Grazing land condition in the Reef Catchments (Mackay Whitsunday Isaac) region

April 2013

Final report to Reef Catchments (Mackay Whitsunday Isaac) Ltd

T Beutel, J Fletcher, L Williams, M Hoffmann, and D Reid

This publication has been compiled by T Beutel, J Fletcher, L Williams, M Hoffman and D Reid of Animal Science, Department of Agriculture, Fisheries and Forestry.

Contents

Abbreviations

RC Reef Catchments.

DAFF Department of Agriculture, Fisheries and Forestry, Queensland.

GCI Ground Cover Index.

WONS Weeds of National Significance.

Summary

This report documents the third round of a grazing land monitoring program in the Reef Catchments (Mackay Whitsunday Isaac) region. The monitoring has occurred on 222 sites in the region's four largest grazing land types. All sites have now been sampled in January 2011, October 2011, and April 2013. The latest sampling comes after dry and wet season samples, and a subsequent decision by Reef Catchments to concentrate sampling in wet seasons.

This document compares the original wet season sample (January 2011) to the most recent sample. We have also re-analyzed twelve years (2001-2012) of remotely sensed ground cover measurements at 670 randomly selected locations, a task begun after the previous sampling, to provide ongoing information about ground cover change in the region. The key conclusions and recommendations of the work are as follows.

1. Land condition remains largely static since 2011.
2. Exotic weeds remain the significant grazing land issue for RC.
3. Ground cover is abundant and quite resilient at catchment / land type scales.
4. Ground cover analysis is now part of the monitoring system.
5. Wet season sampling should occur approximately biannually.
6. Maintain and use this land condition monitoring system.

The monitoring program has also produced or updated a number of legacy products for Reef Catchments including an interactive land condition database for all sites and samples, which incorporates a new photo comparison tool and a new Sites book which documents all site data for the most recent round of sampling.

Introduction

Beutel et al (2011) provided a snapshot of grazing land condition in January 2011 for the Reef Catchments (RC) natural resource management region of Queensland. The report assessed land condition and a number of other related variables across 222 sites over the four largest grazing land types found in the region. These same sites were resampled again in October 2011 (Beutel 2012), along with an analysis of longer term remotely sensed ground cover measurements on 670 sites across the region. This second round of sampling allowed comparison of wet and dry season samples, and was used as the basis for deciding whether an ongoing land condition monitoring program should be based around wet or dry season samples.

These studies drew a number of conclusions about land condition in the region. Four main issues were highlighted:

- a large proportion of grazing country was in suboptimal (C and D) condition;
- an abundance of weeds was the main contributor to poor land condition assessments;
- ground cover levels were generally high and so not a major factor in poor land condition assessments; and,
- on this basis, sampling seemed best focused on wet season sampling when weeds were most visible.

This report discusses the outcomes of the third round of sampling in RC's grazing land condition monitoring program. Data were collected in April 2013, about two years after the original sample. In this work, we focused on three main questions:

- What picture does this latest survey give of regional grazing land condition?
- How do the results from 2013 compare to those of January 2011?
- On the basis of this, what can be recommended in terms of further sampling for the region?

The study also continues and builds on Beutel et al's (2012) analysis of ground cover change in the region's catchments and land types. This new analysis uses Queensland Ground Cover Monitoring Program's new generation of ground cover data (Scarth et al 2010), and an extended time series (2000-2012). It provides an additional perspective of ground cover change to that delivered from the 222 land condition assessment sites.

The report is presented in three main sections.

- *Methods and Results* revisits the methods used and the statistical results of our analyses. These include both field assessments and the ground cover analysis.
- *Legacy products* details the materials produced by the project including the monitoring database and new Sites book.
- *Discussion and recommendations* outlines the major conclusions of the work and their implications.

Methods and results

Methods and results are in three parts. *Climate briefly* summarizes climatic conditions leading up to the original and most recent sampling periods. *Field assessments* provides an overview of methods used during field assessments, and the results of their analysis. *Ground cover analysis* summarises the analysis of ground cover data at 670 sites previously used by Beutel et al (2012) for the period 2000 to 2012.

Climate

The current round of sampling occurred in April 2013. Seasonal conditions for this sample were substantially drier than those at the time of the first sample (January 2011), a difference largely attributable to the very wet conditions leading up to January 2011 rather than particularly dry conditions leading into April 2013 (Figure 1).

