream, and potentially into the GBR lagoon. None of the landholders reported knowledge of water quality data derived by others from experimental studies conducted on their land or in their district (e.g., Landcare monitoring), however, published articles on sediment plumes in the GBR lagoon following flooding events were acknowledged. Fact sheets put out by the Fitzroy Basin Association (FBA) about rehabilitation experiments (FBA 2006 a, b, c; FBA 2008) indicate that the FBA staff and the management board believe that the subsidised works they were supporting was improving off-site water quality.

1. Rehabilitation methods

A full range of methods to rehabilitate bare areas on varying soil types with varying degrees of scalding and erosion has been tried by the landholders. Grazing management approaches have been tested: from reduced grazing pressure, to long-term spelling in rotation systems, to cell and holistic grazing methods with short grazing periods followed by long periods of rest. With scalds on more difficult soil types, mechanical approaches from adding mulch or tree litter, to light disturbance with crocodile plough seeders, to more aggressive disturbance with chisel tynes, rippers and blade ploughs have been used. Adding pasture seed during disturbance and managing grazing is most commonly practiced and recommended. Fertiliser is rarely added. There are examples of successful rehabilitation following well-defined practices of aggressive disturbance, mixed pasture seeding, and grazing control, of both small scald patches and whole paddocks. With the whole paddock approach, the scalds were regenerated, and other rundown pastures across the paddock were also renovated. This method allowed the whole paddock to be grazed to suit the annual pasture growth, and avoided cattle concentrating on any relatively small patches. There have been partial and complete failures from all rehabilitation methods reported as well. Poor rainfall, unsuitable soil types, poor quality seed, and too much grazing too soon are usually blamed for failures.

Landholder comments and direct quotes on commercial rehabilitation methods:

- Good rehabilitation is possible by deep ripping methods; providing sites are spelled after the ripping.
- Deep ripping and pasture seeding has prevented bare areas from spreading.
- Spreading mulch has helped establish new pastures on ripped scalds.
- Fertilising has helped establish and grow new pastures after disturbance, but it is expensive.
- Successful rehabilitation of silty surfaced scalds has occurred with ripping and pasture seeding with grazing controlled for some years.
- Short grazing rotations with long spells and maintaining electric fencing to exclude grazing of some patches has allowed pasture recovery.

- Successfully rehabilitated scalds to 50-70% groundcover after starting in smaller paddocks between 2003 and 2007.
- Deep ripping, with pasture seeding, and grazing spelling is a method that works on fertile silty soil scalds in brigalow country in the Fitzroy catchment.
- A new pasture established after deep ripping and seeding with pasture grasses and legumes, and it has persisted with long rest periods in a cell rotational grazing system. The paddock was only grazed sparingly to suit the pasture recovery for several years.
- 300 ha of scalds in brigalow buffel pasture have been rehabilitated over 20 years with the best success from 2000 to 2003 with fair rainfall seasons'.
- Blade ploughing and seeding whole paddocks followed by several years of spelling has been successful on a brigalow clay soil in the Fitzroy.

Failure of rehabilitation works does occur

Some landholders have tried mechanical rehabilitation and had failures, so have abandoned ideas of further attempts. For example:

- I have tried grader ripping of bare patches without success.
- No pastures established in a drought.
- I couldn't keep cattle away from the renovation patches long enough for recovery.

In one environment the scald rehabilitation method was:

- Manage bare areas by rotational grazing with two grazes/year and long rests between each graze period. Include long wet season spells of six months to help increase cover on bare patches when used as part of a rotation system.
- Sites need fencing of favourable landtypes on valleys and frontages.
- For deep ripping use a dozer with three tynes, on the contour with strips about 10m apart (old contour ripping method).
- Soils: you need to check soil types, soil structure, salinity problems, subsoil dissolving types (sodic), also surface crusting types are problematic.
- Add bales of hay mulch on bare areas and concentrate herd for surface impact at wet times.
- Need nutrient cycling and organic matter (OM) build-up to maintain perennial grasses.

Some successful rehabilitation methods reported by landholders included a requirement to rip the surface to increase soil moisture infiltration plus add organic matter to the soil. Methods used on level, eroded and scalded areas:

- Rip surface for water infiltration and grow any plants to get OM started.
- Top dress bare patches with OM from cattle camps and near dams – property bought a scraper to shift high quality OM and top soil. Up to 30 cm of OM, dung, topsoil and grass litter was added to scalds.
- Rotational grazing has been practiced since 1963 – graze 1/3 at any time and rest up to 2/3 of the area.
- Rests paddocks after mechanical ripping and topdressing treatments over summer for 6-18 months.
- Use rest in summer for rehabilitation of all pastures, to prevent deterioration back to D-condition.
- Larger areas can only rip and reseed with pasture grasses.

Grazing management after rehabilitation

Some properties have seen the need for managing and regenerating overgrazed areas for many decades. One landholder reported:

- I ripped areas in the 1970s (some 40 years ago) and seeded pastures and can still see the effects (in a horse paddock).
- Need to shape gullies with a dozer to help natural rehabilitation and to manage water flow.
- Spell over summer for grasses to spread and seed.
- Don't burn grass cover (no fires since 1980) to keep all litter for surface protection and seed for grass regeneration.
- Spell paddocks to reduce clay pans. Paddock spelling is important for improving land condition and for cattle feed. Cows go into fresh (rested) paddocks with bulls in for 3-4 months.
- I develop and manage a whole paddock at one time. The paddocks are not all bare, only bare patches. The whole paddock renovation method stops selective grazing that makes bare patches.
- Tried renovation strips but was not always successful if paddock was grazed as the cattle concentrate grazing pressure along the strips.

Herd impact for rehabilitation

Some landholders expressed a view that herd hoof impact, with high density stocking rates, was expected to assist pasture cover improvement over time, with planned spelling. The alternative method suggested was to concentrate high cattle numbers to pug and trample in hay organic matter and pasture seed in a wet period with hoof action over a short time (perhaps for hours even). This approach could be evaluated with lanes of electric fences to drive herd to small fenced bare patches when wet conditions and soil surface conditions are suitable, for example, during weaner training after rain. There was no direct evidence reported of this method of regenerating scalds on its own from any site, however, there is interest in seeing this method evaluated experimentally (a request to the project team).

2. Ground cover / surface conditions

The region/locality and soil type have a significant influence on what is regarded as a suitable ground cover level to provide some grazing and reduce runoff losses. This also influences what machinery is suitable for disturbance and what pasture species to sow and the anticipated pasture production. Some of the better soils are the medium brigalow clay soils (vertosols) and brigalow softwood scrub on silty soils, while soil types regarded as being more difficult to rehabilitate include the sodic soils (sodosols and dermosols) supporting Eucalypt woodlands in lower rainfall areas. The surface has to be rough to hold water and allow time for infiltration. The rougher the surface starts off gives better pasture establishment results. Levels of cover desired were not well defined, however, suggestions of a minimum of 40% was necessary, with >70% being desirable at the end of summer. Maintaining high ground cover at the end of the dry season was recognised as a desirable pasture management goal, to protect soils from early storms, but it was not used a key indicator of management success.

Some of the landholder comments on ground cover and surface conditions include:

- Heavy machinery is required for good disturbance to increase water infiltration and establishing grass on bare tablelands red soil (basalt).

- Hard setting yellow clay needs deep ripping or blade ploughing to maintain some soil structure for water infiltration and hold the soil together; disc ploughing causes loss of structure and powdering surface and sets hard and becomes bare again. Tynes are better than discs for opening the soil and not setting hard quickly.
- The tree clearing bans (Government) and brigalow regrowth are causing an increase in competition to grass and reducing cattle production.
- Have lot of uncleared country and am not allowed to touch it (Govt. tree clearing bans).
- Steep saline subsoil gully heads have natural erosion irrespective of grazing and are insignificant in area so are not treated, but lose soil down creeks.
- Must know soil types and avoid 'melting' subsoil types (sodic) – brigalow clay soils will recover (rehabilitate) to pasture; hard set, bare red ridges are hard to rehabilitate.
- Urochloa (Sabi grass) is spreading and grows fast early after rain on good soils after ripping.
- Cover rating of 4 or 5 provides sufficient organic matter for recovery, not rating 3.
- Start rehabilitation when still have some native pasture plants present for best results.
- Leave soil well disturbed and rough to collect rain and get infiltration.
- Pre-rehabilitation the gullies ran dirty water in creeks, to 5 m deep; now after good rehabilitation they run clean water 60 cm deep.

3. Time-lag

There was no fixed time frame to determine rehabilitation success. Landholders advised a wide range in time-lag between rehabilitation and a productive pasture for cattle grazing and adequate surface cover; from within one year to complete failures. On some good quality, fertile soils, with well adapted pasture species, above average to high rainfall year and a long growing season in the first year of rehabilitation produced a pasture that was considered a success. These sites then required careful grazing management in subsequent years to maintain the rehabilitation. Some sites required careful and low grazing pressure and long rest periods when initial pasture establishment was poor. There was always question if the rehabilitation should be redone to achieve a good pasture sooner; however, the high costs and risks were the major considerations.

There were complete failures of pasture establishment in rehabilitation attempts and even an increase in erosion losses by inadequate soil disturbance and poor rainfall or drought years. A sequence of drought years ensured a failure and complete loss of the investment in rehabilitation. Some managers with poor establishment sites persisted with light grazing and long rest periods over four to ten years to achieve an acceptable surface cover. The lost grazing during these extended periods adds greatly to the initial cost of the rehabilitation.

Some landholder comments to the question "How long did perennial grass recovery to C- or B-condition take?"

- 3-4 years in one brigalow clay loam soil paddock ripped and seeded in Oct. 2003 to have good pasture , about 50% cover by 2007 and >90% cover by 2011 after several good rainfall years.
- Time-lag – expect 3-4 years after mechanical treating for perennial grass establishment, seeding, deep roots development and organic matter build up in the surface.
- Need to keep treated areas fenced and manage grazing for long periods; may graze within a year and can take many years after treating. Will be forever unless you change grazing management that caused the bare patches in the first place.
- Lag time can be as low as one year with very expensive disturbance methods and good conditions: fertile soil type and high rainfall, long growing season.

- Time may be to 10 years with lower inputs to start – keep up exclosures to control annual grazing.
- Do rehabilitation work in good rainfall years (i.e. *la Niña*).
- Time-lag depends on amount of inputs and rainfall seasons.
- Must manage grazing to allow perennial grasses to seed.
- Time to recover takes 'years' and depends on the seasons.
- Good rehabilitation in three very good rainfall years (2009-2013).
- Long lag time in poor years if start with some pasture established – response is in the good years.
- Rehabilitation can fail in poor (dry) years.

4. Barriers to rehabilitation

Barriers to rehabilitation are always costs first and then a range of other interacting issues directly related to the particular property, their landtypes, machinery availability, labour costs and availability and business situation. Insufficient knowledge of what is best to do and what methods have the best chance of success affects some landholders. Some soil types were known to be difficult for plant establishment and growth. These were the saline and sodic types, and especially if they had lost all A-horizon and had the B-horizon subsoil exposed. Other producers had lack of labour and no time available to conduct rehabilitation work that they considered would have a minimal effect on their total property gross income as a barrier.

The risks of a poor result or even total failure and loss of the investment were barriers to some landholders. It is possible to have complete failures and make the scald worse by losing more surface soil with poor pasture establishment. When to conduct rehabilitation work was a limit on occasions as an above average rainfall summer gave best chance of success, while a drought almost guaranteed a failure. Long-term rainfall forecasting was not usually considered adequate to plan for rehabilitation work months ahead. The equity level and current debt were restrictions on spending extra time and cash for some producers.

Comments from landholders on barriers to rehabilitation:

- Time – when to do rehabilitation for best chance of success and lack of time availability.
- Lack of money availability and the high costs relative to future production value.
- Poor equity position or high debt levels restricted discretionary expenditure.
- There is no good local rehabilitation information available at the time, to guarantee success.
- Input into rehabilitation depends on available budget; want to improve pastures for cattle grazing and cover for soil protection.
- Not enough is known about best rehabilitation methods for different landtypes – Need to try experimenting on own landtypes.
- Barriers – need more money, more time and extra labour to do more rehabilitation of scalds (owners are older and 'have no spare cash').
- Limitations are can't treat trees (Government legislation) and steep slopes.
- No time, no money, and too old to rehabilitate scalds.
- No machinery and not sure what to do to achieve successful rehabilitation.
- Too much other work to do, with higher cost/benefit outcomes than renovating scalds.
- High costs and poor returns from effort and long time for success or perhaps failure.
- Small areas can't be rested easily; especially on small properties.
- Snowed under with other work on property; work away from home for extra cash.

- Government bans on tree clearing and bureaucratic red tape have caused increased grazing pressure on pasture and reduced cover, with potential of scalds developing.
- Double in Shire rates and charges now with forced amalgamated Shires has added to financial pressures, so don't have money for rehabilitating scalds.
- Cattle prices are same as 20 years ago and costs have increased annually.
- Direct initial costs are a barrier, and need to graze rehabilitated paddocks lightly for a few years and this is an extra real cost.

5. Costs and benefits

Costs of rehabilitation are always high relative to the expected production return and land value. There is a wide range of costs, depending on machinery availability and pasture species/cultivars required. The benefits are not well-defined, nor are they assured. Some benefits are the aesthetics of having good pastures and being able to include the rehabilitated sites in grazing rotations. Actual financial benefits are not known and are difficult to estimate by the landholders and the community benefits of reducing sediment losses are understood but not quantified. Landholders consider their own benefits from rehabilitation and not the benefits for the wider community as a rule. Off-property effects are not easy to recognise or quantify, so are not included in on-property management decisions. Any relationship between establishing a pasture over a scald and reduced sediment and nutrient losses and the improvement in water quality reaching the GBR lagoon are not known.

Some landholder comments on costs and benefits include:

- Costs estimate \$130 ha^{-1} – for tractor, ripping and pasture seed.
- Time is 1 hour ha^{-1} for ripping and seeding with the right equipment.
- What other profit or cost benefit measures do you use? Bare areas give surrounding areas twice the rainfall – runoff from scalds to surrounding pasture is useful.
- Rehabilitation resulted in slight production increase over time.
- Is a permanent increase in stocking rate after good rehabilitation success.
- Originally unproductive bare areas that have been rehabilitated are now worth \$2000 ha^{-1}.
- Budget is critical in what can be done and results expected.
- Now too costly for mechanical rehabilitation methods, so use spelling and grazing management instead to assist rehabilitation; Need good rainfall and a long time frame.
- Need to do basic infrastructure first – fencing, waters, and get grazing management right – before starting rehabilitation testing.
- High initial cost of rehabilitation and potential low economic returns are a limit.
- Long lag-time from mechanical treatment to getting any return.
- Can rehabilitate from poor D-class to top C-condition, by ripping and seeding, with good grazing value; can take a long time, many years.
- 100% bare scalds in 2005 and to 100% pasture cover in eight years with good management,
- Should keep photo and management records of rehabilitation paddocks.
- Estimated rehabilitation costs approximately \$40 ac^{-1} for cultivation plus \$20 ac^{-1} for seed plus cost of excluding grazing (fencing or whole paddock rested). This is a high cost on small properties and they need infrastructure developed first (smaller paddocks + waters).
- Buffel grass must be let seed in the first year for survival and plants must be well established before grazing (first year spelling is recommended).
- Bambatsi panic works well for rehabilitating heavy clay and wet soils.

- *Bothriochloa pertusa* (Indian bluegrass/couch) is a naturalised grass 'weed' and is first to regrow in the wet season, with Urochloa (Sabi grass) growing quickly, but it burns off early by April. Both can help cover bare areas.
- Need good surface disturbance to get grass establishment (water infiltration).
- Cutter-bar costs twice as much as ripping and takes twice as long – need a higher external financial subsidy – twice fuel costs + extra wear and tear on machinery.
- Lose some grazing of whole paddock to protect a small renovated patch is a real cost.
- Closing up until grass seeds over first summer is essential, but is a business cost.
- Scald rehabilitation is very expensive even with own machinery.

6. Social and economic drivers

There is not any direct social pressure on landholders to conduct rehabilitation of scalds. However, there are improved aesthetic values (appreciated by landholders), as well as a potential to increase in cattle production and property sale value from rehabilitating bare areas. There can be an implied poor manager or an 'over-grazer' by neighbours if scalds are developing and expanding. This can be subtle pressure to improve land management, but not necessarily to conduct rehabilitation works. Producers often cannot make a good estimate of the financial gross margins/AE before and after regeneration. The direct costs can be estimated in advance, but the effects on subsequent returns are uncertain and difficult to calculate by landholders.

Stage of property business development is critical for producer input to rehabilitation of relatively small degraded/bare patches. Beef producers don't have time or money to put into small patches while they have infrastructure to develop or repair, and labour and cash are usually limited. Producers need significant Government financial input and often additional knowledge to get bare patch rehabilitation achieved successfully.

Some comments from landholders on social and economic drivers include:

- I believe in rehabilitation of scalds and clay pans and don't like to see bare areas,
- Hate to see scalds, bare patches - want grass cover.
- Must manage cattle numbers – adjust stocking rates to keep good pastures, but can be caught out with droughts or a late start to summer rain.
- Have small areas bare and it is annoying to see them.
- Producers need to see the changes after rehabilitation and that it works – see the pastures succeed and cattle perform.
- Must manage after rehabilitation works – grazing pressures and time of grazing are critical.
- No external social drivers; can see benefit of rehabilitation work on land condition and on cattle production – It pays to do it where success is likely.
- No local social pressure, but do discuss what rehabilitation is happening locally and finance options.
- Am aware of others around district that have bare areas and need rehabilitation.
- Joint groups such as LandCare to increase awareness between local producers of all issues, such as rehabilitation of scalds. Some LC groups encourage others to try rehabilitation and use visible sites near roads. Need flexibility in what should be done on different properties – different soils, management, grazing pressures, knowledge, machinery, etc.
- Land prices are grossly overvalued relative to animal production and sale values of cattle. At current local prices need about $2500 per beast area sold to make an investment in land pay; makes it expensive to pay extra for rehabilitation work.

- Yes some social pressure to do rehabilitation of scalds. Other people in the area seemed to be doing it but the social pressure wasn't the reason they did it. They felt they would do it anyway even if there were no social pressure because it was the right thing to do for the land.

Landholder comments on Government financial incentives for rehabilitation works:

- A subsidy of 50/50 of costs is fair – 50% to include owner labour and machinery.
- Do incentive payments make rehabilitation worthwhile? – Yes.
- Incentives – amount and types depend on stage to business development; Government to pay fuel, fencing, seed – all direct costs mainly; labour subsidy in cases; some don't have own good machinery for ripping and would need Government financial help.
- Can the Government highlight bare areas on properties via satellite photos and advise owners of where important/bad areas are and what can be done about them – by soil type.
- Reef Rescue funding 50% for subdivision fencing is enough, but need more fencing of different land types for ease of rehabilitation and grazing management.
- Incentives – the 50% LandCare system is working well – must include in-kind labour of owner plus his machinery, etc.
- Need over 50% incentive payment in drier years, perhaps to 75% - can be failures and longer lag times for any return?
- Incentives: between 50-75% of all costs; Not 100% as owners need to have their own money in rehabilitation to encourage continuing management.
- Need higher Government % subsidy for rehab of smaller bare areas; it is expensive and of little grazing value relative to whole property.
- The 50% subsidy is good in good seasons when 'guaranteed' of success; require 75% subsidy in poorer, drier years or where success is not 'guaranteed'. Grazing management is critical and stocking rates must be reduced.
- Need cash costs of actual rehabilitation job on each property, not a percent of a general cost based on generic works. Some sites are more expensive than others, e.g., may require two chainings and stick raking and heavy dozer to rip. Need to take into account hills, regrowth, gullies, difficulty areas, time required, machinery types required, chaining, stick raking, ripping and seeding costs.

An alternative was expressed by several landholders:

- No incentive should be offered as it is unfair to good managers who maintain pastures and manage grazing in all seasons and it rewards poor managers.

Common landholder comments on their rehabilitation works:

1. If rehabilitated areas are kept as set stocked they revert back to bare scalds; paddocks or patches must be able to be spelled in new rehabilitation work and this requires fencing and water.
2. Cattle selectively graze the rehabilitated areas – sweeter grass after soil disturbance (nitrogen released) and sowing new pastures.
3. Spelling and short rotation grazing is needed following rehabilitation of bare silty areas; I have a successful method to rehabilitate fertile silty soils: by ripping, seeding, spelling, long-term grazing management; adding hay initially is also beneficial.
4. Select responsive land and soil types e.g., heavy fertile soils suit pasture rehabilitation.

5. Blade plough and sow pasture grasses and legumes, include 0.5 kg silk seed for rapid cover; need litter and grazing control in first couple of years; blade plough in winter and sow seed.
6. No grazing for first summer after rehabilitation; light grazing in first autumn and winter if good establishment; no or limited grazing over second summer; then graze according to seasons and pasture production.
7. No economic return from light eucalypt country rehabilitation (poor pastures) Vs. good returns from rehabilitating scalded brigalow country (productive sown grass pastures).
8. Build contour banks around wash areas to divert water.
9. Graze conservatively and set stocking with limited spelling maintains pasture and cattle production; need to look after topsoil and perennial grasses, must manage grazing on your pastures.
10. Producers need more grass over 'hot' spots (bare eroded patches); property must be at suitable stage of business development to be able to give time, energy and money to work on these bare areas. Can't give time for patch rehabilitation when still developing main property infrastructure such as paddocks and waters.
11. Need more advice on rehabilitation treatment requirements e.g., disturbance methods, fencing, pasture seed, future grazing management, keeping cattle off treated areas, electric fencing or barb fencing of susceptible areas, costs and returns.
12. Different soil types respond differently to heavy grazing, rainfall and resting; carrying capacity is different on different land types and this makes over or under grazing likely on different land types in one paddock; can cause overgrazing damage and an increase in the bare patches.
13. Clear fence lines and build contours across roads and planned road drains to prevent wash and erosion; positive planned action can prevent future scald development and gives its own benefits.
14. Monitor small scalds and use grazing management for improvement in their condition, such as resting; need to manage grazing over much wider area than the rehabilitation site, usually need to manage grazing over the whole paddock and stop water wash over scalds.
15. Consultants suggests using high stock density grazing to improve regeneration of bare areas, but can cause poor and slow establishment; doesn't seem to work very well.
16. Stage of development of property affects interest, time, money, labour, weeds, etc. and capacity available for scald rehabilitation.

Management practice survey

A summary of the grazing management practice survey of landholders in the Burdekin and Fitzroy catchment found three main forms of managing declining land condition: 1. Adjust stocking rates, fence for stock control and frequently use rotational grazing; 2. Stocking rates were not adjusted and the occasionally use of rotational grazing; and 3. Use set stocking rates and adjust for pasture annual growth.