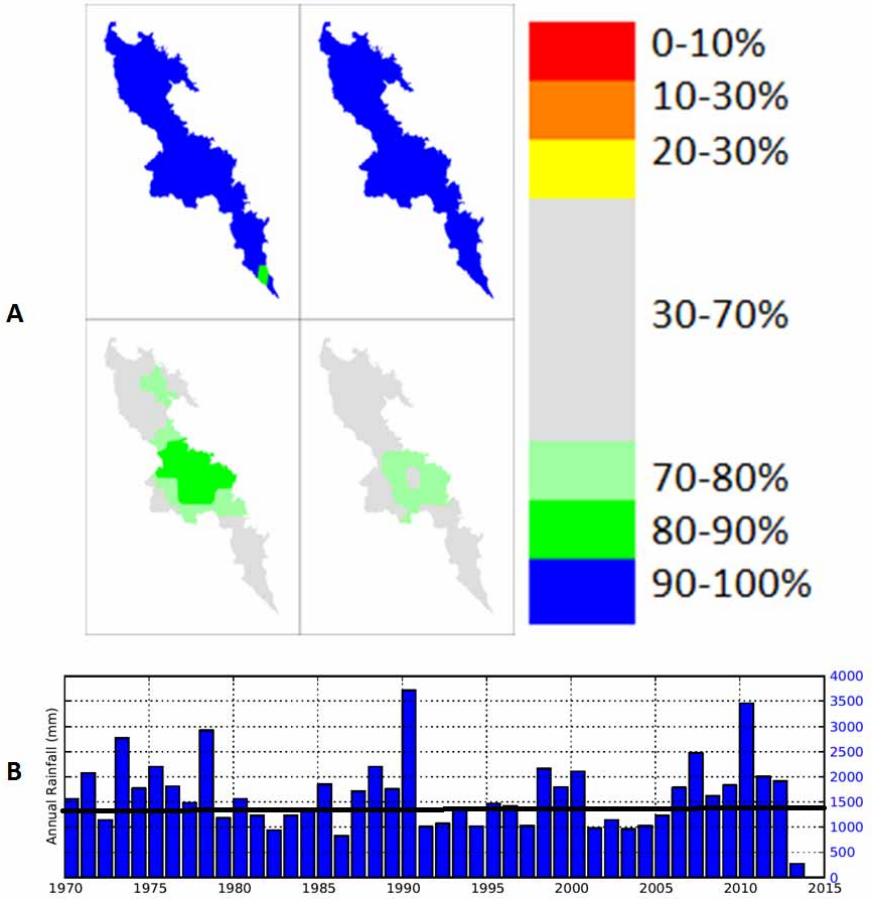


Figure 1: **Seasonal conditions in 2011 and 2013. A: January 2011 (top row) and October 2013 (bottom row). Images in each row show rainfall relative to historical records in the 3 (left) and 6 (right) months up to and including the sampling month. B: Annual rainfall (with median line) at Mackay 1970-2013 (adapted from www.longpaddock.qld.gov.au).**

Field assessments

The April 2013 sampling followed largely the same methods as Beutel et al (2011, 2012) - sampling the same sites (Figure 2), and recording the same data as previously. Some alterations were made however, either to improve the quality of the data collected, or to accommodate changes of circumstance beyond our control. These changes were as follows.