Of the landholders with degraded grazing land, methods of recovering condition included: An assessment of the impact of the degraded area on productivity of the whole paddock, and then manage grazing accordingly. This may include fencing to control grazing, building diversion banks up slope, breaking the surface of scalded areas and sowing grass seed. Along with these rehabilitation methods, there should be a review of grazing management and stocking rates across the whole paddock. Other owners who were aware of the degradation problem did not make management changes and considered the degraded areas as simply 'out of production'. The time and expense of regeneration, if possible, was not considered the best use of their limited resources.

3. Review of rehabilitation of degraded grazing lands

Two reviews on the rehabilitation of grazing lands are reported: first, from a systematic analysis of the relevant, international publications drawn from papers, reports, and other published sources, and second, from the up-to-date information gathered direct from the Kimberley region on the largest successful rehabilitation project undertaken in Australia.

Literature Review Summary

An analysis of over 200 publications from papers, reports, reviews and other published sources on water quality and the GBR, and land rehabilitation, particularly related to grazing lands was based on the six project objectives. This published information complements the information obtained from the landholder surveys on their practical experiences in rehabilitation attempts, and from the field rehabilitation experiments. The summary of the literature review is reported here and the full review is reported in Part II (Silcock and Hall 2014).

Summary

Over 200 potential references were reviewed with many covering aspects of water quality, grazing lands and their effects on the Great Barrier Reef (GBR), and rehabilitation of degraded landscapes. There was little reported information on the mechanical rehabilitation of bare, D-condition grazing lands in the reef catchments. There is, however, literature on machinery suitable for soil surface disturbance, pasture technology for developing permanent perennial pastures and on grazing management for improving C-condition land. This literature review is complementary to the other two aspects of this project, the field experiments of mechanical disturbance, and the landholder surveys on their rehabilitation experiences.

Rehabilitation of degraded grazing lands of the GBR catchments has become a major focus of the Reef Rescue Programme primarily because the large area of land involved has the potential to contribute significant sediments and nutrients to the GBR lagoon. Poor water quality from grazing lands has the capacity to do serious damage to the reef ecosystems. Any reduction in sediment runoff from eroding land implies a worthwhile improvement in water quality entering the GBR lagoon. A limitation with this idea is that it assumes almost no net losses as the turbid water moves downstream and minimal ability of the marine and reef ecosystems to recover from short-term stresses. Recent published research indicates that neither assumption is correct. It also does not recognise the dynamic nature of natural ecosystems in the semi-arid tropics where there is perpetual shifting of species dominance and mixes in response to the perturbations in the surrounding environment, particularly grazing pressures, climatic extremes and high seasonal variability.

High levels of sediment, pesticides, nutrients, or fresh water does kill or weaken some reef species, however, other species benefit, either directly by better using the incurring resources or by expanding into the ecological gap left by the damaged suite of species. For example, the increase in algae due to extra sediment and nutrients at the expense of hard corals is well known, but if the perturbation is short-lived (like a flood plume) or not widespread, then recolonisation by the displaced species can occur, provided no ongoing trauma occurs. However there is good evidence to suggest that the amount of sediment and nutrients reaching the ocean from agricultural and urban land is well above the 18th century levels, and thus could be damaging the reef ecosystems and the fishing and tourism industries that depend on them being in good health. There is also data to show that the quality of pastures on grazing lands is often poorer than 150 years ago and that areas of land may be denuded more than is desirable, particularly by grazing in drought periods.

Thus it is beneficial to all if better pasture quality and cover on grazing lands is encouraged and achieved. The main questions are what should the pasture quality target be and how can this be achieved at a realistic social and economic cost. Because the relationship between runoff and sediment load against ground cover is strongly non-linear, logic says that the greatest benefit will accrue from revegetating the barest areas, such as D-condition land. This eroded land is often found close to major watercourses so that the payoff is greater for the investment made in improvements because there is little scope for deposition of entrained sediment between those eroding areas and the nearby fast-flowing channel water.

Published studies, plus this project's research, have shown that the regeneration of healthy, perennial pastures on D-condition land is possible on many soil types provided several pre-conditions and favourable seasonal co-incidences are met. These include: grazing animals, including macropods; have to be excluded completely for some time; significant disturbance of the soil surface is needed for all soils that do not have a natural loose surface; and, good growing season rainfall has to be received shortly after the surface disturbance and pasture seed has been sown.

If good rains are not received soon after rehabilitation, resowing of pasture seed may be needed along with re-cultivation to loosen and roughen the soil surface. There is a broad range of appropriate cultivation implements available for rehabilitation work, but the options for perennial grasses and legumes to sow are limited, as is the availability of adapted native species seed.

Field Review: Kimberley Region, Western Australia

To verify the rehabilitation information identified in the literature review, a field review was conducted of the largest successful rehabilitation project undertaken in Australia, the Ord River Regeneration Reserve (ORRR) to reduce sediments entering Lake Argyle in the Kimberley region of northern Western Australia (WA). This work is regarded as the most successful extensive regeneration work conducted in Australia and covers some 46000 km^2 of the Ord River catchment above Lake Argyle. The rehabilitation commenced in the early 1960s and proceeded for some 30 years with the WA Government resuming the cattle grazing land, totally destocking of cattle and feral animals and conducting extensive mechanical disturbance and pasture seeding works throughout this period. The area is now rehabilitated with exotic grass-dominated pastures, is not grazed, and is managed as a national park. Recent commercial property rehabilitation work in the Fitzroy River catchment of WA was also inspected as part of this review. The full report is published as Part IV (Hall 2014 b).

Lessons for regeneration of grazing lands of the reef catchments of Queensland

Reviewing the rehabilitation of these D-condition field sites has provided information with relevance to rehabilitating degraded grazing lands in the reef catchments of Queensland.

The Ord River catchment of Western Australia was severely overgrazed over about four to six decades in western areas, initially by sheep grazing and later by uncontrolled cattle grazing. Grazing locations and stock numbers were not managed so the best landtypes near permanent waters in rivers were degraded to D-condition by extensive surface sheet erosion. This situation of uncontrolled grazing is not a practice followed in Queensland, however, a combination of heavy grazing and droughts can produce similar land condition results on a smaller scale. This type of erosion can be avoided by improved landholder knowledge in pasture management, resulting in better forward planning of stock numbers and grazing pressure, as part of drought planning strategies. Improved accuracy of climate forecasting will assist this management approach.

Initially the Ord River Regeneration Reserve (ORRR) regeneration developed very slowly, while total grazing pressure was not managed, resulting in continuing over-grazing of the native pasture and the new sown exotic pastures. Successful regeneration required complete removal of cattle, donkeys and camels, and restricting native fauna grazing by reducing the spread of water supplies. To obtain grazing control the WA Government eventually had to resume full control of the land. In Queensland, similar effective grazing control can be obtained on the smaller degraded areas while the land remains under private ownership. Financial support from the Government (both State and Federal) may be required in some circumstances and can be justified by the wider benefit to the whole community by regenerating degraded patches to improve water quality flowing into the Great Barrier Reef (GBR).

In the Ord River scheme, mechanical disturbance methods for establishing pastures were tested during the 1960s and selected for the soil types and slopes. The off-set twin disc machinery that was widely used in the ORRR was not successful in some environments of the Fitzroy catchment in a recent rehabilitation program. Much of the degraded Ord River catchment was flat to gently undulating which provided the opportunity for shallow banks and cultivation on the contour to contain most of the water, and allow infiltration in the seeding zone. The friable clay and clay loam oil types of the original grasslands of the Ord River were also more suited to pasture establishment and production than are some of the hard-setting red earth soils supporting spinifex at the Fitzroy sites. As the Ord river areas were extensive and bare, the contour marking out, and disturbance and seeding passes were relatively rapid and straight forward. The steep gully erosion areas were avoided and not treated, but eventually they stabilised after the surrounding country was revegetated. In the Queensland GBR catchments, most soils of the grazing lands or 'hillside' eroded areas are now considered treatable with current mechanical disturbance methods and existing exotic pasture species. Severe gully and streambank erosion requires a different management approach; however, with successful rehabilitation of bare areas across the grazing lands, these water courses may become more stable and lose less sediment into the Reef Lagoon. Grazing management education, followed by improved grazing practices, and aggressive mechanical disturbance treatments are both required to achieve higher ground cover levels and to maintain better condition pastures across the landscape. This will result in improved pastures, higher economic returns, and a reduction in sediments and nutrients leaving grazing country over the longer-term.

Professional input into the design and construction of any water holding systems, such as horseshoe ponds, is necessary to have the best opportunity of collecting maximum water and maintaining structures for many years. Poorly designed structures can fail and concentrate water which can create more serious erosion and even gullying. Using larger machinery, such as a G16 grader, has been most effective and economic in constructing water-ponding banks in the WA Fitzroy. Qualified surveying staff and large machinery are available in Queensland to conduct these designs and structures where necessary. Shallow ponding with some ripping or disturbance, without seeding exotic pastures, has produced varying degrees of herbage cover from early seral native species colonisers within one or two good summer seasons. Converting this initial cover into useful grazing pastures is the next challenge.

Feral animal grazing management was necessary, as the fresh pasture protected from cattle grazing is selectively grazed by marsupials, both kangaroos and wallabies, and their populations can quickly grow to plague proportions. This will destroy any pasture seedlings establishing in the regeneration area as is occurring close to the Fitzroy River in the West Kimberley. This problem of high marsupial populations will arise throughout Queensland and will require managing for successful rehabilitation of degraded areas.

Pasture species were evaluated for the Ord catchment soil types with the best adapted exotic tropical grasses *Cenchrus ciliaris* (buffel grass) and *C. setiger* (Birdwood grass) and the forb *Aerva javanica* (kapok bush) being selected. Experiments testing potential species, seeding rates and depths, combined with surface disturbance and shallow ponding banks were conducted to develop the methods most likely to be successful. In Queensland, the Reef Rehabilitation Project (RRRD.024) has evaluated some commercial mechanical disturbance methods and pasture species with potential to rehabilitate degraded D-condition landtypes in the two major reef catchments of the Burdekin and Fitzroy Rivers. There is an established seed industry capable of supplying adequate quantities of quality seed of the best adapted grasses and legumes. The pasture species suitable for rehabilitation of degraded soil types are also productive grazing pastures. Sowing and species recommendations are included in the Reef Rehabilitation Technical Report. Queensland does not have the restrictions on sowing proven exotic pasture species in grazing lands, as is a limitation in the WA rangelands.

A good rainfall summer season in the first year is a great assistance in achieving a successful base pasture to start the rehabilitation process. This first year pasture will then develop much faster if it receives a run of good seasons. In the Ord, regeneration was slow for the first two to three decades and then made rapid progress during the run of higher rainfall years in the 1990s, to produce the ‘spectacular’ recovery reported in 2002. By this time total grazing was controlled and there had been widespread establishment of plants to produce a seed supply, which allowed the good seasons to produce dense, well grown and seeding pastures across much of the regeneration area. Soil surfaces are now soft, not scalded, and have extensive cryptogam cover, indicating their good health. For rehabilitation of degraded areas in Queensland, these extended time periods and cycles of consecutive good seasons will need to be considered. Rehabilitating D-condition landscapes is not always successful and is not a short, several years, process and can take decades under less favourable circumstances.

A full report on this field review of the rehabilitation programs in the Ord River and Fitzroy River catchments of the Kimberley of WA is included in Part IV (Hall 2014 b).

Discussion

The three research approaches provided direct measured and indirect evidence of the potential and options to rehabilitate degraded D-condition grazing lands of the GBR catchments. The multiple options for mechanical disturbance and seeding was demonstrated and the rehabilitation success was recorded up to 14 years after the initial treatment. The landholder surveys provided evidence of the successes and failures of rehabilitation works across a wide range of landtypes and regions. The literature review and field review of the largest rehabilitation works in Australia provided further evidence of the main issues associated with rehabilitating D-condition grazing lands and that rehabilitation can be achieved on a large scale with the correct inputs.

The project conducted measurements on the effects of mechanical treatments on bare D-condition patches in native and sown pastures on five soil types in grazing land in the Burdekin and Fitzroy catchments. By the definition of D-condition land, mechanical and/or chemical intervention is required to produce soil cover limiting further erosion and losses of sediment and nutrients, within an acceptable time-frame. The three project experimental sites were in the bare D-condition eroding state when their rehabilitation treatments commenced. Data was produced on mechanical treatment effects on pastures, soil surface and sub-surface conditions, ground cover, rates of cover development, runoff loss of water, soil and nutrients, and on regeneration costs. The field experiment period was from October 2011 to June 2014. Other forms of D-condition land such as severe gully erosion and woody weed invasion require different intervention approaches and were not included in this study. There are recommendations on effective treatments and subsequent management to rehabilitate bare D-condition grazing land in the two catchments.

On-ground inspections of potential experiment sites were conducted to select the field experiment sites, because the initial Landsat imagery investigation did not identify if the long-term low cover areas on particular properties were caused by historical over-grazing, natural landscape phenomena or cultivation effects. This imagery analysis work is yet to be attempted. There were not sufficiently detailed soil maps available to over-lay the bare patches to accurately identify contributing soil types. This is also a separate study required to advance the current mapping of bare D-condition areas.

Field experiments, landholder survey and literature review – application of findings

Suitable methods of mechanical rehabilitation

The three experiment sites have demonstrated that there are successful mechanical rehabilitation methods available for some soil types and locations across the Burdekin and Fitzroy River catchments. There is no single method recommended for all situations, however, with the appropriate high levels of mechanical disturbance, a sown pasture of adapted species can develop given suitable climatic conditions over the following two to five years with careful pasture grazing management during the establishment period.

There are no current methods suitable for rehabilitating some soil types with their chemical and physical constraints to pasture establishment, survival and growth. More intensive disturbance and soil amelioration inputs, as yet unidentified, will be required to have a chance of establishing pasture cover on such soil types. The sodic dermosol soil at the Spyglass experiment site was one soil type that will require further research to identify rehabilitation methods. After deep ripping some early seral native plants (*Sporobolus* and *Portulaca* species) established in hollows on this soil type. As surface silt washed into these shallow hollows, these plants may allow perennial sown pasture species, such as *Cenchrus* and *Urochloa* species, to establish as the surface catches a deeper sediment layer, starting a pasture development sequence, providing rainfall conditions remain favourable over several years.

Selecting the better soil types, such as potentially more fertile grey and black cracking clays (vertosol) and loams (sodosol), will give the greatest chance of success. The extensive grass plant death that occurred across all treatments at Spyglass between April 2012 and April 2013 could be attributed to the effects of the extended drought period, with an extra four months of hot dry conditions through spring and early summer, on shallow-rooted first-year plants. However, the high salinity and sodicity, as well as reduced nutrient availability from the high alkalinity in the sub-soil to the three soil types could have also been a contributing factor. To identify if these sub-soil constraints are detrimental to long-term plant survival at this site will require monitoring the pastures into the future. Determining if there are suitable soil amelioration products and approaches available will require further study.

Access to heavy machinery is required to conduct a sufficient level of disturbance on these hard set D-condition bare scalded patches. Dozers, graders and some 200hp four wheel tractors are required for blade ploughing and deep ripping. The lack of such equipment on properties is a hindrance to rehabilitation even when there is an awareness of the problem and knowledge of what methods should be tried. Hiring contractors for rehabilitation adds greatly to the costs and is a disincentive. An alternative approach suggested by some landholders in this position was to investigate alternative disturbance methods using high stock density grazing, with pasture seeding early in summer after rain when the surface can be broken by hoof impact. Electric fencing has potential to help concentrate high stock numbers on these relatively small bare areas and could also be used to keep cattle off the site to allow any pasture recovery. There are no known attempts at rehabilitating D-condition patches by this method in any of the experiment areas; however, the landholders have interest in seeing if it is possible and under what circumstances. There is anecdotal evidence of hoof-impact rehabilitation by wild animals from southern Africa.

Soil disturbance levels

The greatest surface and sub-surface disturbance was from blade ploughing followed by deep ripping. These methods hold maximum surface water and assisted deep infiltration to hold moisture for the developing pasture. Even with a high rainfall first season and good pasture establishment and growth to 3000 kg ha^{-1} dry matter, the second rainfall year has a significant bearing on the rehabilitation success. Three consecutive high rainfall summers at Banana had a high yielding mixed species pasture, compared with Injune taking four years to produce a 70% cover pasture in average or poorer years, and near 100% cover by eight years, with the final years having average or better rainfall seasons. The experience at Spyglass shows one good summer can produce a good mixed grass and legume pasture, however, with a drought occurring in the second summer, pasture survival can be low and new plants need to establish, irrespective of the level of disturbance.

There is a wide range of potential equipment available for creating high levels of disturbance in bare patches. There are varying types and sizes of blade ploughs and cutter-bar machines which break up the sub-soil and lift the surface, sometimes from as deep as 50 cm, producing a roughened surface that can last for many years. Deep ripping equipment is usually a heavy drawbar-mounted toolbar with three or four 50-70 cm tynes, but can include heavy tyned chisel plough types. These usually rip to a shallower depth such as 20-30 cm. There are also single tyned trailing implements that can penetrate over 50 cm but these are usually too slow and expensive to be used for grazing land rehabilitation work. High horsepower tractors are required to use this high disturbance machinery on hard-set bare areas.

Chisel ploughing with heavy framed multi-tyned implements creates less deep sub-soil disturbance then the blade ploughs, cutter bares or ripper tynes, and is suited to the better soil types such as vertosols (cracking clays) than most hard setting scalded soils. Although these implements can give 100% surface disturbance, the soils are usually prone to surface sealing and can re-set again after a short time and little rainfall, making pasture establishment difficult, and likely to fail.

The crocodile plough seeder has advantages of requiring a smaller machine to pull and can run over logs and stumps through a woodland and can distribute a wide range of seed types, it rarely gives sufficient surface disturbance to get a pasture established on a scalded bare surface of D-condition land.

Pasture seed distribution is required to establish a pasture and maintain cover on bare patches. In many cases native pasture plants would be successful; however, there is rarely seed available of the appropriate species for the soil type. Any native pasture seed when available is more expensive than most exotic pasture species. Roller drum seeders mounted on blade ploughs or above ripper toolbars can be used for seed distribution while conducting the mechanical soil disturbance. The three-point linkage fertiliser spinner broadcasters are suitable for heavy and coated seed distribution. There is always a problem spreading the fluffy (uncoated) grass seed.

There was a successful rehabilitation pasture established, at varying levels, in the first year at Spyglass with all treatments. The pasture plant population, species mix and summer growth was sufficient to start a pasture to rehabilitate this site on two of the three soil types. However, the second summer started with an extremely dry spring followed by a hot dry early summer. It was not until a cyclone (Oswald) influence arrived at the end of January that useful rainfall occurred. This meant the pasture growing season was delayed from the usual October storms to late January, some four extra months of hot dry conditions. This was too long for most of the first year grass plants to survive. Their root system would have been shallow from seedling emergence in mid-December 2011 on 96 mm rainfall and maturing by April 2012.

The shallow ponding methods of holding water onto scalds above a shallow bank, usually in a “U” shape, for an extended period after rain are more suited to the drier inland clay pans than to the bare patches in the more undulating and higher rainfall Burdekin and Fitzroy catchments. In a review of shallow ponding for rehabilitating degraded native pastures by water spreading, Koch *et al.* (1994) reported this method could effectively utilise runoff to rehabilitate pastures adjacent to water courses on flat country in south–west Queensland. This ponding approach requires some similar inputs to those required in the Reef catchments, such as mechanical disturbance by creating low banks, sowing pasture seed along the banks, and grazing management to allow pasture establishment and seeding

Recommendations on adapted sown pasture species for rehabilitation

Selecting grasses and legumes well adapted to the soil and climatic environment of the rehabilitation sites is critical for any chance of success. There are a range of both stoloniferous and tussock type grasses and herbaceous and shrubby legumes suited at varying degrees, to most soil types if the Burdekin and Fitzroy catchments. Selecting the most suited species combination will give the most chance of producing a successful pasture cover. An understanding of the soil type to be treated is necessary to select the appropriate species, as some are only suited to either light or heavy textures soils. The species sown at the three project sites include many of the most suited species for these catchments, such as buffel grasses, Indian bluegrass, Sabi grass, creeping bluegrass, and legumes such as butterfly pea, stylo species and desmanthus. Some cultivars failed to establish in any significant population at these sites, which may be due to species not adapted to the soil types and also the rainfall conditions experienced.

Rainfall amounts and its distribution have a major influence on the success or otherwise of a sown pasture establishment in all environments. Years of above average rainfall in the GBR catchments will provide the most likely chance of rehabilitation success, as mean rainfall is marginal for exotic grass establishment on all but prepared seedbeds with sub-soil moisture and weed competition managed during the seedling phase. The SOI is a reasonable indicator of either above or below average summer rainfall in northern Queensland when the index is either very high or very low respectively. Selecting years with the strongly positive SOI values will give a higher chance of receiving sufficient rainfall for successful rehabilitation and pasture establishment in the first summer. Establishment failure can be expected in low rainfall or drought years.

A soil profile nutrient and chemical analysis is recommended before attempting to rehabilitate a badly eroded site, such as where 30-50 cm of the topsoil has been lost. Especially assess the salinity and sodicity levels and select pasture species best adapted to these soil conditions. Even with the surface soil suitable for pasture growth it is possible the sub-soils of badly eroded surfaces will have plant root constraints, such as high sodicity or alkalinity levels. Treating high alkalinity soils will require the addition of high rates, such as 2-3 t/ha, of fine gypsum to improve the likelihood of pasture survival even with good first year establishment on a more favourable surface soil.

At the Spyglass eroded site, with 30-50 cm of topsoil lost, the three soil types all had high alkalinity levels in the profile (e.g., pH of >8) as well as medium to high salinity (EC >0.7 m^S/cm), and were medium to strongly sodic (ESP >15%). The soils also have a degree of dispersion at the surface of the dermosol and increasing below 30 cm in the other two soils. These soil conditions are not inductive to pasture growth, however, conditions in the surface of the sodosol and vertosol soils were less harsh, and allowed good pasture establishment and growth in the first year after disturbance.

The sub-soil chemical constraints, together with the drought conditions over the second year, could have contributed to the death of most first-year grasses. The poor summer rainfall would then have contributed to the relatively low pasture growth over the second year. The high alkalinity levels would restrict nutrient availability in the three soil types; however, soil disturbance is also known to release available nitrogen which initially promotes grass production.

To avoid facing serious sub-soil constraints for pasture establishment and growth, rehabilitation of bare or scalded patches should commence before the more favourable A-horizon has been completely lost.

One widely adapted stoloniferous grass, *Bothriochloa pertusa* (Indian bluegrass/couch) has potential to stabilise many soil types, and however, it can have low drought tolerance and may leave surfaces exposed after an extended drought. Also, some landholders do not favour this grass due to an apparent lower production than some other potential species.

The grazing value of pastures on rehabilitated sites may be much lower than the previous pasture quality. At Spyglass where up to 50 cm of surface soil had been eroded, the subsoil fertility the high pH limited nutrient availability. This meant the pasture quality at the first opportunity to graze, in the first winter after plants had seeded and matured, was below animal maintenance levels. Pasture quality in winter was higher at the blade ploughed site in the Fitzroy where there had been only a few cm of A-horizon eroded.

Management after rehabilitation

Managing for total grazing pressure after rehabilitation will define the success or failure after an initial pasture establishment. Pasture rest from grazing is required to develop a strong root system, allow seeding and subsequent further seedling recruitment. These factors are required over several years at least to maintain the initial successful rehabilitation. A population of kangaroos or wallabies on a small area of rehabilitation can have a deleterious effect on pasture survival equal to grazing by cattle. A spelled patch of pasture within a grazed paddock is attractive to marsupials. If management doesn't allow for these at least annual resting periods, the rehabilitation work will be in jeopardy. Landholders trained in pasture management principles (e.g., GLM, RCS workshops) will be able to monitor their rehabilitation success and manage annual grazing accordingly.

Temporary electric fencing may be an option to manage grazing of rehabilitated patches within larger paddocks. Properties with multiple small paddocks, such as a cell system, have an easy option of managing timing and amount of grazing of a relatively small part of their property, a single cell paddock, compared with landholders using larger rotational grazing methods or systems with few paddocks.

Incorporating D-condition rehabilitation methods and subsequent management into Grazing Best Management Practice workshop module along with other topics such as soil health, grazing land management, animal production and whole business management has the prospect of explaining what encouraging landholders to conduct more rehabilitation themselves. The module would demonstrate what needs to be done, when, what areas to select, how to manage the sites in subsequent years, what costs and benefits to expect. Such an approach would add to better understanding and knowledge of the bare D-condition land problem by landholders and possibly increase their desire and social pressure to improve overall pasture and grazing land management on their properties. This should improve land condition more broadly and increase long-term farm profitability.

The aim of managing pastures after successful rehabilitation is the same as for all grazing land and can be defined by the following quote from the FutureBeef web site: *'Grazing land management is about managing cattle (numbers, types and location) to make the most of your pastures while maintaining or improving land condition and biodiversity. Healthy country means healthy cattle and a healthy, sustainable business. Managing for climate, wherever possible, also plays a significant role in your grazing land management strategies*.'

Quantified sediment and nutrient losses from mechanical rehabilitation

The rainfall simulation measurements from two replicated plots at 16 sites, has quantified sediment and nutrient losses from the three experiment sites, all with different levels of pasture rehabilitation success. These measurements covering one, three and nine summers after the initial mechanical disturbance and reseeding treatments, demonstrate the differences between methods, soil types, locations and seasonal conditions.

The rainfall simulations were conducted on well grown pastures at all three sites in winter following above average rainfall over the 2011-12 summer showing good conditions for controlling sediment losses. At Spyglass, the greater the level of disturbance was highly correlated with increasing the amount of infiltration and soil moisture and inversely related to the time to commence runoff in a rainfall event. There were similar proportional responses at the Banana blade-ploughed site, which was the roughest surface measured, and at the Injune deep ripped site. The bare areas remaining at these sites produced the most sediment and produced runoff in the shortest time. The partial rehabilitation sites were intermediate between the good rehabilitation and the bare, scalded sites under both rehabilitation methods.

The rainfall simulation technique was successful in quantifying the sediment and nutrient losses in runoff from the one year old disturbance methods at Spyglass and at the three and nine year old disturbance treatments at the Banana and Injune sites respectively. The method also clearly demonstrated the significant improvement in water quality between achieving successful rehabilitation, even if it takes 4-6 years after disturbance, compared with achieving only partial rehabilitation, and the high losses continuing on un-rehabilitated land, even when it is almost flat. Steeper sloping eroded landscapes were not measured, but are expected to contribute higher sediment losses and they have the potential to develop gullies, contributing much higher sediment losses.

Understanding barriers and drivers of rehabilitation

The barriers to landholders doing their own rehabilitation work and the drivers encouraging mechanical renovations were discussed with the survey participants. There was a wide range of barriers, even for those landholders who had done their own rehabilitation work without any form of assistance, either by advice or financial subsidy. Knowing what to do and under what circumstances for most likely success was always a barrier. There was never a guarantee of initial successful establishment or of a long-term perennial pasture.

The availability of suitable large machinery at a reasonable price was a common barrier, even for landholders with some of their own machinery, and the total cost was always a consideration. This high cost per hectare and potential risk of failure limited the incentive and capacity of many producers to rehabilitate D-condition patches. The economics of rehabilitation was considered a better investment when larger areas of native pasture, beyond the bare areas, could be renovated and sown to improved pasture species, grasses and legumes, at the same time. Star *et al.* (2011) reported that it was economically viable for landholders in the Fitzroy region to rehabilitate the more fertile soil types such as brigalow, while the less fertile Eucalypt soils required financial assistance to break even.

Availability and access to labour was a common barrier, as properties are managed with minimal labour these days. When additional labour was required it was often not available due to the lower farm wages paid relative to the much higher rates of pay in the mining industries. This lack of additional labour often meant the landholders were too time-poor to do additional operations, such as rehabilitation, that was costly (in time and money) and probably would not ever make a positive financial return to the property. Any benefits to the wider community were not a strong incentive to many landholders to do their own relatively small patch rehabilitation. Being seen to have good pastures, land condition and cattle by neighbours was a greater incentive than any potential wider community and reef catchment benefit.

There are not reliable pasture species available for some degraded soil types, especially with exposed infertile or sodic sub-soils, and those pastures with some potential are expensive and prone to failure over time. As this project found at Spyglass there are some soils that require more than aggressive disturbance, pasture seeding and a good rainfall summer to rehabilitate (e.g., the sodic dermosols).

The law of diminishing returns was quoted as a barrier to further rehabilitation on one property as ripping, seeding and controlled grazing had improved the larger bare scalds and those remaining were getting smaller. The renovation costs were increasing, so the economics and reward for effort and risk became less attractive.

Costs and benefits of rehabilitation of D-condition bare areas

Most landholders considered mechanical rehabilitation of bare scalds was not a cash profitable operation, and the benefits to their business were not directly received in additional production and increased cattle profitability. A cost of over $200-$300 per hectare is easily reached in rehabilitation of small areas and this cost may be well in excess of the land value even when improved to good condition.

An analysis of Spyglass results using the Land Reclamation Economics Tool indicates a negative NPV for all rehabilitation options used on small areas at the experiment site. There was a potential positive return when a significant amount of a larger paddock (e.g., 2000 ha of a 2500 ha paddock) was successfully rehabilitated. This positive return is based on the extra cattle production only, and excludes the community benefits of the reduced sediment and nutrient losses and improved water quality flowing into the GBR lagoon off the rehabilitated site.

The results of property economic studies by Gowen *et al.* (2012) and Star and Donaghy (2010) show that it is not always financially viable for a landholder to conduct mechanical rehabilitation to improve bare land from D-condition back to C or B-condition. This is due to both the high capital costs involved when mechanical intervention is required plus the opportunity cost of excluding cattle during regeneration. This direct cost analysis does not include any financial or social benefits that may accrue to the wider community by rehabilitating D-condition grazing lands, such as improved water quality flowing off grazing lands into the GBR.

Incentives required to encourage and assist landholder rehabilitation

External financial incentives are required to assist landholders conduct rehabilitation of D-condition bare eroded areas. It is uneconomic from a direct landholder cattle production perspective in all but favourable soil types and in a series of above average rainfall years. Well established landholders with well-developed properties and little debt can absorb the capital costs and loss of grazing costs for extended establishment periods. Most landholders are not in this position and with the main benefits for improved water quality flowing into the GBR affecting the wider urban community, it is appropriate external subsidies are offered.

The Spyglass rehabilitation treatments required a break-even subsidy of between 50-60% of total costs. The current subsidy of 50% is recognised as suitable for most rehabilitation projects, providing soil types, adapted species and seasonal conditions are favourable. Initial success is required with this level of subsidy to cover the additional costs to the landholder. A higher subsidy of 75% would provide a risk buffer for rehabilitation works in more difficult environments and in less favourable rainfall years.

A system of transparent monitoring of the inputs and results of subsidised rehabilitation works is required to assist and encourage other properties to conduct their own rehabilitation. At present there is no information available externally on how the subsidy money was spent and the immediate and long-term results of the work. This hinders others from developing plans and attempting rehabilitating their own D-condition bare patches. Publicising the successes of subsidised rehabilitation work should educate and encourage other landholders to attempt their own work. The more D-condition land rehabilitated within the reef catchments will have a greater effect on improving water quality flowing from grazing lands into the GBR lagoon.

Great Barrier Reef – beyond grazing lands

The value and importance of increasing and maintaining the health of the GBR by improving water quality flowing from grazing lands is not only of local significance, but relevant to the Queensland and Australian psyche and State and National economies. Local and international tourism on the reef remains a significant industry for the east coast of Queensland and relies on the healthy ecosystem continuing. The World Heritage listing of the GBR demonstrates its relevance and value to the world community, so it is imperative the grazing lands, along with other agricultural and mining industries and urban communities manage water quality flowing into reef catchments. Figure 57 shows a range of water craft and the investment in private, tourist and commercial boats in a small marina on the Queensland coast, all relying on a healthy reef ecosystem and visitors wishing to see this natural wonder.

Figure 57. A small coastal marina relying on the GBR for tourism, recreation and commercial activities.

Rehabilitating degraded D-condition grazing lands, along with managing other land-based activities for improved water quality flowing into the GBR lagoon is a responsibility for all land managers and also a responsibility of Governments. The clear deep blue water on the outer reef (the right side of Figure 58) is not an issue for this review, however, the inner lagoon waters (on the left of the figure) is affected by water flowing off D-condition grazing lands. This report shows that water quality from these degraded lands can be better managed technically, and also practically, if there are appropriate policies and finances in place, and all concerned have the will to make it succeed.

Figure 58. Aerial view of the deep blue water on the outer GBR beyond the fringes of a reef complex.

Conclusions

Recommendations on grazing management, after rehabilitating D-condition scalds back to a grazing pastures, include stocking around the safe long-term carrying capacity to maintain the new land condition, of C, B or even A, and this will maximise long-term profitability (O'Reagain *et al.* 2014). These authors suggest that stocking rates should be varied in an adaptive risk-averse manner as pasture production varies between years and to include periodic wet-season spelling to maintain the new land condition. Hall *et al.* (2014) suggest that cattle producers can obtain similar ecological responses and carry similar numbers of livestock under a range of stocking methods. These could include intensive and extensive rotations or continuous grazing with summer rest periods. Therefore, there is a degree of flexibility in managing the rehabilitated areas to produce the desired outcomes for both the landholder and the wider community. These outcomes include: increased water infiltration, maintaining ground cover and a productive pasture, improved biodiversity, providing economic cattle production, and also the desired improvement in water quality running off these grazed landscapes into the GBR lagoon.

Summary of key findings:

The success of rehabilitation of D-condition grazing lands was highly correlated to seven inter-related key aspects:

1. A high degree of mechanical surface disturbance or intervention (for example deep ripping, blade ploughing, adding mulch cover after aggressive surface disturbance) is required to retain water and increase infiltration; disturbance includes overland water flow control measures.
2. Selecting the most suitable soil types for pastures to establish (non-sodic clays, clay-loams and loams); some amelioration applications may be beneficial.
3. Sowing well adapted pasture species (tropical grasses and legume cultivars).
4. Long-term grazing control over the first 3-7 years to allow pasture establishment, seeding and spread.
5. Conduct disturbance and seeding rehabilitation in years with above average seasonal rainfall conditions (*la Niña* years preferably).

6. Start rehabilitation before all topsoil is lost, exposing chemical and physical constraints to pasture development, and
7. Plan and monitor grazing management strategies early to prevent the development and spread of bare D-condition areas by maintaining surface cover, healthy soils and productive pastures.

Future Directions: D-condition grazing land and water quality

a. A detailed on-ground survey with some quantification of results of mechanical methods, grazing management and conditions of successful landholder rehabilitation sites will expand rehabilitation knowledge across the two catchments. At rehabilitated sites on multiple landtypes in the Burdekin and Fitzroy, field measurements of pasture cover, composition, and soil surface conditions to be conducted to better define what methods and management produces adequate rehabilitation. Information on successful methods and management would be valuable in the key messages for Grazing BMP for these catchments, and beyond.

b. The Burdekin rehabilitation experiment site located on the Spyglass Research Facility, Charters Towers, can be maintained and managed to evaluate longer-term rehabilitation and management requirements over a range of annual rainfall conditions. This information is required in any rehabilitation recommendations for landholders. As this study was initiated and conducted over only three summer seasons, a longer time frame is required to have confidence in continuing success of the better treatments. Therefore, continued annual monitoring of the Spyglass rehabilitation treatments over varying seasonal conditions, with recorded management history, is recommended to provide a time-series of rehabilitation from a known starting point and annual management. Less frequent periodic measurements of the Fitzroy sites will be beneficial to understand the longer-term management and seasonal conditions required to maintain pasture cover and reduced sediment losses from these previously eroded, bare D-condition landscapes.

c. Trials of soil physical and chemical amelioration methods to establish pastures on the difficult soil types is required. For example, the sodic dermosol soil, that was unsuccessful by all mechanical methods evaluated in the rehabilitation experiment at Spyglass. Research is required to develop rehabilitation recommendations for this soil and similar saline or sodic soil types in the Burdekin and Fitzroy catchments.

d. A study to identify and map the soil types with D-condition patches requiring rehabilitation across the two catchments and their extent. Then establish field experiments to determine the most economic methods of rehabilitation, their management requirements and effects of seasonal conditions on long-term rehabilitation success on these difficult soil types. This will allow a more targeted communication, education and incentive funding program. Some of these D-condition areas on shallow light textured soils, such as to the west of the Burdekin River in the Greenvale region, have been identified from detailed satellite imagery. As part of this study there needs to be an identification of the soil types suited to the various mechanical rehabilitation methods and especially those requiring additional amelioration technologies. Linking the potential economic costs and returns from various rehabilitation methods across the main soil types will help target soils and environments requiring subsidised support.

e. A review and on-ground pasture/soil condition measurement of catchment organisation (e.g., FBA and NQDT) incentive-funded rehabilitation works on properties. This would include site inspections, recording disturbance methods, grazing management history, pasture and soil surface measurements, annual conditions, landtypes and soil types. This targeted investigation would expand knowledge of what makes successful rehabilitation and would provide a better analysis of costs involved and attitudes to, and effectiveness of, external financial incentives. The successful rehabilitation works could be used to promote the methods widely across the catchments to encourage other landholders to conduct their own D-condition land rehabilitation. The new land rehabilitation costs/benefits economic calculator for landholders could be evaluated widely using actual site data and modified if required.

f. Investigate alternative and less costly methods of rehabilitating D-condition bare patches that are likely to appeal to landholders. One approach with cattle producer interest is to use high density herd impact (hoof impressions) on bare patches with added pasture seed, and timing when there is the appropriate soil moisture content. This method is suggested by some land management consultants with little or no local proven successful examples, but it appeals to cattle producers who do not have ready access to machinery for aggressive mechanical disturbance, and it may be an economical approach.

References

The references related to the detailed reports in the Appendices are included within each report.

Fraser, G. (2013). Improving the capacity to represent surface runoff processes in rangeland biophysical models. PhD Thesis, School of Agriculture and Food Sciences, The University of Queensland, Brisbane, Ald, Australia. Pp. 210.

FutureBeef (2013): http://futurebeef.com.au/resources/tools-and-services/land-reclamation-economics-spreadsheet/

FutureBeef web site: http://futurebeef.com.au/topics/grazing-land-management/rolling-ball-model-%e2%80%93-a-slippery-slope-to-poor-productivity/

Gowen, R., Edwards, B., Moravek, T. and Star, M. (2012). Economic modeling for grazing systems in the Fitzroy and Burdekin catchments IIA. Land regeneration case studies. Queensland Department of Agriculture, Fisheries and Forestry, Brisbane, Qld, Australia.

Hall, T.J., McIvor, J.G., Reid, D.J., Jones, P., MacLeod, N.D., McDonald, C.K. and Smith, D.R. (2014). A comparison of stocking methods for beef production in northern Australia: pasture and soil surface condition responses. *The Rangeland Journal*, **36:** 161–174.

Koch, A.J, Bryant, W.J., Herbert, J.G., Muller, A.D. and Grey, H.J. (1994). Guidelines for rehabilitation of degraded native pastures using shallow ponds and water spreading techniques. Department of Primary Industries, Queensland, Brisbane, Qld, Australia. Pp. 10.

Kvale, S. (2007). 'Doing Interviews'. Publisher Sage, London. (ISBN: 9780761949770). Pp. 160.

Littleboy, M. and McKeon, G. (1997). Subrouting GRASP: Grass production model. Documentation of the Marcoola version of Subroutine GRASP. Appendix 2 of 'Evaluating the risks of pasture and land degradation in native pasture in Queensland'. Rural Industries and Research Development Corporation, Australia.

McKeon, G.M., Day, K.A., Howden, S.M., Mott, J.J., Orr, D.M., Scattini, W.J. and Weston, E.J. (1990). Management for pastoral production in northern Australian savannas. *Journal of Biogeography* **17**, 355-372.

McKeon, G., Hall, W., Henry, B., Stone, G, and Watson, I. (2004). Pasture degradation and recovery in Australia's rangelands – Learning from History. Queensland Department of Natural Resources, Mines and Energy, with contributions from many rangeland scientists and graziers (Brisbane, Qld, Australia).

Moravek, T. (2013). 'Land Reclamation Economics Spreadsheet', Department of Agriculture, Fisheries and Forestry, Brisbane, Queensland Government, Australia.

O'Reagain, P., Scanlan, J., Hunt, L., Cowley, R. and Walsh, D. (2014). Sustainable grazing management for temporal and spatial variability in north Australian rangelands – a synthesis of the latest evidence and recommendations. *The Rangeland Journal*, **36:** 223–232.

Quirk, M., and McIvor, J. (2003). 'Grazing Land Management: Technical Manual.' Meat and Livestock Australia: Sydney, NSW, Australia.

Star, M., Donaghy, P. and Rolfe, J. (2011). Economically viable land regeneration in Central Queensland and improved water quality outcomes for the Great Barrier Reef. *The Rangelands Journal* **33:** 267-276.

Tongway, D. J., and Hindley, N. L. (2005). Landscape function analysis. Manual Version 3.1. CD-ROM (CSIRO: Canberra, Australia.)

Tothill, J. C., and Gillies, C. (1992). The pasture lands of northern Australia. *Tropical Grassland Society of Australia, Occasional Publication* No. 5.

Tothill, J.C., Hargreaves, J.N.G., Jones, R.M., and McDonald, C.K. (1992). BOTANAL - A comprehensive sampling and computing procedure for estimating pasture yield and composition. 1. Field sampling. CSIRO, Division of Tropical Crops and Pastures, Tropical Agronomy Technical Memorandum No. 78, (CSIRO: Brisbane, Qld, Australia.)

Troup, A.J. (1965). The Southern Oscillation. *Quarterly Journal of Royal Meteorological Society*. **91:** 490-506.

Whish, G. (ed.) (2011). *Land types of Queensland*. Version 2.0. Prepared by the Grazing Land Management Workshop Team, Department of Employment, Economic Development and Innovation, Brisbane, Qld, Australia. PR07-3212.

Appendices

Appendix 1: Climatic data at three rehabilitation experiment sites.

The mean monthly and annual climatic data from the regions of the three field experiment sites in the Burdekin and Fitzroy river catchments is shown in Table 1.

Table 1. Long-term monthly climate statistics at the three field experiment site regions.

Injune

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max Temp (°C)	33.6	32.1	30.8	27.7	23.4	20.3	20	22.3	26.1	29.4	31.4	33.1	27.5
Min Temp (°C)	19.6	19.1	16.3	11.9	7.7	4.5	3.1	4.4	8.1	12.7	15.9	18.1	11.8
Mean rainfall (mm)	89.8	89.2	61.3	41.8	33.3	30.6	29.6	25.4	26.3	47.2	74.2	89.9	638.2
Median rainfall (mm)	75.6	71.4	42.5	23	24	20.4	17	16	16.1	38.7	68.3	76.2	630.8
Rain days (no.)	6.6	6.1	4.5	3.4	3.1	3.2	2.8	2.7	3	4.8	5.9	7.1	53.2
Sunshine (hrs)													
Clear days (no.)	8.8	7.4	11.7	11.6	11.5	11.9	15	16.4	16.6	13.6	10.4	8.9	143.8
Cloud days (no.)	7.6	8.2	5.8	5.1	6.9	5.6	4.8	3.8	3	5	6	6.4	68.2
Temperature 9am (°C)	26.3	25.2	23.7	20.2	15.4	11.4	10.8	13.7	18.4	22.5	24.7	26.2	19.9
Rel. Humidity 9am (%)	59	65	62	64	70	76	71	60	51	48	52	55	61
Wind speed (km/h)	9.7	9.4	9.6	7.8	6	5.5	6	7.8	10.6	11.4	10.6	10	8.7

Biloela (for Banana)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max Temp (°C)	33.2	32.2	31.2	28.9	25.4	22.2	21.9	23.9	27	29.8	31.7	32.9	28.4
Min Temp (°C)	19.8	19.5	17.7	13.7	10.1	6.5	5.2	5.6	8.6	13.2	16.4	18.4	12.9
Mean rainfall (mm)	101.3	101.4	63.1	38	41.4	34.4	30.1	21.4	23.3	54	76.5	98.6	683.9
Median rainfall (mm)	86.2	75.8	51.2	20.2	30.1	23.6	19.7	18	12.4	45.7	79.5	94.1	684.8
Rain days (no.)	7.6	6.7	5	3.4	3.4	3	2.9	2.4	2.6	5	6.1	6.9	55
Sunshine (hrs)	8.2	7.6	7.9	7.9	7.3	7.6	7.9	8.5	9	8.9	9	8.9	8.2
Clear days (no.)													
Cloud days (no.)													
Temperature 9am (°C)	26.7	26	24.8	22.2	18.4	14.5	13.8	15.8	19.8	23.2	25.2	26.4	21.4
Rel. Humidity 9am (%)	65	67	66	65	69	71	69	64	57	57	58	60	64
Wind speed (km/h)	8.8	9.2	10.1	9.8	9.4	7.8	7.7	8.1	8.6	9.3	8.7	8.5	8.8

Charters Towers (for Spyglass)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max Temp (°C)	33.7	32.6	31.6	29.9	27.2	24.8	24.5	26.6	29.6	32.4	34.1	34.8	30.2
Min Temp (°C)	21.9	21.7	20.5	17.9	14.8	12.1	11	12.1	14.7	17.6	19.9	21.2	17.1
Mean rainfall (mm)	136.9	130.1	103.5	43.4	24	26.5	16.8	13	14.8	22	41.4	86.9	659.2
Median rainfall (mm)	111.4	108.8	90	27.8	11.4	12.7	5.8	1.8	3.1	11.7	29.3	74.7	644.8
Rain days (no.)	8.8	8.3	6.4	3.5	2.4	2.5	1.9	1.1	1.4	2.1	3.4	5.6	47.4
Sunshine (hrs)													
Clear days (no.)	7.7	6.7	9	12.8	13.7	15.1	17.8	17.8	16.9	15.4	12.6	10.7	156.2
Cloud days (no.)	9.7	9.4	7.9	5.3	5.7	4.8	4.2	3	2.5	3.3	4.6	5.7	66.1
Temperature 9am (°C)	27	26.4	25.6	23.8	20.9	18	17.2	18.9	22	24.8	26.6	27.4	23.2
Rel. Humidity 9am (%)	69	72	70	68	66	67	65	63	59	58	59	63	65
Wind speed (km/h)	6.5	6.3	6.6	6.8	7.2	7.3	7.3	7.4	7.4	7.5	7.1	6.2	7

Appendix 2: Botanical composition species identification booklet.