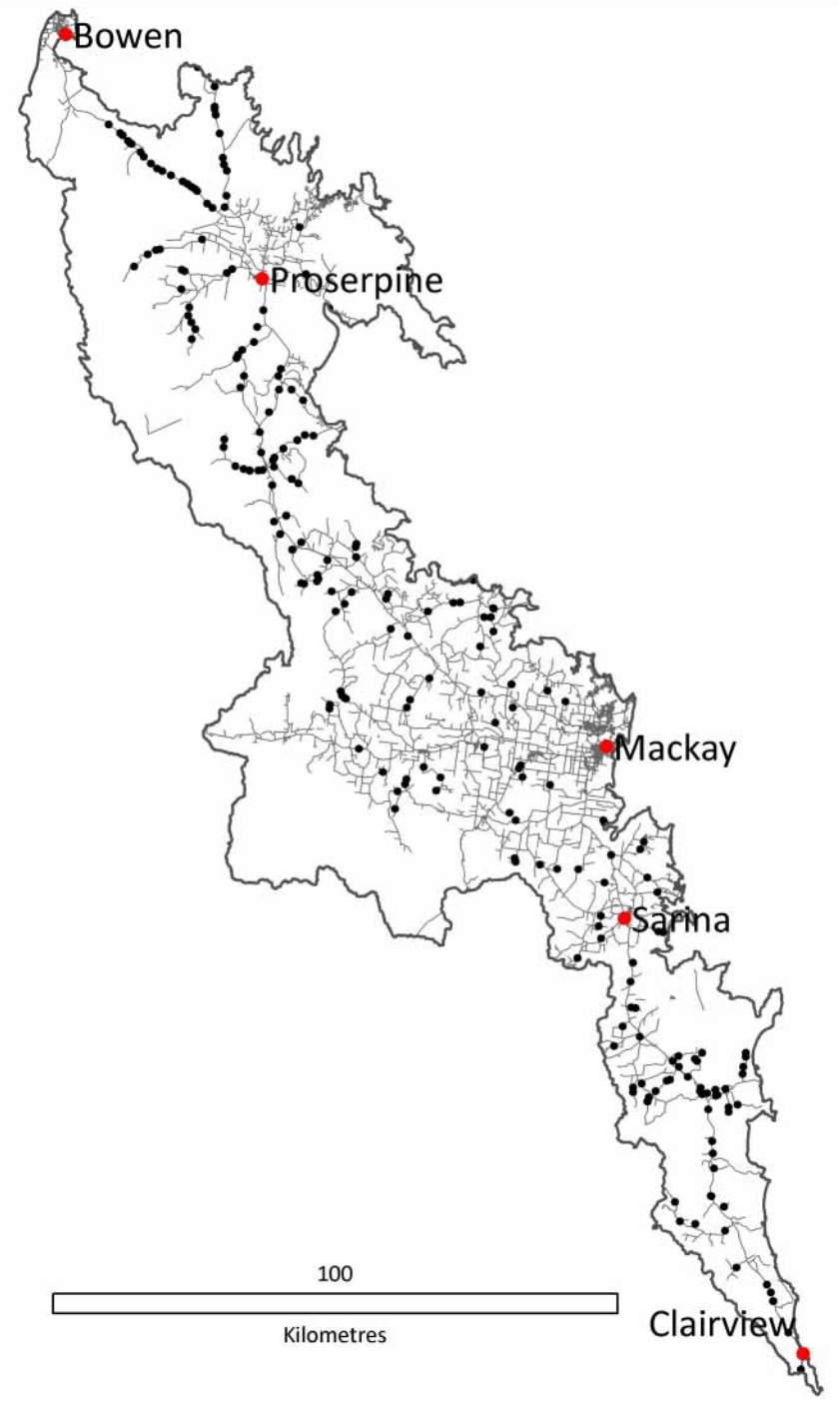


Figure 2: **Rapid assessment site locations superimposed on the region's road network**

- Three sites were moved slightly (<50m), two to accommodate new fencing not present in the first sample, and one because the exact point and direction of the original photograph could not be relocated.
- One site was partially covered with new stock yards after the January 2011 evaluation. A replacement site was identified and used nearby for the April 2013 sample.
- One site was converted to cane farming after the January 2011 evaluation. A replacement site was identified and used nearby for the April 2013 sample.
- One extra site was included in the analysis that was evaluated in 2011 wet season sample, but accidentally omitted from Beutel et al (2011). That site was re-assessed for the April 2013 sample.

Apart from these alterations, the same methods were used as in Beutel et al (2011), and the full methodology is provided there.

Tables 1 and 2 show the land condition classifications for each major catchment and land type in each sampling period. Our analysis[1] indicated no significant differences between catchments in terms of land condition. Land condition did however vary significantly between land types, with condition significantly better in Alluvial flats than any other land type.

Over both sampling periods, levels of land condition were quite poor with more than 60% of sites in C or D condition. Beutel et al (2011) concluded this pattern was largely driven by weed abundance when they examined six other variables collected at the same time as land condition records. Analogous investigations on the pooled 2011 and 2013 wet season data (Tables 3 and 4) indicate similar patterns – some differences between land types and catchments, but generally high levels of ground cover, a preponderance of perennial pastures, very little erosion but a regionally high abundance of weeds.