A booklet (33 pages) of photographs of over 60 pasture species (grasses, legumes, forbs) found in the Burdekin and Fitzroy River catchments was developed prior to recording composition to ensure consistent species identification between sites and across years by field recording staff (title page only shown below).

Pasture species photographic identification

Botanical composition of field sites

Reef Rehabilitation Project

RRRD.024

2012 - 2014

Trevor J. Hall

Department of Agriculture and Fisheries, Toowoomba

Appendix 3. Soil types description, analysis at three rehabilitation experiment sites.

Descriptions and classifications of the three experiment sites, Spyglass, Injune and Banana (by P Zund and J Ross, Qld DNRM, Brisbane).

Trial site 1. Spyglass

Spyglass **Soil A (site 4)**	***Sodic Brown Clay (Dermosol)***

Brief soil description: Shallow brown structured clay overlying buried sand, strongly sodic throughout.

Landscape: Alluvial plain, almost flat.

Vegetation: Cleared woodland. Degraded pasture.

Soil classifications: *Australian soil classification:* Sodic, Eutrophic, Brown Dermosol.

Great soil group: Brown clay *Principal profile form:* **Uf6.41**

Local name:

Scalding associated with sodic Dermosol (Soil type A)

Dermosol soil description:

Horizon	*Depth (cm)*	
B2	0-10	Dark yellowish brown (10YR3/4); medium heavy clay; moderate blocky structure; few carbonate soft segregations. Clear change to:
B3	10-40	Yellowish brown (10YR5/4), mottled; sandy light clay; moderate blocky structure; common manganiferous soft segregations. Diffuse change to:
D	40-70	Dark yellowish brown (10YR4/4); loamy sand; massive structure; few coarse fragments (subrounded pebbles); very few ironstone nodules.
Note:		*It is likely that the original surface layer (A horizon) has been lost in this degraded area. The soil was probably a texture-contrast Sodosol in its original condition.*

Surface condition: Hard setting, surface crust, some scalded areas.

Site A — *Sodic Brown Clay (Uf6.41)*

Surface fertility

pH (lab.)	EC dS/m	Cl mg/kg	NO_3-N mg/kg	Org. C %	Total N %	C:N ratio	P Meh-3 mg/kg	Extr. K	S Meh-3 mg/kg	Extr. trace elements (Meh-3) mg/kg Cu	Zn	Mn	Fe
8.8	0.22	207	<1	NA	NA		31	NA	<5	1.1	0.30	98	46

Dermosol soil profile chemistry (NQRES 4)

Depth	pH (1:5 soil/water solution)	EC	Cl	NO_3	Particle size –MIR (%)				Exchangeable cations 'Meh-3' (cmol(+)/kg)				CEC sum	ESP	Tot. element			moist WP	Disp. ratio
(cm)		dS/m	mg/kg	mg/kg	CS	FS	SIL	CLA	Ca	Mg	Na	K		%	P	K	S	%	R1
0-10	8.8	0.22	207	<1					13.45	6.72	3.75	0.68	25	15					
20-30	8.7	0.75	1100	<1					5.80	3.91	3.20	0.26	13	24					
50-60	8.0	0.72	1050	<1					3.76	2.59	1.36	0.18	8	17					

Note: Extraction of elements using Mehlich-3 is relatively new in Australia, but good correlations with traditional tests have been indicated for exchangeable cations, sulfur and trace elements. The exchangeable sodium (Na) result has been corrected for soluble Na, using the method of Rayment and Lyons, 2011 (i.e. to simulate a prewash).

General Dermosol soil qualities (Soil type A)

Infiltration	Slow, due to surface sealing.
Permeability	Moderate to low.
Nutrient availability	Incomplete information. Mehlich-3 phosphorus has not been validated for Australian conditions. Sulfur may be a limiting nutrient for pasture production.
pH	Strongly alkaline at the surface, and in upper subsoil – indicates poor nutrient balance.
Salinity	Medium to high salinity below the surface horizon will reduce pasture yield.
Sodicity/dispersion	Strongly sodic (ESP ≥ 15) throughout. Field tests indicate strong dispersion at the surface and in the upper part of subsoil.
Physical root limitations	None observed.
Available water store	Estimated to be low for pasture growth.

Spyglass Soil B (Site 5)	*Grey Sodosol ('yellow duplex')*

Brief soil description: A texture-contrast soil with a bleached hard setting clay loam surface overlying a grey, strongly sodic subsoil.

Landscape: Terrace plain.

Vegetation: Open woodland. Browns box (grey box).

Soil classifications: *Australian soil classification:* Eutrophic, Mesonatric, Grey Sodosol.

Great soil group: Solodic soil *Principal profile form:* **Dy3.13**

Local name: Yellow duplex

Grey Sodosol supporting open Eucalypt woodland

Sodosol soil description:

Horizon	*Depth (cm)*	
A1e	0-12	Greyish brown (10YR5/2) moist, white (10YR8/1) dry; clay loam, massive structure. Sharp change to:
B21	12-30	Dark greyish brown (10YR4/2); medium heavy clay; moderate blocky structure. Gradual change to:
B22	30-60	Dark greyish brown (10YR4/2), faintly mottled; medium clay; few gravel fragments; moderate coarse lenticular structure parting to moderate blocky; ferruginous segregations along root channels. Diffuse change to:
B23	60-100	Yellowish brown (10YR5/4), distinct yellow mottles; fine sandy medium clay; few gravel fragments; moderate coarse prismatic structure parting to blocky; few manganiferous concretions and ferruginous soft segregations. Clear change to:
D	100-120	Light brown (7.5YR6/4); loamy sand; few gravel fragments.

Surface condition: Hard setting.

Site B *Grey Sodosol (Dy3.13)*

Surface fertility

pH	EC	Cl	NO_3-N	Org. C	Total N	C:N ratio	P Meh-3	Extr. K	S Meh-3	Extr. trace elements (Meh-3) mg/kg			
(lab.)	dS/m	mg/kg	mg/kg	%	%		mg/kg		mg/kg	Cu	Zn	Mn	Fe
5.9	0.07	77	<1	NA	NA		4	0.39	<5	0.4	0.3	35	104

Sodosol soil profile chemistry (NQRES 5)

Depth	pH EC Cl NO_3 (1:5 soil/water solution)				Particle size –MIR (%)				Exchangeable cations 'Meh-3' (cmol(+)/kg –				CEC sum	ESP	Tot. element			moist WP	Disp. ratio
(cm)		dS/m	mg/kg	mg/kg	CS	FS	SIL	CLA	Ca	Mg	Na	K		%	P	K	S	%	R1
0-10	5.9	0.07	77	<1					3.95	2.06	0.66	0.39	7	9					
20-30	7.5	0.55	785	<1					12.05	7.06	5.18	0.32	25	21					
50-60	8.3	1.24	1910	<1					14.60	10.08	7.35	0.43	32	23					
80-90	8.5	0.71	1060	<1					6.65	4.40	3.05	0.27	14	21					
110-120	8.4	0.54	775	<1					3.32	2.69	1.92	0.20	8	24					

Note: Extraction of elements using Mehlich-3 is relatively new in Australia, but good correlations with traditional tests have been indicated for exchangeable cations, sulfur and trace elements. The exchangeable sodium (Na) result has been corrected for soluble Na, using the method of Rayment and Lyons, 2011 (i.e. to simulate a prewash).

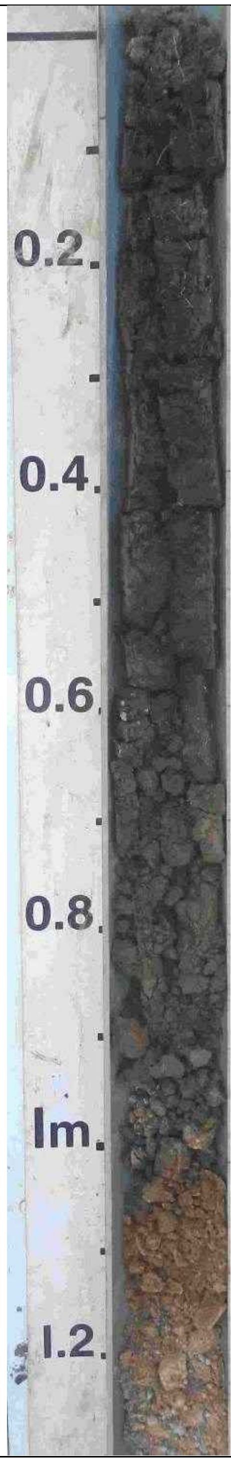
General Sodosol soil qualities (Soil type B)

Infiltration	Slow, due to hard setting, dense surface soil.
Permeability	Low in the subsoil.
Nutrient availability	Incomplete information. Phosphorus is probably low and sulfur may be a limiting nutrient for pasture production (similarly potassium).
pH	Medium acid at the surface; moderately alkaline in the subsoil.
Salinity	Medium to high salinity below the surface horizon will reduce pasture yield.
Sodicity/dispersion	Strongly sodic (ESP > 15) in the subsoil. Field tests indicate moderate dispersion at 30 cm and strong dispersion below 1 m.
Physical root limitations	None observed.
Available water store	Limitations to plant rooting depth reduce the available water store. The salinity profile indicates that effective rooting depth in this soil is about 40 cm, and therefore available water store is low for pastures.

Spyglass Soil C (site 6) — *Black Vertosol (Cracking grey clay)*

Brief soil description:	A dark cracking clay soil with a hard setting crusty surface (not self-mulching) overlying a salty and sodic subsoil.
Landscape:	Flat alluvial plain.
Vegetation:	Cleared woodland. Queensland bluegrass.
Soil classifications:	*Australian soil classification:* Episodic, Crusty, Black Vertosol.
	Great soil group: Grey clay — *Principal profile form:* **Ug5.15**
Local name:	Black cracking clay

Black Vertosol soil supporting rehabilitated sown pasture



Vertosol soil description:

Horizon	*Depth (cm)*	
A1	0-15	Very dark greyish brown (10YR3/2); medium clay; moderate blocky structure. Clear change to:
B21	15-45	Very dark greyish brown (10YR3/2); medium clay; strong blocky structure; few fine manganiferous concretions. Gradual change to:
B22	45-70	Very dark greyish brown (10YR3/2); medium coarse blocky structure parting to moderate lenticular; few medium calcareous nodules; few fine manganiferous concretions. Gradual change to:
B23	70-105	Brown (10YR4/3); medium clay; strong polyhedral strong 5-10mm structure; moderate coarse blocky moderate structure, parting to strong polyhedral; few manganiferous soft segregations. Abrupt change to:
D1	105-120	Brownish yellow (10YR6/6); coarse sandy loam; few gravel fragments; massive structure; common manganiferous soft segregations. Clear change to:
D2	120-130	Light yellowish brown (10YR6/4); loamy coarse sand.

Surface condition: Hard setting, surface crust, periodic cracking.

Site C — *Black Vertosol - Cracking clay (Ug5.15)*

Surface fertility

pH (lab.)	EC dS/m	Cl mg/kg	NO_3-N mg/kg	Org. C %	Total N %	C:N ratio	P Meh-3 mg/kg	Extr. K	S Meh-3 mg/kg	Extr. trace elements (Meh-3) mg/kg Cu	Zn	Mn	Fe
7.9	0.08	40	<1	NA	NA		3	0.58	<5	1.4	0.2	56	52

Soil profile chemistry *(NQRES 6)*

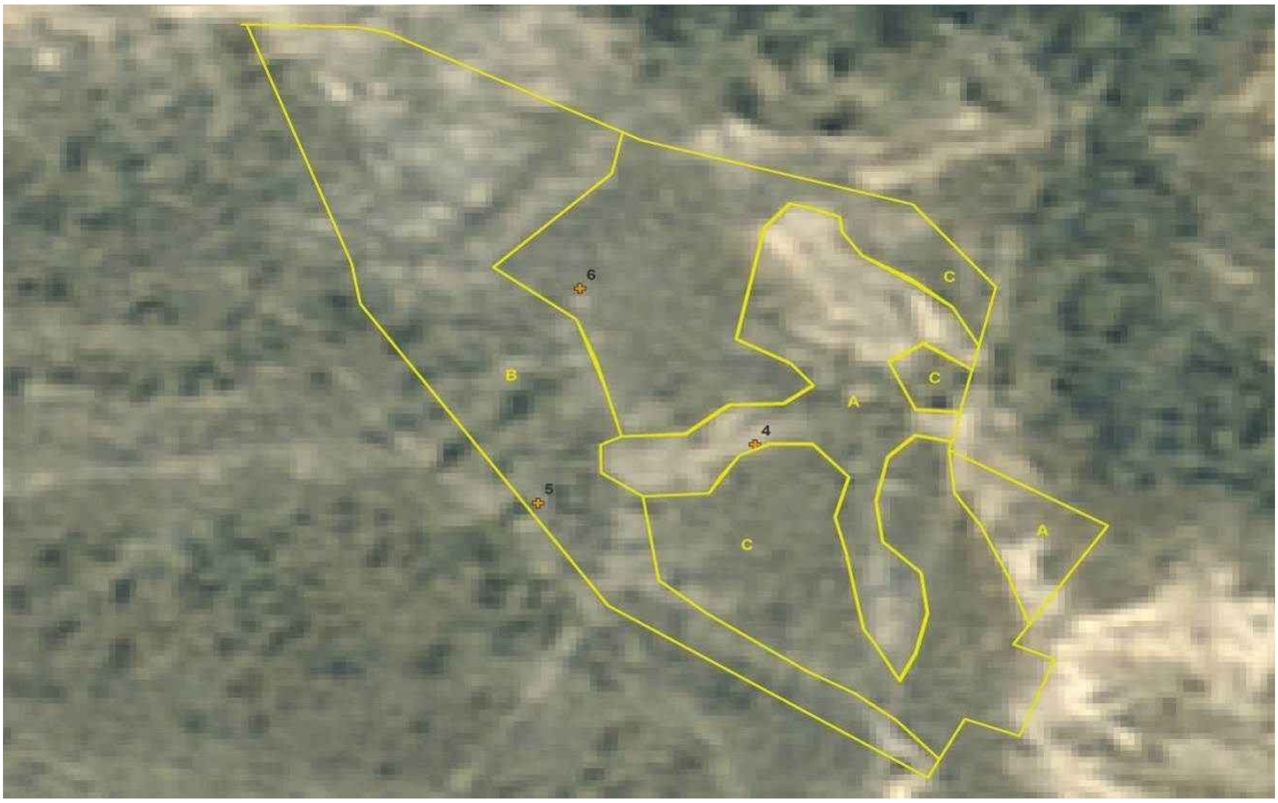
Depth	pH (1:5 soil/water solution)	EC	Cl	NO_3	Particle size –MIR (%)				Exchangeable cations 'Meh-3' (cmol(+)/kg –				CEC sum	ESP	Tot. element			moist WP	Disp. ratio
(cm)		dS/m	mg/kg	mg/kg	CS	FS	SIL	CLA	Ca	Mg	Na	K		%	P	K	S	%	R1
0-10	7.9	0.08	40	<1					21.30	8.42	3.01	0.58	33	9					
20-30	8.1	0.45	610	<1					21.45	8.67	5.89	0.46	36	16					
50-60	8.2	1.18	1780	<1					22.45	10.42	5.68	0.46	39	15					
80-90	7.8	0.99	1500	<1					19.65	8.67	4.46	0.44	33	13					
110-120	7.7	0.48	703	<1					6.50	3.23	2.32	0.23	12	19					

Note: Extraction of elements using Mehlich-3 is relatively new in Australia, but good correlations with traditional tests have been indicated for exchangeable cations, sulfur and trace elements. The exchangeable sodium (Na) result has been corrected for soluble Na, using the method of Rayment and Lyons, 2011 (i.e. to simulate a prewash).

General Vertosol soil qualities (Soil type C)

Infiltration	Slow when swollen.
Permeability	Low in the subsoil.
Nutrient availability	Incomplete information. Mehlich-3 phosphorus (P) has not been validated for Australian conditions. Sulfur may be a limiting nutrient for pasture production (similarly potassium). Zinc deficiency.
pH	Moderately alkaline at the surface – indicates poor nutrient availability.
Salinity	High salinity below about 40 cm.
Sodicity/dispersion	Sodic (ESP > 6) at the surface, and strongly sodic (ESP~≥ 15) in the subsoil. Field tests indicate slight dispersion at 30 cm and moderate dispersion below 1 m.
Physical root limitations	None observed.
Available water store	Limitations to plant rooting depth reduce the available water store. The salinity profile indicates that effective rooting depth in this soil is about 40 cm, and therefore available water store is low for pastures

A map of the three soil types described at Spyglass is shown in the following Figure. Soil type A is the sodic Dermosol, B is the grey Sodosol and C. is the black Vertosol soil. The locations of the profiles used to describe and analyse the soils are shown as numbers 4, 5 and 6 respectively.



Soil type map and location of three profiles described and analysed at Spyglass (Sept. 2012).

Soil profile analysis

Soil profile analyses methods

Method	Analyte	Name	ALHS	PQL	Unit	Method Description
S_AQ4_AA v2	Cl	Chloride	5A2	20	mg/kg	Soil: Cl NO3-N Aqueous (1:5)
S_AQ4_AA v2	NO3-N	Nitrate nitrogen	7B1	1	mg/kg	Soil: Cl NO3-N Aqueous (1:5)
S_AQ4_EL v1	EC	Electrical conductivity	3A1	0.01	dS/m	Soil: pH EC Aqueous (1:5)
S_AQ4_EL v1	pH	pH	4A1	0.1	-	Soil: pH EC Aqueous (1:5)
* S_MEH3_ICP v3	Al	Aluminium	18F1_Al	5	mg/kg	Soil: Elements Mehlich 3 ICP
* S_MEH3_ICP v3	B	Boron	18F1_B	0.25	mg/kg	Soil: Elements Mehlich 3 ICP
* S_MEH3_ICP v3	Ca	Calcium	18F1_Ca	10	mg/kg	Soil: Elements Mehlich 3 ICP
* S_MEH3_ICP v3	Cu	Copper	18F1_Cu	0.25	mg/kg	Soil: Elements Mehlich 3 ICP
* S_MEH3_ICP v3	Fe	Iron	18F1_Fe	5	mg/kg	Soil: Elements Mehlich 3 ICP
* S_MEH3_ICP v3	K	Potassium	18F1_K	10	mg/kg	Soil: Elements Mehlich 3 ICP
* S_MEH3_ICP v3	Mg	Magnesium	18F1_Mg	10	mg/kg	Soil: Elements Mehlich 3 ICP
* S_MEH3_ICP v3	Mn	Manganese	18F1_Mn	1	mg/kg	Soil: Elements Mehlich 3 ICP
* S_MEH3_ICP v3	Na	Sodium	18F1_Na	10	mg/kg	Soil: Elements Mehlich 3 ICP
* S_MEH3_ICP v3	P	Phosphorous	18F1_P	3	mg/kg	Soil: Elements Mehlich 3 ICP
* S_MEH3_ICP v3	S	Sulfur	18F1_S	5	mg/kg	Soil: Elements Mehlich 3 ICP
* S_MEH3_ICP v3	Zn	Zinc	18F1_Zn	0.15	mg/kg	Soil: Elements Mehlich 3 ICP

Fitzroy experiment sites - Soil Analysis

Trial site 2. Injune

Injune Rehabilitation	*Red Dermosol*

a. Rehabilitation site (Deep ripping 2003): Red Dermosol soil type

Image across the rehabilitation paddock at Injune in July 2012.

Project: P2REEF **Site:** 61 **Observation:** 1

Soil Name: No record

Location:	GDA 94	ZONE	55	688897mE	7198425mN	Lat: -25.31883	Long: 148.8766
Location:	AGD 84	ZONE	55	688669mE	7198071mN	Lat: -25.32196	Long: 148.87438
Location:	AGD 66	ZONE	55	688784mE	7198244mN	Lat: -25.32039	Long: 148.87549

Described By: John Ross (ROSJ) **Date:** 04-JUN-13

Landscape:

Geology: No record
Landform Pattern: No record
Runoff: No record
Microrelief: No record
Drainage: Well drained
Depth to Water: No record
Rock Outcrops: No record
Surface Coarse Fragments: No record
Surface Condition: Hard setting
Disturbances: No record

Substrate Lithology: No record
Element: No record
Permeability: No record
Microrelief Component: No record
Slope: No record

Classifications:

ASC: Red, Dermosol **Confidence:**
GSG: **PPF:**

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
A1	0 to .15	Reddish brown (5YR43) moist; clay loam, fine sandy; massive largest peds structure; subangular blocky moderate 5-10mm next size peds structure; gradual to
B21	.15 to .4	Dark reddish brown (2.5YR34) moist; light clay; polyhedral moderate 10-20mm structure; diffuse to
B22	.4 to 1.1	Reddish brown (2.5YR44) moist; heavy light clay; polyhedral strong 5-10mm structure; diffuse to
B23k	1.1 to 1.4	Reddish brown (5YR44) moist; few 2-10% fine <5mm distinct pale mottles; light clay; polyhedral strong 5-10mm structure; common 10-20% medium 2-6mm calcareous soft segregations; gradual to
B3	1.4 to 1.5	Reddish brown (5YR44) moist; heavy clay loam; polyhedral weak 5-10mm structure; few 2-10% medium 2-6mm calcareous concretions

Field Tests:

Depth	PH-1
.05	6.2
.1	6.3
.3	7.0
.5	8.0
1	8.5
1.2	8.5
1.5	8.5

PH-1: pH by Raupach and Tucker method

Site Notes:

Site Sunnyholt. Good and Moderate pasture rehabilitation.

`

Lab Results

Sample	Depth (m)	Checked	pH	EC (dS/m)	Cl (mg/kg)	Particle Size (%) CS	FS	Si	C	Exchangeable Cations pH 8.5(m.eq/100g) CEC	Ca	Mg	Na	K	ESP %	Total Elements(%) P	K	S	Moisture(%) Air Dry	1500	Dispersn Ratio
1	0-.15	N	6.3	0.12	<20																
2	.2-.3	N	6.8	0.04	25																
3	.5-.6	N	8.1	0.17	101																
4	.8-.9	N	8.5	0.27	158																
5	1.1-1.2	N	7.9	2.62	188																
6	1.4-1.5	N	8.0	1.43	268																

Injune - Rehabilitation experiment site soil profile (surface to 150cm)

b. Injune

Injune Grass pasture near Control bare	*Brown Dermosol*

Image. Buffel grass pasture surrounding eroding bare patches with annual forbs from recent rain.

Project: P2REEF **Site:** 62 **Observation:** 1

Soil Name: No record

Location:	GDA 94	ZONE	55	688996mE	7198436mN	Lat: -25.31872	Long: 148.87758
Location:	AGD 84	ZONE	55	688768mE	7198082mN	Lat: -25.32185	Long: 148.87536
Location:	AGD 66	ZONE	55	688883mE	7198255mN	Lat: -25.32028	Long: 148.87647

Described By: John Ross (ROSJ) **Date:** 04-JUN-13

Landscape:

Geology: No record

Landform Pattern: No record

Runoff: No record

Microrelief: No record

Drainage: Well drained

Depth to Water: No record

Rock Outcrops: No record

Surface Coarse Fragments: No record

Surface Condition: Firm

Disturbances: No record

Substrate Lithology: No record

Element: No record

Permeability: No record

Microrelief Component: No record

Slope: No record

Classifications:

ASC: Brown, Dermosol **Confidence:**

GSG: **PPF:**

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
A11	0 to .1	Dark brown (10YR33) moist; clay loam, sandy; subangular blocky strong 2-5mm structure; clear to
A12	.1 to .3	Dark brown (10YR33) moist; sandy loam; subangular blocky moderate 5-10mm structure; gradual to
B2	.3 to .7	Brown (7.5YR43) moist; sandy clay loam; angular blocky moderate 10-20mm structure; few 2-10% fine <2mm manganiferous soft segregations; diffuse to
C1	.7 to 1.4	Reddish brown (5YR44) moist; loamy sand; single grain structure

Field Tests:

Depth	PH-1
.01	8.0
.1	9.0
.2	8.5
.4	8.5
.6	6.5
.8	6.5
1.2	7.0
1.4	7.0

PH-1: pH by Raupach and Tucker method

Site Notes:

Site Sunnyholt Homestead 1 Good Grass. Next to Bare Site.

Lab Results

Sample	Depth (m)	pH Checked	pH	EC (dS/m)	Cl (mg/kg)	Particle Size (%) CS	FS	Si	C	Exchangeable Cations pH 8.5(m.eq/100g) CEC	Ca	Mg	Na	K	ESP %	Total Elements(%) P	K	S	Moisture(%) Air Dry	1500	Dispersn Ratio
1	0-.1	N	7.3	0.33	21																
2	.2-.3	N	7.6	0.06	<20																
3	.5-.6	N	7.2	0.03	<20																
4	.8-.9	N	7.0	0.01	<20																
5	1.1-1.2	N	6.9	0.02	<20																

c. Injune

Injune Control bare ***Red Dermosol***

Image. Eroding bare patches in grazed buffel grass pastures at the Injune Control treatment site.

Project: P2REEF **Site:** 63 **Observation:** 1

Soil Name: No record

Location:	GDA 94	ZONE	55	687845mE	7201005mN	Lat: -25.29567	Long: 148.8658
Location:	AGD 84	ZONE	55	687617mE	7200651mN	Lat: -25.29881	Long: 148.86357
Location:	AGD 66	ZONE	55	687732mE	7200824mN	Lat: -25.29723	Long: 148.86469

Described By: John Ross (ROSJ) **Date:** 04-JUN-13

Landscape:

Geology: No record
Substrate Lithology: No record
Landform Pattern: No record
Element: No record
Runoff: No record
Permeability: No record
Microrelief: No record
Microrelief Component: No record
Drainage: No record
Slope: No record
Depth to Water: No record
Rock Outcrops: No record
Surface Coarse Fragments: No record
Surface Condition: Hard setting
Disturbances: No record

Classifications:

ASC: Red, Dermosol
Confidence:
GSG:
PPF:

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
A1	0 to .2	Dark brown (7.5YR32) moist; clay loam; silty; subangular blocky moderate 5-10mm structure; gradual to
B21	.2 to .6	Dark reddish brown (5YR33) moist; light clay; angular blocky moderate 10-20mm structure; very few <2% fine <2mm manganiferous soft segregations; diffuse to
B22	.6 to .8	Dark reddish brown (5YR34) moist; clay loam, fine sandy; angular blocky moderate 5-10mm structure

Field Tests:

Depth	**PH-1**
.05	5.8
.1	6.0
.3	6.2
.6	7.0
.8	7.0

PH-1: pH by Raupach and Tucker method

Site Notes:

Site Sunnyholt Homestead 1 Bare Control.

Lab Results

Sample	Depth (m)	Checked	pH	EC (dS/m)	Cl (mg/kg)	CS	FS	Si	C	CEC	Ca	Mg	Na	K	ESP %	P	K	S	Moisture(%) Air Dry	Moisture(%) 1500	Dispersn Ratio
1	0-.15	N	6.1	0.38	63																
2	.2-.3	N	6.1	0.27	45																
3	.5-.6	N	6.4	0.1	<20																
4	.7-.8	N	6.6	0.06	20																

Particle Size (%): CS, FS, Si, C. Exchangeable Cations pH 8.5(m.eq/100g): CEC, Ca, Mg, Na, K. Total Elements(%): P, K, S.

Injune - Soil profile at Control-Bare site (H1 pdk) (from surface to 130 cm)

Trial site 3. Banana

Rehabilitation experiment paddock – Brown vertosol (heavy clay)

Banana	***Brown Vertosol***

Image. Rehabilitation site on a brown vertosol soil cleared of brigalow forest at the Banana site (2012).

Project: P2REEF **Site:** 64 **Observation:** 1

Soil Name: No record

Location:	GDA 94	ZONE	56	216398mE	7293557mN	Lat: -24.44573	Long: 150.2027
Location:	AGD 84	ZONE	56	216185mE	7293192mN	Lat: -24.4489	Long: 150.20054
Location:	AGD 66	ZONE	56	216291mE	7293370mN	Lat: -24.44731	Long: 150.20162

Described By: John Ross (ROSJ) **Date:** 05-JUN-13

Landscape:

Geology: No record
Substrate Lithology: No record
Landform Pattern: No record
Element: No record
Runoff: No record
Permeability: No record
Microrelief: No record
Microrelief Component: No record
Drainage: No record
Slope: No record
Depth to Water: No record
Rock Outcrops: No record
Surface Coarse Fragments: No record
Surface Condition: No record
Disturbances: No record

Classifications:

ASC: Brown, Vertosol **Confidence:**
GSG: **PPF:**

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
A1	0 to .18	Dark brown (7.5YR34) moist; light medium clay; few 2-10% subangular medium pebbles 6-20 mm; angular blocky moderate 10-20mm structure; gradual to
B21	.18 to .4	Brown (7.5YR44) moist; medium heavy clay; lenticular strong 20-50mm structure; gradual to
B22	.4 to .5	Strong brown (7.5YR46) moist; medium heavy clay; lenticular strong 5-10mm structure; few 2-10% medium 2-6mm calcareous concretions

Field Tests:

Depth	PH-1
.1	7.5
.2	8.5
.3	9.0
.5	9.5

PH-1: pH by Raupach and Tucker method

Site Notes:

Site Banana Pasture Rehabilitation. Control Bare.

Lab Results

Sample	Depth (m)	Checked	pH	EC (dS/m)	Cl (mg/kg)	Particle Size (%) CS	FS	Si	C	Exchangeable Cations pH 8.5(m.eq/100g) CEC	Ca	Mg	Na	K	ESP %	Total Elements(%) P	K	S	Moisture(%) Air Dry	1500	Dispersn Ratio
1	0-.15	N	6.5	0.11	25																
2	.2-.3	N	6.7	0.19	42																
3	.4-.5	N	8.2	0.18	29																

Banana soil profile – Part Rehabilitation site (surface to 65cm)

Banana soil profile – Bare Control site (surface to 50cm)

Fitzroy Catchment Rehabilitation - Injune and Banana experiment sites Soil Analysis

Site No.	Depth (m)	pH	EC	Cl	NO3-N	Al	B	Ca	Cu	Fe	K	Mg	Mn	Na	P	S	Zn
	Units	-	dS/m	mg kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Injune. Good and Moderate pasture rehabilitation (site 61).																	
1	0.00-0.15	6.3	0.12	<20	38	612	<0.25	1910	2.29	146	353	296	107	35	49	9	3.86
2	0.20-0.30	6.8	0.04	25	3	541	0.36	3290	2.75	92	196	496	43	88	28	<5	2.09
3	0.50-0.60	8.1	0.17	101	1	298	1.03	4030	3.16	44	182	679	117	166	26	14	1.03
4	0.80-0.90	8.5	0.27	158	1	196	1.54	4640	2.5	39	135	845	141	253	35	67	1.73
5	1.10-1.20	7.9	2.62	188	1	19	3.16	7380	2.28	40	129	1140	157	356	39	2390	1.9
6	1.40-1.50	8.0	1.43	268	1	240	3.28	3380	2.04	56	114	892	239	315	37	891	2.06
Injune H1: Good Grass. Next to Bare (site 62).																	
1	0.00-0.10	7.3	0.33	21	107	493	0.9	4500	1.97	138	488	373	174	21	132	26	8.43
2	0.20-0.30	7.6	0.06	<20	11	418	0.43	2130	1.5	93	131	281	46	17	27	6	2.06
3	0.50-0.60	7.2	0.03	<20	2	584	0.36	1620	2.31	134	159	454	53	27	13	7	1.82
4	0.80-0.90	7.0	0.01	<20	1	279	<0.25	616	0.92	80	61	137	38	13	12	<5	10.7
5	1.10-1.20	6.9	0.02	<20	1	297	<0.25	594	1.74	116	68	133	49	15	22	<5	37.9
Injune H1: Bare Control (site 63).																	
1	0.00-0.15	6.1	0.38	63	120	485	0.47	3720	1.97	131	641	546	73	32	69	27	14.3
2	0.20-0.30	6.1	0.27	45	93	534	0.46	3270	2.94	128	250	636	48	34	34	14	5.73
3	0.50-0.60	6.4	0.1	<20	32	508	0.37	2290	2.31	118	185	476	75	32	14	6	2.92
4	0.70-0.80	6.6	0.06	20	12	434	0.39	1720	2.31	114	177	396	131	47	11	<5	8.64
Banana Pasture Rehabilitation. Control Bare (site 64).																	
1	0.00-0.15	6.5	0.11	25	29	553	0.51	2150	2.17	59	214	584	171	68	9	14	2.32
2	0.20-0.30	6.7	0.19	42	48	865	1.46	3130	1.94	38	174	906	143	73	4	23	0.76
3	0.40-0.50	8.2	0.18	29	18	474	2.12	5350	1.6	30	153	944	136	58	<3	22	3.97

Appendix 4: UAV aerial 3D survey of Spyglass rehabilitation site.

1. Project description

Overview of UAV Survey Project
A low level, detailed aerial photographic survey was conducted across the Spyglass rehabilitation experiment site and over similar landscapes surrounding the experiment in December 2013; two years after the treatments were applied. Two additional un-rehabilitated areas in the vicinity with D-condition land were also surveyed to establish a baseline before any future rehabilitation and grazing management changes are implemented. The three surveyed areas are shown in Figure 1. The whole area was included in the high resolution satellite image (World view) obtained on 1 October 2011 immediately before commencing the regeneration experimental treatments.

Method

The three sites surveyed were selected from the eroded areas shown on the World view satellite imagery and confirmed by on-ground inspections. The corners and sides of each area were marked by GPS and reflective plastic markers to accurately orientate all photographs within each survey area. Approximately 2000 overlapping photographs were taken of each area to produce a 3-D image to accurately define the extent and degree of erosion. After future rehabilitation work these areas could be re-surveyed to calculate the recovery responses.

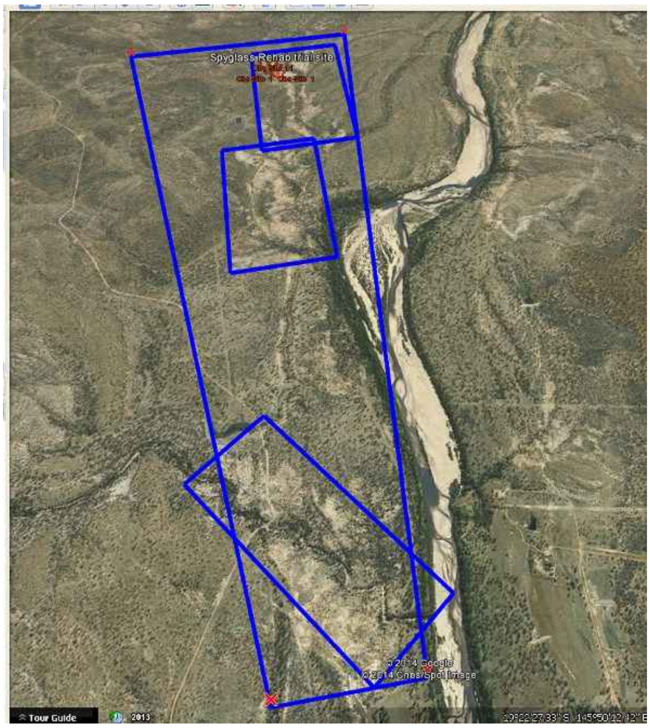


Figure 1. Three UAV aerial photographic survey site areas at Spyglass; the rehabilitation experiment site is covered by the northern survey area.

Some of the fixed site and portable GPS units, the UAV, corner markers and computer control equipment used for the survey are shown photographically in Figure 2.

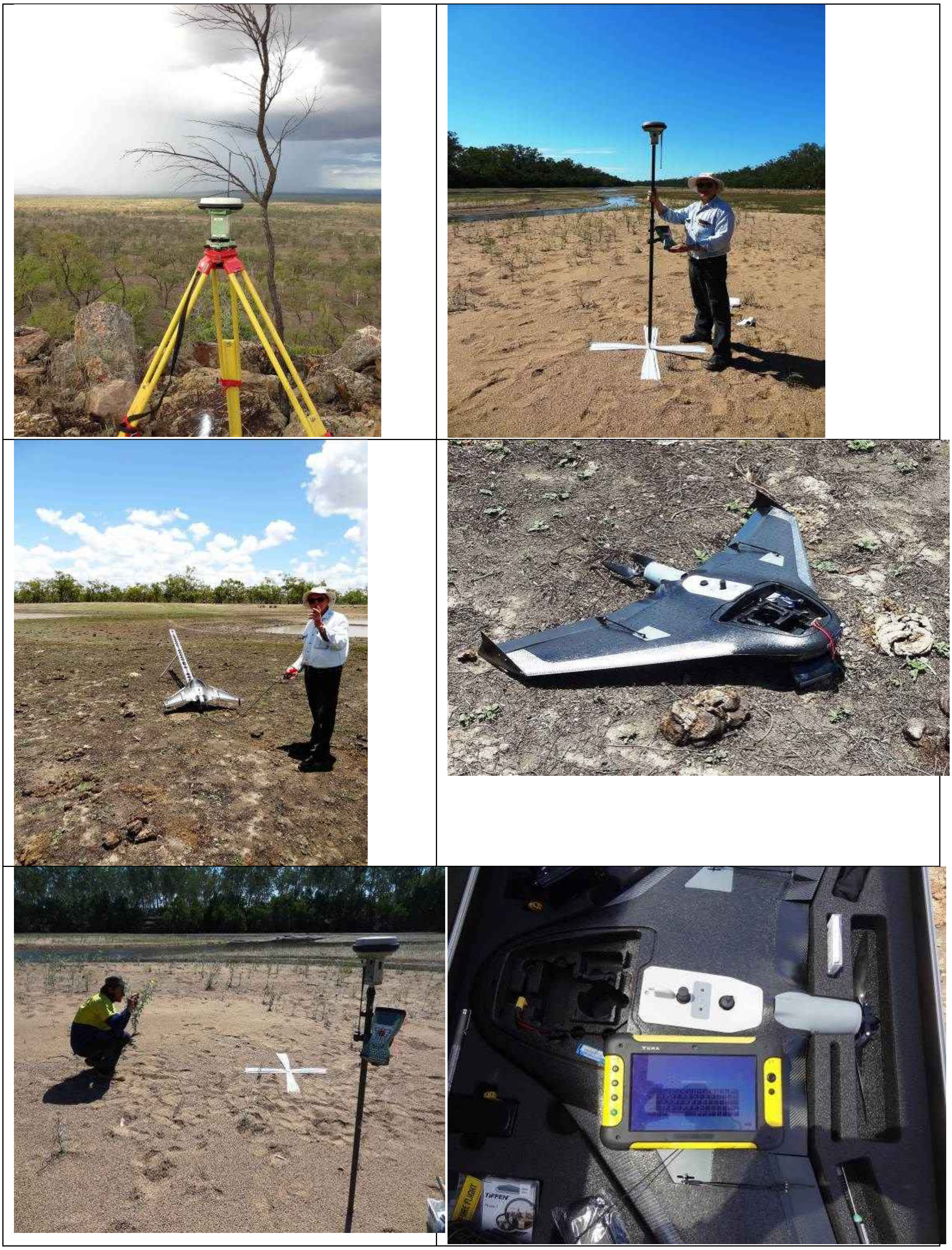


Figure 2. GPS units, UAV, marker reference points and aerial survey equipment used for the Spyglass aerial 3D survey (2013).

UAV Imagery Results (Spyglass)

Examples of vertical and 3-D images of the low-level UAV photographic survey (at low resolution) show the extent of sheet and gully erosion in this area on Spyglass west of the Burdekin River (Figure 3).

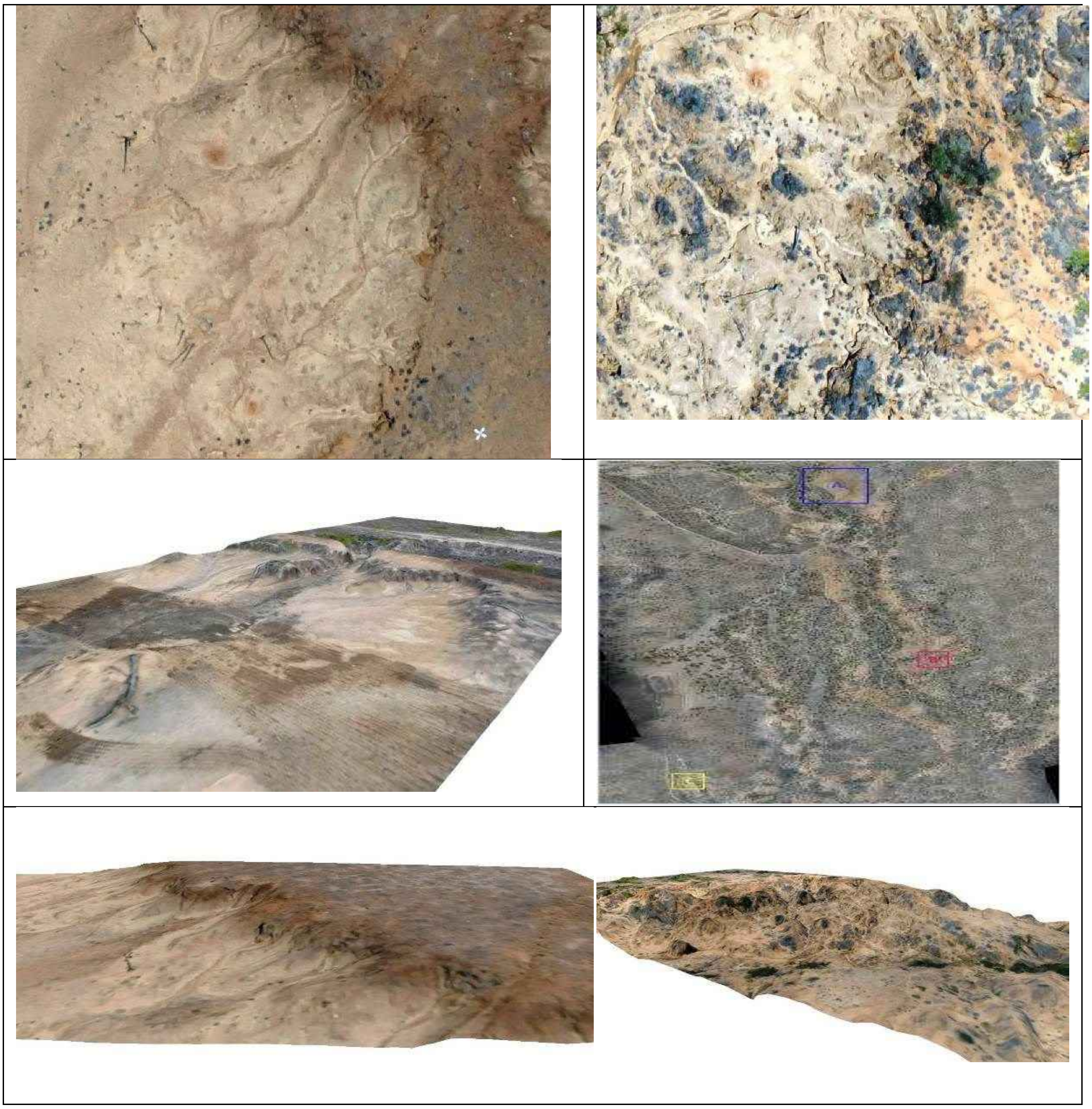


Figure 3. Aerial vertical and 3-dimensional photographic imagery from the UAV survey of D-condition areas at and near the Spyglass experiment site (December 2013). (photo 3- centre left, shows the cultivated gypsum strip across the eroded landscape south of 'double dam').

An example of the aerial imagery produced by the UAV survey (Figure 4) shows the surface cover produced by the Spyglass rehabilitation treatments (on west of the creek and bounded by the fenceline). The untreated east side of the creek has remained bare and eroding.

Figure 4. UAV image of Spyglass rehabilitation experiment site two years after treatments were applied (December 2013). Fenced experiment site is visible on west side of creek with unfenced control on east side.

The success of the hay mulch treatment on the break-away gully head at Spyglass can be seen in the UAV image (Figure 5) from December 2013. The treatment is located to the east of the clearly visible road. The establishment of grass and litter washed down two hollows into the head of the gully. Untreated eroded areas of the break-away have remained bare and eroding.

Figure 5. UAV image of hay mulch treatment (to right of road) and untreated bare gully head at Spyglass in December 2013.

A detailed report on the UAV aerial photographic survey of the three degraded areas on Spyglass was produced and is available separately (Matthew Power and Trevor Hall).