Table 1: Percent of sites in each land condition class per catchment and season. There were no significant differences between catchments or years.

Catchment	Sample	A%	B%	C%	D%
Pioneer	**2011**	11	44	33	11
(n=9)	**2013**	11	11	56	22
O'Connell	**2011**	21	24	40	16
(n=68)	**2013**	22	25	41	12
Plane	**2011**	18	20	48	13
(n=89)	**2013**	25	15	42	19
Proserpine	**2011**	11	11	64	14
(n=56)	**2013**	13	16	59	13
All catchments	**2011**	17	20	49	14
(n=222)	**2013**	20	18	46	15
Total	**Both**	**18**	**19**	**48**	**15**

[1] All analyses used a generalized linear model assuming multinomial error distribution and a logit link function. All models included the fixed effects of either Season x Catchment or Season x Land type. In cases of over dispersion, the dispersion parameter was estimated (McCullagh and Nelder 1989).

Table 2: Percent of sites in each land condition class per land type and season. Condition was significantly better on Alluvial flats sites (blue cells) than in all other land types (red cells). No year effect was observed.

Land type	Sample	A%	B%	C%	D%
Alluvial flats and plains	**2011**	35	26	33	06
(n=53)	**2013**	41	22	31	06
Coastal eucalypt forest	**2011**	17	17	48	17
(n=57)	**2013**	17	15	52	15
Coastal tea tree plains	**2011**	6	18	61	14
(n=45)	**2013**	14	14	47	24
Eucalypt hills and ranges	**2011**	9	18	54	19
(n=67)	**2013**	10	19	54	16
All catchments	2011	17	20	49	14
(n=222)	2013	20	18	46	15
Total	**All**	**18**	**19**	**48**	**15**

Our analyses also looked for change in either land condition or the six component variables measured at each site (ground cover, pasture type, erosion extent, mid-storey, tree cover and weed abundance) between 2011 and 2013. No significant change was detected in land condition, either within particular land types or catchments, or across the region (Tables 1 and 2). We did however observe a significant increase in ground cover in 2013 and a corresponding significant decrease in erosion extent in the same year. (Table 5). These differences in the amount of ground cover and eroded areas between 2011 and 2013, though significant are relatively small. The 2013 sample occurred after a longer series of above median rainfall years (Figure 1), which may explain the change, though this is largely speculation. The level and trend though of both variables does not suggest any issues of concern, though it can be monitored in future work. More broadly, the lack of change in land condition and other variables from 2011 to 2013 suggests that land condition has remained largely static over the 2011-2013 period.

Table 3: **Comparison of ground cover (A), pasture type (B), and erosion extent (C), tree cover (D), mid-storey cover (E), and weed abundance (F) records between catchments. Numbers represent percent of sites in each category. Proportions in blue rows are significantly different to proportions in red rows.**

A: Ground cover	50-80%	>80%
Pioneer	0	100
O'Connell	0	100
Plane	5	95
Proserpine	6	94
Total	4	96

B: Dominant pasture type	Perennial	Perennial/ annual	Annual/ perennial	Annual
Pioneer	56	44	0	
O'Connell	79	18	3	
Plane	76	20	3	1
Proserpine	59	36	5	
Total	72	24	3	0

C: Erosion extent	Moderate (5-50%)	Slight (<5%)
Pioneer	6	94
O'Connell	7	93
Plane	3	97
Proserpine	4	96
Total	5	95

D: Tree cover	Cleared	Isolated plants/clumps	Very Sparse or sparse	Mid-dense or Dense
Pioneer	39	22	6	33
O'Connell	63	15	1	22
Plane	53	23	3	20
Proserpine	57	14	7	21
Total	57	18	4	22

E: Mid-storey cover	None	Sparse	Open	Medium	Dense
Pioneer	33	28	11	17	11
O'Connell	54	11	13	16	7
Plane	52	10	3	16	18
Proserpine	35	9	23	17	16
Total	48	11	11	16	14

F: Weed abundance	Abundant	Moderate	Slight	None
Pioneer	0	44	56	0
O'Connell	22	26	39	13
Plane	17	39	34	9
Proserpine	22	19	41	18
Total	19	30	38	12