Appendix 5. Survey: Landholder comments on their rehabilitation works.

These are additional comments on rehabilitation and results from the landholders surveyed on their experiences from rehabilitation works on their properties (see Section 2 of main report for summarised details of the survey).

Abbreviated landholder comments on their rehabilitation work related to the six project objectives include:

1. **Grazing management after rehabilitation**

- Contour ripping with pasture seeding can work – buffel grass, stylos, Wynn cassia, black speargrass (natives); have tried green panic, which was unsuitable.
- Renovation broke the surface crust and caused wash and more erosion on red jump-up soils.
- Most effective was large pitting with a bucket on a tractor plus pasture seeding.
- Tree litter was dragged onto scalds with cut-up whole trees; this helped establish cover
- Ripping plus tree litter and seeding gave good rehabilitation strips.
- Cover with a litter blanket of 100% was best for establishment.
- Have tried grass hay litter, but it decomposes too quickly – trees are better as it lasts longer.
- Break up soil surface for water infiltration to regenerate pasture; rip, cultivate.
- Want to add OM – dung from cattle yards, camps with bobcat; feed bulls in yard.
- Build contour banks (apron) around wash areas to stop wash over scalds and gully heads – divert water away to help regeneration.
- Fence off scalds to exclude grazing; not reseeded.
- Take time-series photos to know what you did and how it worked.
- Ploughed scalds to clean rubbervine and chinee apple in gullies.
- Ploughed across contour 30 cm deep to cut off woodies and increase infiltration; planted seed Katambora Rhodes, Verano, Seca.
- Other props have ripped 45 cm deep.
- Has 30-40 acres scalds but no rehabilitation yet; tried seeding buffel and legumes on bare soil not disturbed, but not successful – had some seedling germination but they burn off before they can get roots deep (moisture or salinity problems probably).
- Ploughing brings up some subsoil that helps seed germination and survival.
- Opens up for moisture increase.
- Need to select soil types to rehabilitation – some work and some don't – on hard red soils grass dies while cultivated grey soils can grow grass.
- Cutter-bar on dozer + seeding buffel, Katambora Rhodes, Seca and 'Fitzroy' stylos (perhaps Verano or Amiga).
- Hard red country started bare, with odd white spear grass (*Aristida* spp.).
- Stick raked and burnt areas established grass best. Buffel has been poor and Katambora has grown ok, with some stylos.

- Seed box on dozer and scratched some patches has grown some grass; Need heavy machinery to break surface of hard red soil – sets like concrete and goes powdery when disturbed, but will re-set hard again.
- Has two types of red country – lighter soil with ironbark and bloodwood (Eucalypts) can be rehabilitated with buffel, but hard red with bendee (*Acacia*) much more difficult to renovate.
- Major soil/land type differences in rehab responses.
- Started contour ripping with dozer from flats to hills and seeded buffel grass, Rhodes, Urochloa, Seca, Verano stylo.
- Bare scalds were present in 1963 when father drew block. Ripping and seeding gave some improvement.
- Used licks blocks to cause soil surface disturbance and grass and weeds cover; shifted block sites to spread disturbance.
- Next contour ripping and graded rills to stop wash + got dung and litter and top soil for OM in tipper to spread on ripped scalds; spread about 5 cm thick. This increased infiltration and grasses and weeds grew. Started to increase biodiversity.
- Better system would be to spread mixed pasture seed on ripped scalds before adding OM layer.
- Has own machinery – has been a machinery owner and operator business.
- Considered electric fence for grazing control but didn't use.
- Site was not fenced, and grazed first year with whole paddock closed up over first 2 summers. Some sites need re-ripping by 3rd year.
- I do not use mechanical treatments, instead use conservative management and spelling to maintain pastures and cover and no bare patches (long rotations for tick control, not cell grazing).
- Use conservative stocking and spelling to maintain good cover and a lot of grass over 6000 ha cleared and cover is managed, plus have 2000 ha as original treed forest.
- Tried ripping and contour bank ponding with pasture seeding (planted buffel grass, butterfly pea and stylos) and no grazing (pulled cattle off) initially and spelling.
- 'Don't overstock and turn off bullocks, even in recent drier years, so keep good cover.
- I use different methods depending on the soil type; have had FBA regeneration funded projects.
- Blade ploughing some soils and deep ripping with seeding and destocking; cattle grazing management is critical. Spell after rain in summer.
- Methods and results depends on the soil type – ripping and large bales of grass hay worked on hard red soils, ripped in strips and plants only established in the disturbed strips and has been slow to spread between hay strips even with ripping.
- Ripping and seeding some hard red soils did not rehabilitate – became hard without establishing a pasture.
- Heavy self-mulching clay flats regenerated in 4 years by aerial seeding Bambatsi panic and silk sorghum, with conservative grazing. Spelled in wet season and grass fully covered after 4 years.
- Grazing management is critical – a must; Spelling in wet season was necessary.
- Gully erosion near the coast regenerated and when sown to Pangola grass has been successful – near Marlborough – Pangola is 'buffel on the coast'.
- I use conservative stocking rates while renovating large areas of a paddock – e.g., all the box flats in an 8000 ac paddock.

- I renovate with a heavy chisel plough with every 2nd tyne removed and with buster points on a Yeoman's plough – have problems of breaking shear pins. Sow a seeding mix of grasses and legumes – buffel grass and Aztec Siratro on heavy soils of box flats and with buffel grass and Wynn cassia on lighter soil of hills.
- Have had good regeneration success on both soil types – ripping keeps native grasses and legumes at depths from shallow on very hard soils to 30 cm deep on soft soils.
- I use ripping (not continuous – like laying bricks in alternating lines) and sow in the ripped sections. Not sure of the exact seed mix but some buffel grass, bluegrass and legumes such as Seca stylo.
- Dozer is 200 HP with 3-tyne ripper with ripper boots and a stick rake blade and pulling a chain to break up the clods.
- 1st plot rehabilitated is brilliant this year (2013); was rundown, suckers increasing, double pulled with chain for best results – both ways and seeded a shotgun pasture mix.
- 2nd area on different landtypes – good forest soils where buffel grass failed and have good creeping bluegrass + stylos.
- 3rd area on red soil, flogged in past, had lost topsoil, sheeted concrete surface, needed raking and surface disturbed with dozer rippers to 20 cm, no runoff in 2013. Seeded mix of buffel grass, green panic, Rhodes, Caatinga stylo, Aztec siratro, Seca and Verano stylo – planted in past 4-5 years. Caatinga stylo few plants established. Site has 85% cover now of grass and legumes. Other end of paddock on forest soils has good rehabilitation of Bisset creeping blue, Seca and Verano stylo.
- Started in dry years a few years ago (2007-2008); raked on contour and seeded. Site was accidentally burnt and then the log heap ash was reseeded – pasture came up good. 50% of paddock was rehabilitated.
- Use rotational grazing, based on pasture requirements and not on cattle or by time to manage pasture cover; don't use cell grazing.
- I use a dozer and heavy chisel plough with 60 cm wide tynes and sow pasture seed.
- Have stick raked some areas, others rip surface over timber with wide 600 mm chisel plough tyne spacing.
- Usually chisel twice on hard soils – first may be 4-6 cm and second 10-15 cm deep.
- Last renovation was 4 years ago; Now have some woodies regenerating.
- Tried development plans with DNRM but tree clearing restrictions have limited recent pasture work.
- Southern 1/3 property is hard set washed and tight surface needing disturbance to renovate.
- Uses Yeoman's disturbance principles; Disturbance with heavy chisel plough (1968) – aerates hard soils and allows water in.
    - Now use a heavy chisel plough 'Gestner' for last three years pulled with a dozer; 600 mm tyne spacing.
    - Costs about \$40 acre^{-1} to chisel plough + pasture seeding costs.
- Improving 12000 ac on Bogey River has tripled production and increased cattle numbers with rehabilitation using buffel grass, Rhodes and Gamba grass (*Andropogon gayanus*) and grazing management.
- Grazing rest in all rehabilitation is necessary. I use grazing rotation with small cow groups of 50-100 head for stud breeding.
- Do the chisel ploughing on a slight angle to contour so can control direction of water movement.

- May crash graze grass off to allow legumes to establish, grow and seed.
- Cultivar Keppel 'pertusa' (Indian bluegrass/couch) is successful for a rehabilitation pasture in this area.
- Blade ploughing with own machinery has worked on bare patches, and cutter-baring can work on some soils.
- Heavy chisel ploughing, using own machinery with reseeding (buffel grass and silk sorghum) has worked in rundown buffel pasture to recently bare areas on brigalow clays.

2. Ground cover and surface conditions:

- Flooding killed buffel on heavy soil flats, leaving them bare.
- Floren bluegrass germination failed – it is very palatable and selectively grazed.
- Didn't really have an answer for these scalds – need information and finances.
- Old scalds are now rough from ripping and retain all water.
- Improving soil health is the aim of rehabilitation – surface disturbance plus pasture seed; use grasses and legumes.
- Must get air and water into soil, so plants grow and increase organic matter and fertility for new pasture.
- Father started planting stylos in 1950-1960s and was not very successful, but now stylos give good cover and are especially good in dry years.
- *Dichanthium annulatum* and *D. aristatum* give very good cover on heavy clay soils and are wet tolerant.
- Cultivation and seeding scalds with spelling from grazing gave good pasture initially and good soil cover.

3. Time-lag for rehabilitation success:

- Fence off rehabilitation sites – can get recovery in six months of a good summer – One season can work well.
- Best areas/soils regenerated with good cover in two good wet years with summer spells and grazing in winter (when dry).
- Rehabilitation in larger paddocks so need to get some grazing value first year.
- Keep reduced grazing for three years needed – even over 3rd summer.
- Depends on soil type – hard poor red soil patches had no grass in first 2 years, other soils had good cover in 1st summer.
- 2-3 years with good seasons for rehabilitation to succeed.
- Needed to graze paddocks partly each year, couldn't afford to shut up whole paddock for two years.
- Need more finance to fence off rehabilitation sites to get successful cover.
- 1-3 years for good recovery in good wet years recently, but no recovery in 10 years of previous a drought period.
- Has had good regeneration over last three good rainfall seasons and keeps cattle in paddock at a conservative stocking rate. Method leaves native grasses present, as start rehabilitation strips before bare condition (still in C-condition).
- Have only begun rehabilitation last year and have not returned to inspect the site so they were unsure of success; Will go out and take photos next opportunity.

- Stock to conditions of the rehabilitated pasture – not to time or for cattle; look at pastures to look after your country.
- Graze lightly in first year (good or poor seasons) so pasture can set seed; in 2nd year graze for a couple months longer, perhaps 25% more grazing; must manage for pasture growth.
- From D-condition to B or A-condition in four pretty good rainfall years after heavy disturbance and seeding.
- Have a good season following rehabilitation and grazing management. Three years is usual time after successful establishment in the first year.
- Need well-adapted pasture species in the seed mix.

4. Barriers to rehabilitation:

- Did own rehabilitation work by trial and error as didn't know what was best; trials included a Landcare funded project.
- Need a fact sheet on how to do high density herd trampling improvement of bare patches, pug up, trample in dead grass, etc. Does it work and if so how to make it work on different soils.
- After trampling herd impact methods are worked out and an education program for producers to use the method with Government subsidy of wire and electric fencing,
- Time and lack of money are major limits.
- Need own machinery to do when time and cash is available; can have extra costs with breakdowns that isn't your problem using contractors.
- Can only work rehabilitation machinery in winter – cooler and need carry over summer soil moisture.
- High costs, need good cattle prices, especially if I need to hire a contractor.
- Limited time available and diminishing returns to continuing rehabilitation after some early successes.
- Cattle producers are price takers and not price setters in the beef cattle industry, so spare cash for low return rehabilitation work is not available.
- Regeneration of good brigalow soils works but not on 'melting' soils (You need to know the soil types and how disturbance will affect surfaces and erosion possibilities).
- Don't know what is the best disturbance method to use or what pastures to plant? What legumes are best for my country?
- Some producers overgraze – don't have opportunity to rest country or regenerate and rest whole paddock for sufficient time. Old managers with old grazing practices can cause bare areas.
- Need enough pasture for stock to continue grazing and leave some grass in the paddock; I don't have spare paddocks.
- Need a good summer to follow dry planting to get pasture establishment and enough feed so cattle don't overgraze new rehabilitation strips.
- Cost is the biggest barrier and machinery availability. Time is not a huge issue –would make time if we had the money to do rehabilitation of scalds.
- Rehabilitation technology is ok; can learn from others, schools, trying myself.
- Knowledge – need to know what to do and how and when. How to do rehabilitation and how to manager area after? What type of renovation is best for different soil types?

- Rehabilitation whole paddock, so need enough other pasture for cattle.
- Government (DNRM) interference with environmental restrictions; tree clearing, ponded pastures, problems doing environmental development property plan.
- Pasture cultivar seed not available when required and the high cost seed.

5. **Costs and benefits:**

- Reduced grazing pressure means increased cattle growth rates and faster turnoff giving better profits.
- Cost price squeeze – Cattle index 100 in 1985 and now only 168 in 2013 – that means low sale prices relative to huge rises in all operating costs, including Government charges and Council rates.
- Government economic rationalism – 'Cannot continue to spend indefinitely more than you earn – or economy will collapse'; same applies to property beef business.
- Rehabilitation is expensive; pulling suckers is also expensive.
- Tractors are not always available to pull regrowth.
- Has used 50 t of Graslan (30 t earlier and 20 t recently) on brigalow sucker control – about \$60 acre^{-1}. Buying new land is expensive so must make most of own land (improve pastures and production and cover as a consequence).
- Graslan costs \$14000 t^{-1} and use up to 14 kg ha^{-1} on heavy soil with dense brigalow regrowth; areas with 10-12 kg ha^{-1} on brigalow and lighter rate in Eucalypt on lighter soils. Uses Graslan because still has good grass cover and gets good grass response. Graslan kills off legumes as well as the trees.
- Qld Government DAF economists have done an economic analysis of the mechanical rehabilitation treatments at the three experiment sites.
- Assumptions were: a rotation stocking method with paddock grazed for about one month per year; Steer trading is used.
- Resting times were not always strategic, but were part of the rotation system.
- First year treatments are spelled and there may be a full wet season rest from December to April/May (as recommended), as part of 4-6 months spelling period in later years.
- Blade ploughing costs \$100 acre^{-1} and better results can last 15 years before needing to pull regrowth on brigalow soils.
- Graslan kills woodies, but costs \$70 acre^{-1} and kills the legumes and it doesn't open surface to increase infiltration.
- Chaining suckers \$12-14 ha^{-1} with 400ft chain and two D7 dozers.
- Use own machinery and buy seed – it is very expensive and not all comes up – need high seeding rates.
- Main benefit was to utilise areas in the future that had previously been unusable. Another benefit was doing something good for the land and this was important.
- Don't know own real costs of rehabilitation, but use own machinery; haven't calculated real costs, but work done with a FBA subsidy payment.
- Chisel plough with wide spacing costs less than full disturbance and leaves some pasture plants to continue growing and seeding.
- With large machine can do country without stick raking to reduce costs.
- If can improve own country for \$40 acre^{-1} this is cheaper than buying more land at \$100 ha^{-1} plus that still needs renovation.
- Chisel plough at \$17 acre^{-1} plus \$13 acre^{-1} for seed (total cost \$30 acre^{-1}).

6. **Social and economic drivers:**

- Some neighbours don't treat for ticks (not in the tick eradication program); and some graze too heavily and cause erosion; running more cattle as costs increase for short-term returns.
- Bare overgrazed areas started early from Soldier settlement blocks being too small and owners needed high SR to make living.
- Banks and Governments at all levels, want high land values to be maintained – Bank loans, avoid bankruptcies, banks don't want to own farms, Council rates value, social unrest, food production, etc.
- Bank lending encourages increasing land values and increasing debt and therefore higher grazing pressure and increased chances of developing bare areas and scalds.
- High debt by some producers causes higher stocking numbers and pasture rundown in dry years; reduced cover and more erosion.
- Some landholders can't afford extra cost of rehabilitation; have no spare cash – in high debt already.
- Want my pastures to be in good condition.
- No external pressure; owners want to look after country himself. Still poor managers in district overgrazing.
- Rehabilitation is beneficial for country and cattle.
- Work weaners to get quite and keep quite as bullocks.
- Some neighbours have looked over fence and now starting to do the same rehabilitation work – working to combine rehabilitation work and to share dozers and chaining.
- Some neighbours do not do renovation work.
- At one time LandCare organisations could provide chisel ploughs for doing own rehabilitation work. Not everyone has suitable machinery for renovation work.
- No external social pressure as there is low economic return.
- Wanted to do rehabilitation for our self.
- Reef subsidy money was used for contours around gullies.
- Producers community now more aware of pasture management and what that can achieve; Do rehabilitation of erosion areas including gullies and scalds.
- On a property where scald rehabilitation over the last 10 years has been successful, there is currently no new rehabilitation work as there are sufficient large bare areas left. It became a case of diminishing returns for the high input costs and long recovery periods.

7. **Government financial incentives for rehabilitation works:**

- For more rehabilitation work need Government money and help with staff/labour (age and finances).
- Need 50% Government subsidy as minimum; preferably higher to increase areas treated.
- Would like Government to do fencing and treatments but would continue grazing management – couldn't guarantee checking electric fences working properly all the time – Government help?
- Encourage owners to nibble away at rehabilitation work regularly.

- Reef Rescue 50% finance has been good for rehabilitation work – fencing and waters.
- Grazing BMP information helps producer community awareness of pasture management and rehabilitation requirements.
- Have used 50% subsidy from LandCare for rehabilitation work.
- Needs higher subsidy to do more work maybe 75% and could pay a contractor to help and would do more rehabilitation work.
- Need extra $ on one-man management properties; time and labour are limited.
- Want a per ha payment basis and I can use my own machinery and time when suitable; Subsidy should be at contractor rates, but have the option to do work with own machinery and not be financially penalised if you have own equipment Vs. others with no machinery and have to use contractor rates. i.e. need a standard rate per ha irrespective of who will do the work.
- Contractor blade plough rate is about \$100 acre^{-1}.
- Cash incentives are essential; more than 50% is needed mostly.
- Labour shortage on most properties is a problem – have essential operations to do before rehabilitation of bare patches.
- Too much red tape and Government hindrances in approvals for doing land development,
- Incentive of tax deductions or brakes from rehabilitation – as community benefits most (GBR) – Community needs to recognise rehabilitation work and the costs to the landholders.
- Needed for conservative stocking maintaining good pastures and cover! Education on alternative grazing management is required.
- Have done own rehabilitation contour ponding with my own money (don't high a property debt).
- Would be happy with 50% subsidy and would do more rehabilitation work.
- Subsidy should be production related.
- 50% is enough of a subsidy for the right work e.g., for fencing to landtypes (brigalow / hills), frontages, land management, etc. – Not subsidies for cattle management e.g., laneways or basic property development.
- Over-grazers (floggers) get access to Government money, instead of learning conservative management.
- Must graze conservatively so maintain native pastures and cattle can select good feed.
- Have had money from Reef Rescue for reclamation of a road way. This provided a big incentive because would not have done it without the funding.
- Have been doing my own rehabilitation work before any subsidies – I see the value in renovation work for improving country and increasing production.
- If producers will only do rehabilitation work with a Government subsidy they will stop when subsidies stop. Will they maintain good pasture management after subsidies stop? Will land revert to overgrazed and there be a re-appearance of bare areas?
- Doing my own rehabilitation without any subsidies – it is important to me to improve pastures.

8. Common landholder comments on rehabilitation work:

- Cattle pads start erosion gullies in some soil types; check grading roads, use telemetry remote management, aim for minimal paddock travel.

- Prevention of overgrazing and scald development by better paddock, track and grazing management in the first place.
- Have used Government funding (Reef Rescue) to fence off gullies and patch regeneration; now have pulled up fences after recovery (needed the Government subsidy for this rehabilitation work).
- Problems in writing applications for rehabilitation work to get Government money; need assistance from professionals who know terminology and how to describe work (AgForce has assisted with funding applications in the past).
- Lucky not to have any property debt and can graze conservatively and use spelling to keep good cover now to stop scalds developing.
- Conservative stocking has allowed improved pastures, reducing dry / drought time feeding, reducing costs, maintaining profits, sell early when dry, increased profitability, no debts and allowed off-farm investments; no stress, maintain enthusiasm for farming; grass responds to rain quickly after droughts as not grazed into the ground – not like a lawn.
- RCS executive link courses have improved my pasture management and rehabilitated some areas.
- Must fence off rehabilitation areas for wet season rest; electric fences need too much maintenance trying to sort out the 'spider web' of insulators; 40km of electric fence had a high labour cost to maintain and became too costly.
- Producers want to rehabilitate scalds but have barriers and resource limits.
- Kangaroos are a serious problem on all pastures including on rehabilitation sites.
- Large machines D9 are very expensive and need equivalent (higher) subsidies.
- Pasture rundown is continuing in old buffel grass pastures and there is increased rundown by droughts creating scalds.
- Have tried contour ripping to increase water infiltration and slow water runoff, trying to grow dense grass strips.
- Timber thickening can be problem in some soil types e.g., black wood (*Acacia* sp.) in Cape River area.
- Stage of development of property affects interest, time, money, labour, weed control, etc. and capacity available for scald rehabilitation.
- Producers want to rehabilitate scalds but have barriers, no time and financial limits.
- Only have small bare areas and some are trial areas to test rehabilitation methods.
- On river frontage (NW Qld) used a crocodile plough seeder and grazing management to get pasture cover on scalds.
- Have used Government funding (Reef Rescue) to fence off gullies and regeneration patches; now have pulled up fences after recovery (needed the Government subsidy for this rehabilitation work).
- Killing Chinee apple or Indian jujube (*Ziziphus mauritiana*) and rubbervine (*Cryptostegia grandiflora*) since 1970s with some pasture rehabilitation success.
- Use contours across roads and seeded Wynn cassia in good years when it grows well, to prevent erosion and degraded areas developing.
- Used crocodile plough seeder on black clay soil to red ridge soils; machines need large tynes to dig scoops as poor/shallow divots only last one season.
- Neighbours have done blade ploughing and planted leucaena to improve pastures including over some bare areas.

- Chopper pilot comments on the obvious increased pasture cover from the rehabilitation work.
- Siratro has come back from old planting years ago – can see now in rehabilitated and spelled pastures.
- Need large divots with dozer leaving loose soil in the bottom of the hole for rehabilitation of bare areas.

Appendix 6: Publications from Rehabilitation Project RRRD.024

1. Project description for staff of NQDT, FBA and DEEDI (2011 and 2012)

Overview of Reef Rescue Rehabilitation Project

Rehabilitating degraded grazing lands – Reef Rescue Project (RRRD.024)

“Quantifying the impacts of rehabilitating degraded lands on soil health, pastures, runoff, erosion, nutrient and sediment movement”

Project aims to provide information for landholders and Reef Rescue on mechanical methods and issues on rehabilitating degraded, bare D class, grazing lands in the Burdekin and Fitzroy catchments.

Improving the ground cover on bare patches of D class grazing land to reduce soil, water and nutrient losses requires mechanical intervention. The most cost effective mechanical treatments or the levels of reduction in erosion and nutrient loss are not well defined or quantified. Grazing management strategies are available to continue improvement from C class to B and A condition. This project aims to identify the effectiveness of mechanical interventions and review landholder attempts at rehabilitation of bare D class land condition in the reef catchments. Quantified data will support other reef recovery projects on the social and economic aspects of land management.

This project is delivering against Caring for Our Country 2011-12 Business Plan target for ‘Great Barrier Reef water quality research and development’. The key issue is to evaluate mechanical rehabilitation treatments for D class grazing land, bare patches, to reduce erosion losses of soil, water and nutrients, to improve water quality of runoff into the Great Barrier Reef; to quantify the rate of cover improvement from mechanical intervention; to estimate the costs of rehabilitation treatments; to identify barriers of adoption of proven mechanical treatments; and to estimate rehabilitation costs and incentives required to encourage landholders to implement mechanical treatments of D class land on their properties. The Reef issue being investigated includes widespread areas of degraded D class land patches across the grazing zones of the Burdekin and Fitzroy catchments. Although individual patches may be small in area, they contribute a disproportionate amount of erosion materials to the reef. This project addresses mechanical approaches to improved regeneration methodologies, costs, benefits and barriers.

The project targets will be achieved through:

- Review of previous demonstration sites, landholder experiences by a semi-structured survey and literature review in rehabilitating degraded grazing lands on different landtypes, concentrating on bare or scalded landscapes in the Fitzroy and Burdekin catchments. Due to paucity of collected quantitative data this will involve selective collection of pasture condition data and collation of experiential learning of the producers and agencies involved. Sites will include NQDT and FBA landholders funded to rehabilitate degraded pastures, Landcare group sites, research trials and other relevant commercial sites.

- Establishment of field trial sites and investigates mechanical disturbance methods implemented by landholders to rehabilitate bare degraded grazing lands. The trials will have different levels of cultivation/disturbance treatments across different soil types (in Fitzroy and Burdekin catchments) with grazing managed to assist establishment and production of the sown pastures. Sites will be seeded and mechanical treatments will include:
    1. deep ripping (high input),
    2. chisel ploughing (medium input),
    3. pitting using a “crocodile plough seeder” (low input)
    4. hay mulch on disturbed and battered gully head (high input)
    5. no cultivation (control – grazing excluded and pasture seed added; on C and D-condition sites)

  Measurements will address pasture establishment, production, cover, litter and condition; soil and landscape condition; soil, water and nutrient losses; and costs.

- Extrapolate ecological and financial results across the landscape. This component of the project will link with associated Reef Rescue projects, such as: the “Getting ground cover right” (RRRD027) and “Integrated assessment of BMP cost-effectiveness” (RRRD039) with emphasis on the grazing lands, and with Qld DERM rainfall simulator and runoff/erosion work. Quantified data on soil, runoff and pasture data will be made available to key research users for extrapolating results e.g., via GRASP pasture growth model; long-term carrying capacity calculations; economic case studies.

These project aims are consistent with targets and Caring for Our Country outcomes. It will provide practical regeneration methodologies with associated costs and benefits, which can be linked to incentives, leading to an ability to improve the management of degraded grazing land in the Great Barrier Reef catchments.

Contact: Trevor Hall DEEDI, Toowoomba Q4350; Mob. 0428 104 865

RRRD.024 Reef Rehabilitation Project: (RDL Project)

“Impacts of rehabilitating degraded lands on soil health, pastures, runoff, erosion, nutrient and sediment movement”

Summary of Objectives:

1. social and economic drivers to rehabilitate degraded grazing lands
2. barriers to rehabilitation
3. mechanical rehabilitation approaches
4. groundcover and surface conditions for managing erosion
5. costs, benefits and incentives of rehabilitation
6. time-lag between mechanical intervention and improved condition

“…impacts of rehabilitating degraded lands on erosion…” – RDL project

Trevor Hall
DEEDI, PO Box 102, Toowoomba Qld 4350
Mob. 0428 104 865

2. Handout of Rehabilitation Project description supplied to Minister for Primary Industries, DEEDI Executive, landholders, Agri-business managers and staff of DEEDI at the Spyglass trial site field day Dec. 2011.

Reef Rescue Project RRRD.024
Reef Rehabilitation Field Trial ('Spyglass') December 2011
Spyglass site (Continong area):

GPS: Spyglass trial site 19.337^{0}S 145.815^{0}E (7846166.36; 256201.62)

Site:

- Soil is very hard set, dry, no winter rain, weather was very hot 38-40^0 C days, low humidity, and negligible wind.
- Cracks in clay soil (vertosol) and very hard set surface of duplex (sodosol) soils.
- Graded contours on duplex soil are fine powder (talcum like) – soil blows as dust in the breeze.
- Heavy clay soil diversion bank has some soil structure.
- Banks need steady rain soon to settle down – no cattle activity.
- No seed on banks, native grass topsoil graded back into base of drains.
- Can't see a vehicle driving on road across site on duplex soil near contour banks due to bull-dust cloud.
- Trial plots were seeded at low rates of all grasses and legumes – with a wide range of species sown as coated or uncoated seed.
- No information on seed quality of any lines.
- Seed from each of four plots was weighed separately and sown separately.
- Buffel cv. Gayndah, Katambora Rhodes and Keppel Indian couch grasses were uncoated seed and sown by hand by walking up and down all plots.
- Butterfly pea and Burgundy bean seeded by crocodile (left side) and all other coated seed was sown by a Crocodile (right side).
- Additional Butterfly pea seed (15 kg from Laroona) was sown in strips across the four plots by spinner spreader (Spyglass tractor).
- All coated seed in the Control treatment was sown by spinner spreader.

Treatment plots (5):

1. **Ripping** – 1 m spacing (3 rippers in 2 m width)* 30-50 cm deep; left deep cracks, large clods; Crocodile plough seeding broke up some surface clods.
2. **Chisel plough** (tynes) – 9 tynes in 2.1 m wide * 10-20 cm deep; surface rough, well cultivated (disturbed); Crocodile broke up surface, some shallow in clay and especially on duplex soil areas.
3. **Crocodile plough seeder** treatment – very hard surface, 3-8 cm pits on average, deeper on some clay areas and shallower on duplex soils. Split halves of Crocodile cylinder was used for different pasture species.
4. **Control – a.** Undisturbed very hard surface on southern half in D-condition (in original dam paddock), seeded by hand and spinner broadcaster.

   Control – b. Parts of the Control are in C-condition and have the most grass cover on the whole site (especially on north side of division fence) and there are areas of perennial tussock grass (in original dam paddock). There are bare areas south of fence and a shallow water course across the Control in the north paddock in the grassy C-condition silty surfaced area.
5. **Hay mulch layer** over gully head – grader leveled the slope of the gully head and crocodile disturbed hard surfaces before seeding by hand (low seeding rate) and

spreading out 20 old round grass hay bales. Hay was moldy and wouldn't roll out.

There was an additional ripped strip (8m wide) between the crocodile and control treatments to provide a direct comparison.

Field operations:

6-7 October 2011:

- Surveying bare area and planning layout of four rehabilitation treatments.
- Site contour and diversion bank surveying.
- Two contour banks up slope on west along the length of site – control runoff from hill side.
- One diversion bank on north end – reduce creek overflow of site, except in main floods.

Rehabilitation field experiment establishment:

6 October 2011:
surveying two up-slope contour banks (to W) and creek diversion bank (to N)

7 October 2011:
surveying site to design plot layout

10-13 October 2011:
building two contour banks, diversion bank, gully head hay mulch site prepared, fence lines cleared, ripping and chisel ploughing treatment plots

11 October 2011:
leveling gully head slope, pasture seeding and spreading 20 round grass hay bales as mulch over gully head (plot 5)

12-13 October 2011:
seeding rehab. field trial (plots 1-4) – by hand spreading, crocodile plough seeding (ripped, chisel, crocodile) and spinner broadcasting (over Control treatment plus additional uncoated Milgarra Butterfly pea seed).

Pasture seeding five plots
Seed sown on four main experiment plots:

Rhodes grass cv. Katambora	**1**
Seca shrubby stylo	**1.5**
Verano Caribbean stylo	**1**
Bambatsi panic	1
Caatinga stylo	1.5
Urochloa mosambicensis-SupaSab	**1**
Buffel grass cv. Gayndah	**1.5**
Bothriochloa pertusa – Keppel Indian couch	1
Desmanthus cv. Progardes	2.5
Creeping bluegrass cv. Bisset	**0.5**
Amiga Caribbean stylo.	1
Butterfly pea cv. Milgarra	**3**
Angleton bluegrass cv. Floren	**0.5**
Rhodes grass cv. Callide	0.5
Burgundy bean	1
Inoculum (coated) for Desmanthus (JCU)	

Grassy hay mulch layer (20 large round bales) spread on graded and crocodile pitted gully head on southern end of trial site after seeding with a grass/legume mix (11/10/2011).

Data plans:

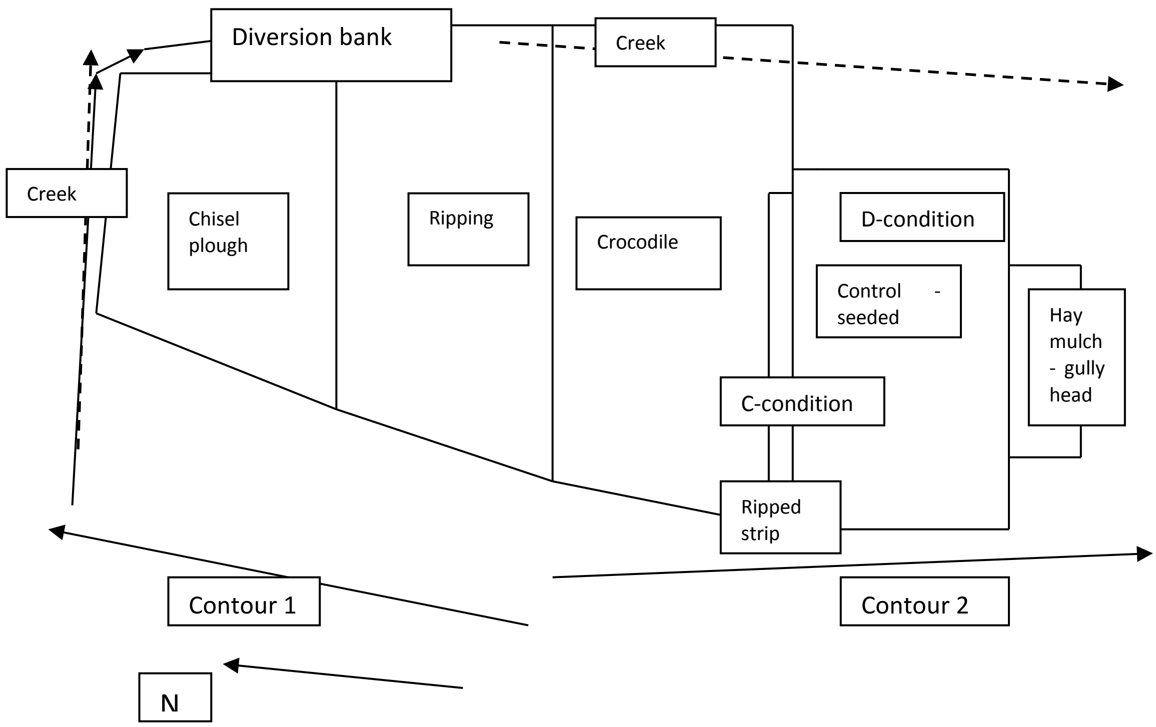
Runoff:	Set up plots for runoff measurements; Measure soil and water runoff Analyse runoff samples.
After rain:	Plant counts – grass, legumes, natives, *B pertusa*, weeds/forbs
After Summer:	Plant populations; Composition and yields (Botanal); Total and litter cover; LFA soil surface conditions (stability, infiltration, nutrient cycling).

Reef Rescue Project (RRRD.024)

Reef Rehabilitation Field Trial ('Spyglass) – 6-14 October 2011

4 treatments of approx. 1 hectare plus a gully head mulch hay treatment (0.2 ha) plus a Control divided into 2 condition states (bare in D-condition and a silty hollow in C-condition)

Trial schematic plan:



3. PowerPoint presentation on Rehabilitation project at the reef Rescue Forum at North Quay, Brisbane (August 2012).

Reef Rescue forum, Brisbane (August 2012): http://www.reefrescueresearch.com.au/events/reef-rescue-forum/2-uncategorised/61-rrrd024-rehabilitating-degraded-grazing-lands.html

4. On-site field day presentation to the North Australian Beef Research Committee (NABRC), cattle producers, MLA, Agency and DAFF staff on the Rehabilitation Project at the "Spyglass' site (October 2012) (40 participants).

5. Project Abstract and PowerPoint Presentation on the Rehabilitation Project RRRD.024 at the NERT TE Hub and Reef Rescue Conference, Cairns (May 2013). The Reef Rescue RandD website: http://www.reefrescueresearch.com.au/events/20-conference-presentations/154-2013-conference-presentations.html

7. *Rehabilitation Project and Spyglass field trial information and summary for the Spyglass Research facility web site (DAF).*

7. Poster presentation and paper on the Rehabilitation Project at the NABRU Conference, Cairns (August 2013).

Paper:

Recovering bare eroded grazing land in the Burdekin

Trevor Hall

DAFF, PO Box 102, Toowoomba, Qld 4350

Introduction

Bare areas of D-condition grazing lands, which can be identified by over 20 years of satellite imagery, occur widely across the Burdekin River catchment. These areas are unproductive for grazing and contribute a disproportionate amount of sediment and nutrients into the Great Barrier Reef lagoon. Rehabilitating these patches will have direct benefits to the cattle producer by providing land cover and pasture, and also benefit the wider community by improving water quality and GBR health.

Methods

Four mechanical soil disturbance treatments (chisel ploughing to 20 cm, deep ripping to 50 cm, crocodile plough seeding with pits to 10 cm, and surface hay mulch after leveling) were compared with an undisturbed control on a bare, eroded, periodically flooded, creek frontage in the mid-Burdekin catchment. The treatments, applied in October 2011, were all surface seeded with a tropical pasture grass and legume mix and grazing was excluded. There were 3 soil types: a crusty deep black vertosol (Ug5.15), a deep grey sodosol (Dy3.13), and a sodic brown dermosol (Uf6.41). Rainfall was 775 mm and 430 mm over the first two wet seasons respectively. Long-term average is 613mm.

Results

There was good pasture germination in cultivated treatments on 100 mm of rainfall immediately after sowing, however, these seedlings died in the following 5 dry weeks and temperatures to 40^{0}C. A second 96 mm rainfall germination event occurred in December 2011 and these predominantly grass plants produced to 90% ground cover by the end of the first summer on the vertosol and sodosol soils, and <20% cover on the dermosol soil type. Over the first summer, treatments produced pasture yields to 3900 kg ha^{-1} from the hay mulch treatment and average pasture cover of 65% from deep ripping. Cover in the control on the dermosol soil was from annual grasses and pigweed (*Sporobolus* and *Portulaca* spp.) as the sown species failed to establish. In the second year, total cover remained similar, litter cover increased from death of first-year grasses, and DM yields all decreased (Table 1).

Table 1. Mean pasture dry matter yield, cover and basal area after the first two summer seasons.

Pasture parameter	Ripping		Chisel		Crocodile		Hay mulch		Control	
	2012	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
Dry matter yield (kg ha^{-1})	3420	2860	3350	2140	2300	1310	3910	3020	1850	420
Total ground cover (%)	65	66	56	57	47	63	97	90	45	42
Litter cover (%)	6	28	2	24	6	41	93	79	2	25
Basal area (%)	1.8	2.1	1.8	1.6	1.5	0.9	1.5	2.2	1.0	0.3

Conclusions

In the first summer, there was greatest establishment and pasture growth from the deep ripping, chisel ploughing (3400 kg ha^{-1}) and the grass hay mulch cover on the disturbed vertosol soil type. There were significant differences in rehabilitation success between the three soil types with most success on the vertosol and failure on the sodic dermosol. Legume yield, >1000 kg ha^{-1}, was highest with ripping and chisel ploughing. In the Burdekin catchment, D-condition bare areas on some soil types, such as vertosols, can be rehabilitated by mechanical disturbance, reseeding by adapted pasture species and excluding grazing, in good rainfall years. Subsequent seasonal conditions and management will determine the long-term rehabilitation success after initial establishment.

Email: trevor.hall@daff.qld.gov.au

---

8. Poster presentation and paper on Rehabilitation Project at the 22nd International Grasslands Conference, Sydney (October 2013).

Paper:

Rehabilitating degraded frontage soils in tropical north Queensland

Trevor J. Hall

DAFF, PO Box 102, Toowoomba Qld 4350; Email: trevor.hall@daff.qld.gov.au

Key words: rehabilitation, degraded pastures, water quality, mechanical disturbance, Great Barrier Reef

Abstract

The extensive tropical grasslands of north Queensland are grazed by beef cattle and provide a significant proportion of the water flowing into the Great Barrier Reef lagoon. Eroded, bare D-condition areas in these grasslands provide a disproportionate amount of water, sediment and nutrients as runoff from these pastures. Rehabilitating these degraded areas will help improve water quality flowing onto the reef. Rehabilitation methods were evaluated on three soil types on a degraded creek frontage in the Burdekin River catchment of north Queensland over the 2011-2012 summer. Five treatments including several mechanical soil disturbance methods with seeding of tropical pasture grasses and legumes, and excluding grazing were evaluated. Grader leveling with surface disturbance, pasture seeding and applying a grass hay mulch layer produced highest yields (3910 kg ha^{-1}), predominantly of grass. The more economical soil disturbance methods of chisel ploughing and deep ripping produced 60% cover and over 3300 kg ha^{-1} dry matter from grasses and legumes on a vertosol and a sodosol soil type. On a sodic dermosol soil there was no successful rehabilitation treatment in this above average rainfall (775 mm) summer.

Introduction and Objectives

Soil sediments and nutrients eroding from the grazing lands of the Burdekin and Fitzroy catchments in north-east Queensland contributes to reduced water quality in the Great Barrier Reef (GBR) lagoon. Degraded and eroded D-condition bare areas and eroding gullies in grazing lands provide a disproportionate amount of soil and nutrient losses from predominately native pasture grasslands used for cattle grazing. These bare patches occur widely across the two catchments and consistently degraded sites have been identified by 24 years of satellite imagery. The objectives of this study were to identify mechanical methods and management practices for regenerating these bare patches. This will assist landholders in returning unproductive land into useful grazing pastures and will provide benefits to the wider community by improving water quality from grazing lands that enters the GBR lagoon.

Methods

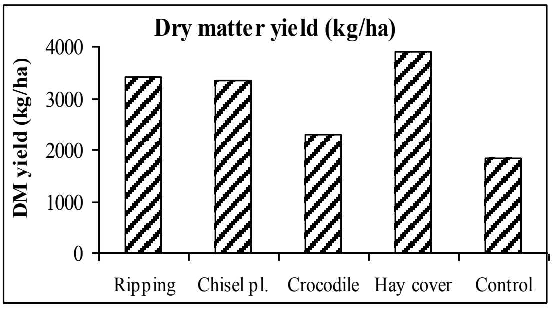
Site. Long-term, bare D-condition areas were identified by the Bare Ground Index from satellite imagery over 1988-2011, and surveyed by ground truthing to locate a 10ha research site in the mid-Burdekin catchment of tropical north Queensland. The site was a periodically inundated creek flat with up to 50 cm of topsoil eroded, in undulating narrow leaved ironbark (*Eucalyptus crebra*) and Reid River grey box (*E. brownii*) flats west of the Burdekin River (GPS 19.337^0 S, 145.814^0 E). There were three soil types identified: a deep grey sodosol (Dy3.13), a crusty deep black vertosol (Ug5.15), and a sodic brown dermosol (Uf6.41).

Treatments and measurements. Four unreplicated mechanical soil disturbance treatments of 1-2ha size: chisel ploughing to 20 cm deep at 20 cm tyne spacing, deep ripping to 50 cm deep at 1m spacing, crocodile plough seeder, and grass hay mulch to 20 cm deep after surface disturbance and leveling with a grader blade, were compared with an undisturbed control. A tropical pasture grass and legume seed mix was broadcast over all treatments including the control. The mechanical treatments, applied to dry soil in October 2011, were followed by 775 mm of rainfall, in an above average rainfall wet season. Pasture measurements were: establishment rating, species yield and ground cover, which were monitored after the first summer season in April 2012. Cattle grazing was excluded.

Results and Discussion

Mechanical rehabilitation on dry soils in spring when the following rainfall conditions over summer are favourable for pasture establishment can produce sufficient pasture cover to limit erosion within the first year. However, pasture rehabilitation in spring can suffer from false germination events. There was 100 mm of rainfall within a week of sowing in mid-October 2011 which produced pasture seedling germination over the trial site. These seedlings all died in over one month of heatwave conditions to 40^0C, eliminating some soft seeded species. There was a second germination event in mid-December 2011 on 96 mm of rainfall. This germination was predominantly Indian bluegrass (*Bothriochloa pertusa*), cv. Milgarra butterfly pea (*Clitoria ternatea*) and cv. Progardes desmanthus (*Desmanthus* spp.). There were soil type differences in establishment success. Cover (to 90%) and yields (>3400 kg ha^{-1}) were highest on the vertosol and sodosol soil type and lowest on the sodic dermosol soil type (cover <20% from annual native *Sporobolus* and *Portulaca* species).

The hay mulch cover treatment produced the highest total dry matter yield (3910 kg ha^{-1}), 55% Rhodes grass (*Chloris gayana*), and cover (97%), with results similar from the deep ripping and chisel ploughing treatments (3400 kg ha^{-1} DM yield and 60% cover) over the first growing season (Figure 1). The crocodile plough seeding produced a lower yield than other disturbance methods, only marginally higher than the control. Cover was similar between the crocodile and the control treatments (mean 45%). Pasture basal area was highest in the deep ripping and chisel ploughing treatments (1.8%) and lowest in the control (1%).



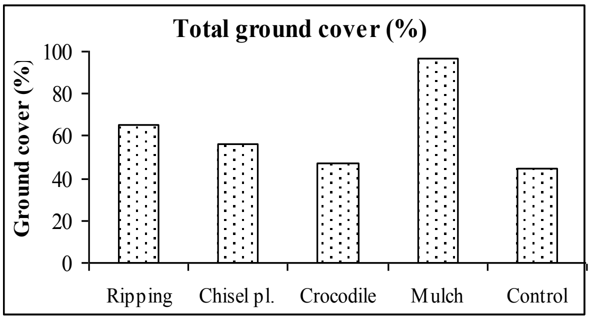


Figure 1. Pasture dry matter yield (kg ha^{-1}) and cover (%) in mechanical treatments (April 2012).