Table 4: **Comparison of ground cover (A), pasture type (B), and erosion extent (C), tree cover (D), mid-storey cover (E), and weed abundance (F) records between land types. Numbers represent percent of sites within each category. Proportions in blue rows are significantly different to proportions in red rows.**

A: Ground cover	50-80%	>80%
Alluvial flats and plains	0	100
Coastal eucalypt forest	2	98
Coastal tea tree plains	3	97
Eucalypt hills and ranges	8	92
Total	4	96

B: Dominant pasture type	Perennial	Perennial/ annual	Annual/ perennial	Annual
Alluvial flats and plains	79	18	4	
Coastal eucalypt forest	69	28	3	
Coastal tea tree plains	60	35	5	
Eucalypt hills and ranges	78	19	2	1
Total	72	24	3	0

C: Erosion extent	Moderate (5-50%)	Slight (<5%)
Alluvial flats and plains	3	97
Coastal eucalypt forest	6	94
Coastal tea tree plains	3	97
Eucalypt hills and ranges	7	93
Total	5	95

D: Tree cover	Cleared	Isolated plants/clumps	Very Sparse or sparse	Mid-dense or Dense
Alluvial flats and plains	69	19	9	3
Coastal eucalypt forest	38	16	23	23
Coastal tea tree plains	52	20	22	5
Eucalypt hills and ranges	48	10	14	38
Total	57	18	4	22

E: Mid-storey cover	None	Sparse	Open	Medium	Dense
Alluvial flats and plains	79	8	11	2	0
Coastal eucalypt forest	46	19	6	23	6
Coastal tea tree plains	32	10	6	17	35
Eucalypt hills and ranges	35	7	20	22	16
Total	48	11	11	16	14

F: Weed abundance	Abundant	Moderate	Slight	None
Alluvial flats and plains	12	28	36	24
Coastal eucalypt forest	19	46	26	9
Coastal tea tree plains	8	31	22	39
Eucalypt hills and ranges	10	46	34	10
Total	19	30	38	12

Table 5: **Comparison of ground cover (A), pasture type (B), and erosion extent (C), tree cover (D), mid-storey cover (E), and weed abundance (F) records between 2011 and 2013 wet season samples. Numbers represent percent of sites in each category. Proportions in blue rows are significantly different to proportions in red rows.**

A: Ground cover	50-80%	>80%
2011	5	95
2013	3	97
Total	4	96

B: Pasture type	Perennial	Perennial/annual	Annual/perennial
2011	72	26	2
2013	72	23	5
Total	72	24	4

C: Erosion extent	Moderate (5-50%)	Slight (<5%)
2011	7	93
2013	2	97
Total	5	95

D: Tree cover	Cleared	Isolated plants/clumps	Very Sparse or sparse	Mid-dense or Dense
2011	47	17	13	23
2013	50	15	21	15
Total	49	16	17	19

E: Mid-storey	None	Sparse	Open	Medium	Dense
2011	49	11	9	18	12
2013	46	10	14	14	15
Total	47	11	11	16	14

F: Weed abundance	Abundant	Moderate	Slight	None
2011	12	46	24	18
2013	12	30	36	21
Total	12	38	30	19

Ground cover analysis

Ground cover is a critical component of land condition, and Beutel et al (2012) analysed long term ground cover change on 670 randomly selected sites in the RC region (Figure 3, Table 6). Ground cover definitions vary slightly, but as used here it refers to rocks and all organic materials on or near the ground, including herbaceous plants, logs, litter and cryptogams.

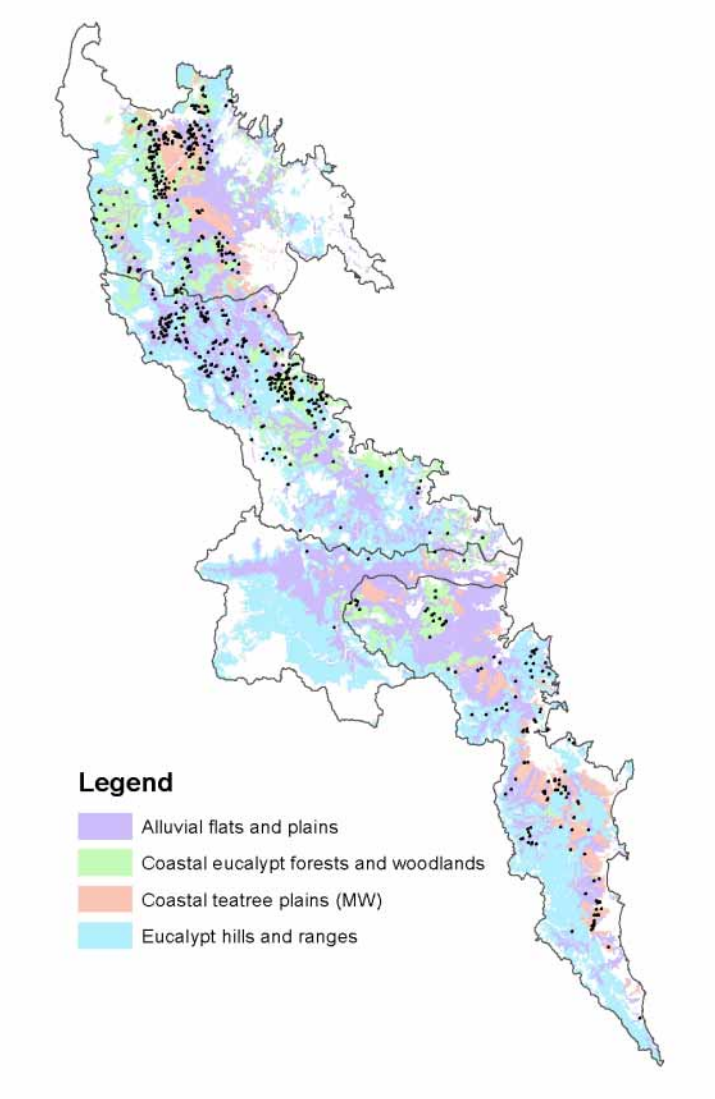


Figure 3: **Location of random ground cover monitoring sites.**

Table 6: **Number of ground cover analysis sites in each catchment and land type**

Land type	O'Connell	Pioneer	Plane	Proserpine	Total
Alluvial flats and plains	111	3	17	55	186
Coastal eucalypt forest	88	2	17	113	220
Coastal tea tree plains	11		53	91	155
Eucalypt hills and ranges	61	1	38	9	109
Total	271	6	125	268	670

The Queensland Ground Cover Monitoring Program has conducted a long term project to estimate ground cover across the state using Landsat satellite imagery. This data has proven critical to a range of land condition assessment and monitoring programs in Queensland (Karfs et al 2009). Recent developments in ground cover monitoring have seen some significant changes to the QGCMP ground cover product. A new iteration of the ground cover product (called fractional ground cover here) has been released (Scarth et al 2010). Fractional ground cover indexes ground cover as per its predecessor (the GCI), but the fractional ground cover data are more accurate than the GCI and available more regularly (4 dates/year rather than one date/year).

The motivation for monitoring fractional ground cover change is to get a clearer picture of where, when, and how ground cover fluctuates in the RC region over the longer term. To do this, we calculated the mean fractional ground cover value for each site in each season (Autumn 2000- Summer 2012) of the fractional ground cover time series. We then calculated the 5^{th}, 10^{th} and 50^{th} percentiles of these values in each season for each land type and each catchment (Figures 4 and 5). Percentile lines indicate the proportion of sites with average fractional cover below the plotted y axis value[2].

These percentile time traces reveal a number of points about ground cover variation in the region.

1. As per the prior analysis, ground cover is generally very high. At least half of all sites in any land type or catchment had average fractional ground cover >80% in every season of the time series. Conversely, there were no seasons where mean cover for sites above the 5^{th} percentile fell below 50%.
2. Cover is generally lowest in 2003-2004 for most land types and catchments, reflective of drought conditions at that time. The wetter conditions of the late 2000s is also reflected in higher ground cover during that period.
3. Focusing on the 5^{th} percentile line (which details the most extreme low cover sites), it seems the Proserpine catchment and the Coastal tea tree and Coastal eucalypt land types had the slowest recovery from drought. All three areas had >5 years during which cover did not average >80% for two consecutive seasons.

[2] So for example the 5^{th} percentile line in Fig 4 (Proserpine) indicates that in the Proserpine catchment at the start of 2004, 5% of sites had average fractional ground cover below 63%.