The dry matter yield of the treatments in pasture species groups (Table 1) shows the hay mulch layer produced the highest yield of both perennial (predominantly Rhodes grass) and annual grasses. There were similar yields from the chisel ploughing and deep ripping treatments (predominantly Indian bluegrass), which both produced similar the high legume yields. The crocodile plough seeder treatment (shallow pits) was inferior to the two more intensive surface disturbance treatments and marginally superior to the undisturbed control.

Table 1. Mean pasture dry matter yield (kg ha^{-1}) in rehabilitation treatments over the first summer.

Species Groups	**Rehabilitation treatments (kg ha^{-1})**				
	Ripping	**Chisel plough**	**Crocodile**	**Hay cover**	**Control**
Perennial grasses	1820	2110	2060	3040	1420
Annual grasses	100	190	60	460	210
Legumes	1430	1030	170	300	200
Forbs	70	30	20	110	30
Total DM yield	**3420**	**3350**	**2300**	**3910**	**1850**

Conclusions

Selecting suitable soil types and the most adapted pasture species offers the greatest chance of success in rehabilitating degraded D-condition bare areas in tropical north Queensland. In an above average rainfall summer, the soil type had the most influence on establishment success, production and cover in the first year. Establishment was most successful on the vertosol soil and failed on the sodic dermosol. False germination events could lead to failure in the first year. In this trial there were two 100 mm rainfall germination events in early summer, which is not an annual occurrence in this environment.

Pasture seeding with grass hay mulch cover, deep ripping and chisel ploughing on disturbed vertosol soil produced the highest herbage yields and ground cover in the first season. This pasture is sufficient to limit soil sediment and nutrient losses from bare areas in these grasslands. The latter two cultivation treatments, which had the highest legume yields thereby improving the grazing value of the new pasture, are recommended for the vertosol and sodosol soil types. Pasture survival and cover levels in following years will determine if these methods of rehabilitation of D-condition bare areas provide a permanent solution to improving land productivity and reducing sediment and nutrient losses from these grasslands.

Appendix 7. Photographs of rehabilitation experiment sites.

A series of photographs from across the three field experimental sites are included in this appendix to show the sites, environments, field experiments and to demonstrate some results throughout the project.

The bare and scalded condition of the field experiment sites before the treatments were established is shown in the following photographs.

***Image 1*. Spyglass: Extensive eroded D-condition land at the rehabilitation experiment site before treatments (1 Oct. 2011).**

***Image 2*. Banana: Un-rehabilitated bare patches adjacent to a blade ploughed rehabilitated pasture (2012).**


***Image 3*. Spyglass experiment site: Surface scalding prior to rehabilitation treatments (Oct. 2011).**

***Image 4*. Spyglass: Surface of chisel ploughing treatment on black vertosol soil type at experiment establishment (Oct. 2011).**


***Image 5*. Spyglass: Eroded, bare and scalded surfaces at the rehabilitation experiment site at establishment (Oct. 2011).**

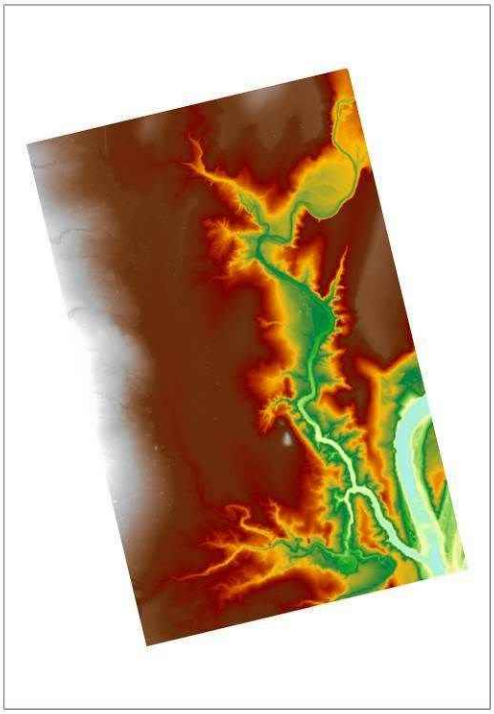


***Image 6*. L. 3D imagery of extent and depth of erosion gullies and gully heads at Spyglass (December 2013); and R. Cattle at the Spyglass rehabilitation experiment site (April 2013).**

Machinery used for rehabilitation of bare D-condition grazing lands in the Burdekin and Fitzroy catchments is shown in the following images.

***Image 7*. L. Three deep ripper tynes on grader tool bar; and R. Typical trailing chisel plough for softer soil types (2011).**

***Image 8*. L. Roller-drum seeder (trailed behind a vehicle) for sowing pasture seed mixes ; and R. Nine tyne toolbar on grader for full surface disturbance.**

***Image 9*. 3-point linkage spinner broadcaster for spreading seed and fertilizer on rehabilitation sites.**

***Image 10*. L. Degree of disturbance from deep ripping (Spyglass); and R. Spreading grass hay mulch on gully head at spyglass (October 2011).**

Machinery operations for water management, contour banks and diversion banks, and battering a gully head with a grader before seeding with a crocodile plough seeder at Spyglass (October 2011) are shown in the following images.

***Image 11*. L. Grader constructing creek over-flow diversion bank; and R. Contour bank to direct hillside water off experiment site at Spyglass (Oct. 2011).**

***Image 12*. L. Grader battering break-away gully head; and R. Crocodile plough seeder sowing grasses and legumes for hay mulch treatment at Spyglass (Oct. 2011).**

***Image 13*. L. Crocodile plough seeding; and R. Chisel ploughed treatment at establishment on black vertosol at Spyglass (Oct. 2011).**

***Image 14*. Eroded edge (50 cm deep) along south side of Spyglass experiment site with upper-slope contour bank above tree line controlling hillside water movements (April 2013).**

***Image 15*. L. Diversion bank to keep creek overflow off experiment site at Spyglass; and R. Contour bank protecting site from hillside water wash.**

***Image 16*. L. Satellite transmission camera; and R. Satellite transmission weather station at Spyglass experiment site.**

***Image 17*. Spyglass – L. Deep Ripping treatment in first summer March 2012; and R. Ripping strips in second summer in February 2013. Note the dead grass tops and regrowing legume under grass. (Green pasture up slope is grazed native grasses on a light textured surface Sodosol soil).**

***Image 18*. Sodic dermosol soil type at Spyglass with native annual *Sporobolus* and *Portulaca* species (no sown species established) after three years (March 2014).**

The clear distinction between soil types that can establish pastures given suitable conditions and other adjacent soil types that are not responsive to any mechanical disturbance treatment with pasture seeding can be seen in the following four images. The top two photos show pasture established on the deep ripping and chisel ploughed cracking clay (vertosol) and surface loam soil type (sodosol), compared with negligible to nil establishment by deep ripping and crocodile seeding on a sodic dermosol soil type at Spyglass at the end of the first summer (March 2012).

***Image 19*. L. Spyglass rehabilitation ripping; and R. chisel ploughing treatments in first summer (March 2012).**

***Image 20*. L. Sodic dermosol soil unresponsive to deep ripping compared with black vertosol soil establishment (rear) (March 2014); and R. Native plants establishing in silt in lower hollow of sodic dermosol (April 2014).**

***Image 21*. L. Hay mulch and seeding treatment at establishment (October 2011); R. pasture established in hay mulch (right of image) compared with bare, unresponsive seeded only grey sodosol soil (left of image) in first year at Spyglass (March 2012).**

***Image 22*. Aerial image of the gully head hay mulch treatment in head of break-away gully (December 2013). Note: the buffel grass pasture establishing in the silt hollows washed from the mulch treatment.**

***Image 23*. Spyglass-Start of rehabilitation of sodic dermosol soil with annual grasses and weeds; occasional buffel grass and Sabi grass plants in silty surface hollow base (March 2014). Site was deep ripped and pasture seeded in October 2011 and gypsum applied in December 2013.**

***Image 24*. Hay mulch treatment with healthy seeding buffel grass and flowering Butterfly pea in the first year at Spyglass (March 2012).**

The success of the blade ploughing and pasture seeding a whole paddock as the treatment at Banana is shown in the following two images of the scalds before treatment and the pasture three years after. Cattle grazing has been managed to suit the amount of pasture produced during these early establishment years. Blade ploughing is a well-used pasture establishment and renovation method in the Fitzroy catchment.

Image 25. Before: **Banana scalded patches at the rehabilitation experiment site (in 2008) before blade ploughing and sowing pastures. (Photo J. O'Reagain).**

Image 26. After: **Rehabilitation site at Banana after rehabilitation by blade ploughing and reseeding with grasses and legumes over the whole paddock and managed grazing (2012).**

***Image 27*. L. Banana experiment paddock bare patches before rehabilitation treatment (2009); and R. Four years after blade ploughing and pasture seeding (2013). (Photos J. O'Reagain and T.J. Hall)**

Sediments and nutrients in runoff water from the three field experimental sites were measured by rainfall simulation. The following four images show the equipment used, borders around a paired field plot, runoff water carrying sediment and a typical soil core to 30 cm deep. This was from a Fitzroy partial rehabilitation site and from a bare site at Injune in 2012.

***Image 28*. L. Rainfall simulation equipment; and R. Plot borders in partial rehabilitated pasture at Injune (July 2012).**

***Image 29*. L. Injune scald site runoff sediment; and R. Rehabilitation site top 30 cm soil profile core (2012).**

There are six fixed sites across the treatments where the same 12 photos (N to S and S to N) are recorded mid-monthly. These photos are added to a database for ease of comparison to show the time-series of pasture responses and effects of the drought. Two examples, the Chisel Ploughing and Crocodile plough seeding treatments, from March 2012 and March 2014 are shown below. These fixed site photos demonstrate the good initial pasture establishment over the site in the first summer (2011-2012) and the subsequent damaging effect of the extended drought (2012 to 2014).

***Image 30*. March 2012: L top. Chisel plough treatment; and R top. Crocodile plough seeding treatment after one good summer; bottom same sites after two drought years, in March 2014.**

Spyglass Fixed photo site – Deep Ripping treatment (N to S)

3/2012

4/2012

5/2012

6/2012

8/2012

9/2012

10/2012

11/2012

Series Continued – Spyglass Deep ripping treatment

12/2012

1/2013

2/2013

3/2013

4/2013

5/2013

6/2013

7/2013

***Image 31*. Spyglass rehabilitation –fixed photo site in Deep Ripping treatment from March 2012 to July 2013.**


Spyglass chisel ploughing and seeding October 2011


Spyglass crocodile plough seeding October 2011


Spyglass deep ripping and seeding January 2012


Spyglass chisel ploughing and seeding March 2012


Spyglass hay mulch and seeding March 2012


Spyglass deep ripping and seeding March 2012

***Image 32*. Spyglass site at treatment establishment and progress of pasture development over the first summer (2011-2012).**

***Image 33*. Injune rehabilitation site: scalds; deep ripping and pasture seeding 2003, partial rehabilitation 2007 and full recovery in 2011.** **(Photos W. Peart and T.J. Hall)**

Fitzroy catchment: Injune bare scald rehabilitation site to established pasture over nine years: 2003-2007-2011-2012

Deep ripping and pasture seeding October 2003

Partial pasture recovery to September 2007

Pasture fully rehabilitated August 2011

Ripping and seeding bare scald, October 2003

Pasture recovery to September 2007

Pasture rehabilitated August 2011

***Image 34*. Injune scald rehabilitation series – Ripping 2003; Partial recovery 2007; and established pastures 2011 (Buffel grass, silk sorghum, Bisset creeping bluegrass, Milgarra butterfly pea, Seca stylo, siratro). (Photos W. Peart and T.J. Hall).**

Deep ripping and spreading seed and NatraMin fertilizer mix over bare scald, October 2003

Partial recovery to September 2007

Pasture rehabilitated, April 2012

Mulch trial on ripped and seeded scald, October 2003

Good recovery to August 2011

Grazed rehabilitated pasture in drought year, May 2013

***Image 35*. Injune experiment site scald reclamation photo series from ripping treatment to established pasture – 2003, 2007, 2011, 2012 and 2013.**

(Photos W. Peart and T.J. Hall)

Deep ripping recovery to April 2012

Partial recovery bare patches in grazed buffel, May 2013 (drought year)

Rainfall simulation plots rehabilitated buffel grass, well grazed – paired plots, May 2013

***Image 36*. L. Injune experiment site ripping and seeding rehabilitation paddock before grazing in 2012; and R. Two sites within paddock after grazing in May 2013.**

Appendix 8. Gypsum experiments on sodic dermosol soil at Spyglass

The initial rehabilitation on the sodic dermosol soiltype at Spyglass was unsuccessful. The two short-lived native species capable of growing on patches of this soil were acid grass (*Sporobolus coromandelianus*) and a black pigweed (*Portulaca* sp.), neither have any grazing value. They can provide patchy groundcover and collect dust and grass seed which can assist other species to grow in silty patches. These plants do not provide any long-term cover on this soil. The sown pasture species in the rehabilitation experiment did not establish, irrespective of the disturbance method. New experiments were established in December 2013 to evaluate chisel ploughing, applying pasture seed and gypsum, on producing a perennial pasture cover on this soil.

Four experimental sites were selected and chisel ploughed with a 7-tyne 2 m wide, 3-point linkage plough in late November 2013 (Figure 1) and seeded with a tropical exotic grass and legume pasture mixture. The mix was similar to that used in the original treatments in October 2011. There were two gypsum treatments: 2 and 3t/ha, which was surface applied by a spinner broadcaster on 1 December 2013 (Figure 2). The following summer growing season rainfall was poor (241 mm between October and March) with rain occurring in autumn (90 mm) in one main event, too late for pasture establishment. This dry summer and late rain was not inductive to good pasture seedling establishment to evaluate the gypsum treatments.

Figure 1. Chisel ploughing scalds at Spyglass (November 2013).

Four gypsum experiment sites

1. Sodic dermosol depression

The plot was at the eastern end of the deep ripping treatment in a wash-away depression. By May 2014, this site had established some sown pasture patches in the accumulated silty centre of the hollow. The main species were buffel grass (*C. ciliaris*) and some Sabi grass; both had mature seed heads present and yielded to 2500 kg ha^{-1}. Other areas only grew acid grass and pigweed yielding to 600 kg ha^{-1}. These two species had matured and were dried off. There are still bare unresponsive patches along the drier sides of the hollow.

There are occasional plants of Milgarra butterfly pea (*Clitoria ternatea*), desmanthus (cv. Progardes, mainly the red stemmed line), annual summer grass (*Digitaria ciliaris*) and *Sida* weed species. Cover in the best rehabilitated buffel grass patches was to 95% and the average cover of the whole area is less than 40% with some patches having no cover.

These new pasture patches have established only in the more favourable centre of the hollow (increased moisture and surface silt) in response to the chisel ploughing, reseeding and applied gypsum. There had been no establishment from the original deep ripping treatment across this hollow and seeding when the experiment was first established in October 2011.

Figure 2. Spreading gypsum across chisel ploughed scalds and water courses, Spyglass (December 2013).

2. Crocodile plough treatment

In the Crocodile plough seeder treatment, the reseeded and chisel ploughed strips with gypsum applied on the sodic dermosol soiltype only grew black pigweed and acid grass. The sown tropical grasses and legumes did not establish in this poor-rainfall summer (Figure 3).

Figure 3. Matured pigweed on gypsum trial strip in Crocodile treatment after first summer (19 March 2014).

3. Control bare treatment

In the Control-bare treatment the gypsum treatment area produced a similarly poor pasture response to that of the untreated Control-bare treatment. The reseeded and chisel ploughed strips with gypsum applied only grew black pigweed and *Sporobolus* acid grass and the sown tropical grasses and legumes did not establish.

4. Double dam site (River paddock)

This site was across an extensive eroded hollow south of Double dam in the River paddock. In March 2014 after the first summer, there was germination of *B. pertusa* in the wetter areas of the strip across the hollow and some patchy establishment in other treated areas. There is a distinct border of *B. pertusa* establishment in the chisel ploughed strip and the undisturbed area of the more favourable wetter zone of the hollow (Figure 4). There was no pasture establishment on the treated or untreated drier, more elevated zones across the hollow.

Figure 4. Chisel ploughed and applied gypsum strip with established *B. pertusa* in River Paddock south of double dam; note no establishment in undisturbed strip (19/03/2014).

There was no pasture establishment on a favoured soil type, a heavy clay soil (vertosol) with chisel ploughing, seeding and applying gypsum over the first summer, 2013-2014 (Figure 5). This is attributed to the lack of suitable rainfall, and no run-on water, as this soil type produced a dense sown grass and legume pasture in the original rehabilitation treatments over the good rainfall summer of 2011-2012.

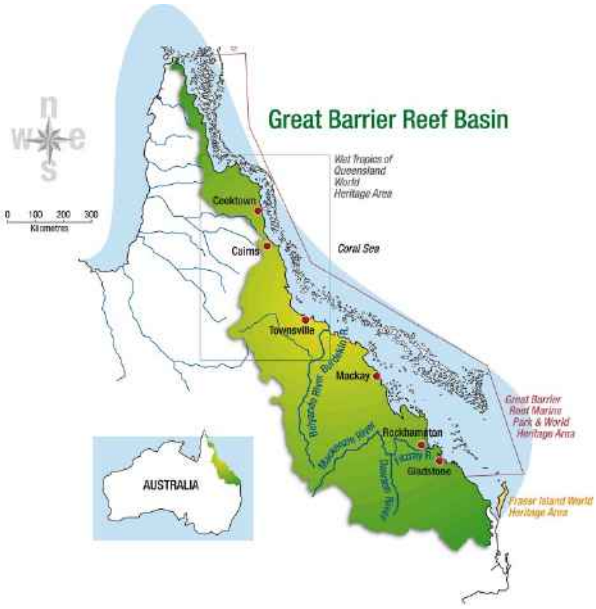
Figure 5. Gypsum strip on clay soil, no pasture establishment, in River paddock south of double dam (L) and depth of eroded surface at northern end of the hollow (R). Note: gypsum truck tracks are still evident after a full summer (19/03/14).

A spring-tyned 3-point linkage chisel plough is suitable for surface disturbance of clay and loam soils for pasture rehabilitation in favourable rainfall summers is shown in Figure 6.

Figure 6. Seven spring tyne, three-point linkage chisel plough suitable for medium level surface disturbance for rehabilitation of clay and loam soil types.

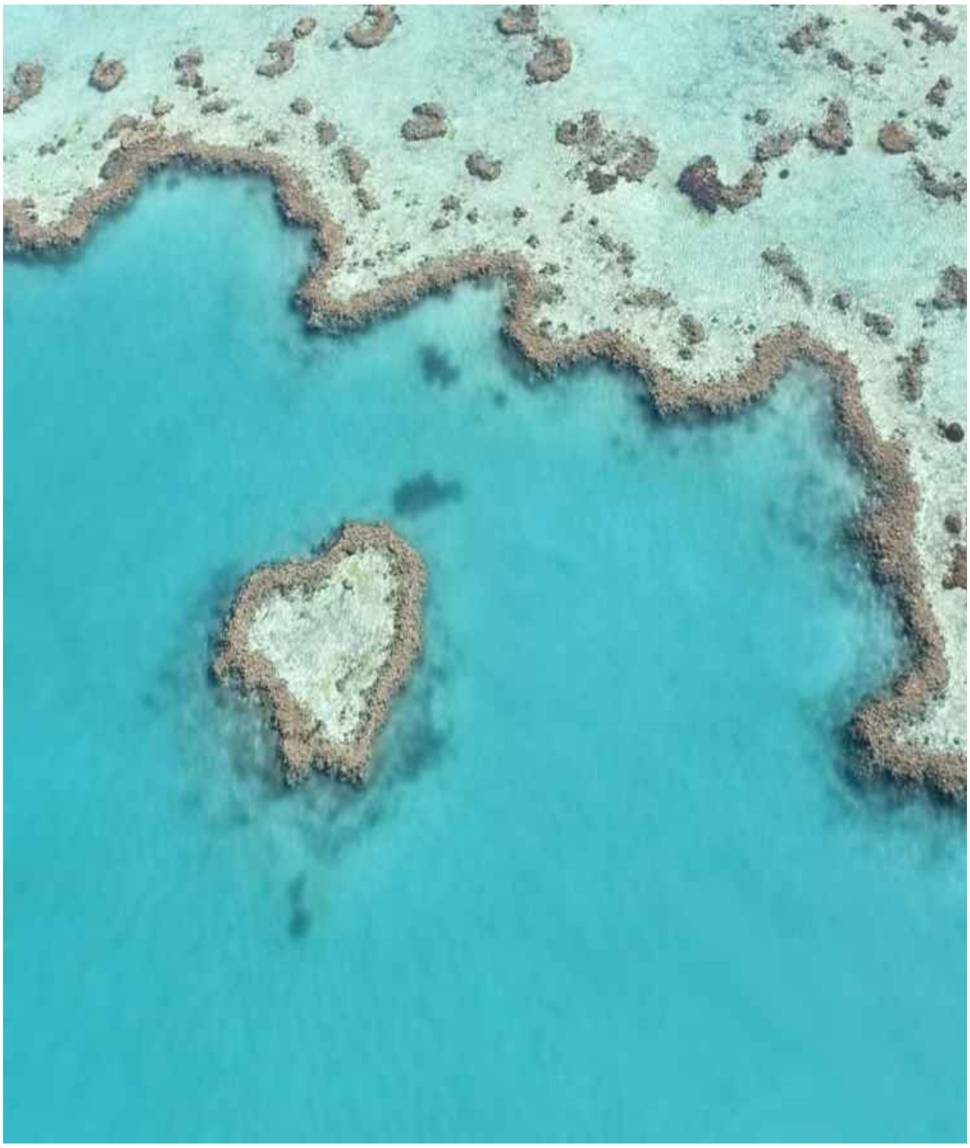
Due to the continuing drought over summer when these experiments were established and the subsequent poor pasture responses, the value of applying gypsum at 2-3 t ha^{-1} to the sodic dermosol soil type has not yet been effectively evaluated. The experiments need to be repeated by chisel ploughing and/or deep ripping, re-applying gypsum at various rates, and reseeding with a tropical grass and legume mix in a higher (above average) rainfall year.

Protecting the Great Barrier Reef from damaging influences from grazing lands in the Reef Catchments is vital for the future health of the Reef as well as for the communities, industries depending on its viable presence and also for the much wider World community where it is also highly valued.



Images showing the value of the Great Barrier Reef World Heritage to the community: significant value to fishing and tourism industries of Queensland and Australia.

Images of the different forms of coral reefs in the Great Barrier Reef.



A popular coral reef off the north-east Queensland coast (web photo).