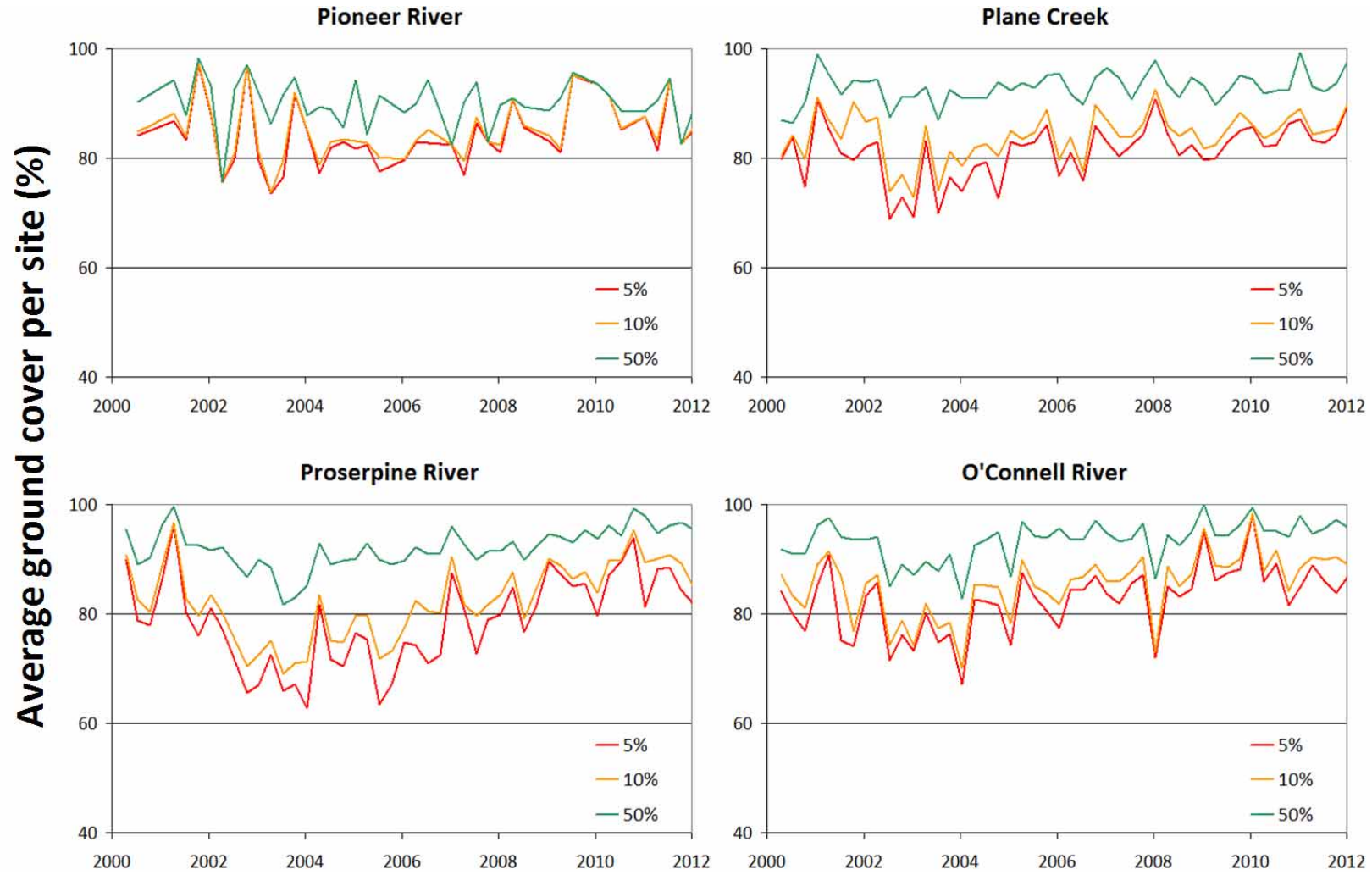


Figure 4: **Percentiles of ground cover on 670 randomly located sample sites in four catchments. Data are based on seasonal fractional ground cover data (Scarth et al 2010). Numbers of sites per catchment varied annually due to cloud masking, but maximum sample size in Pioneer, Plane, Proserpine and O'Connell catchments is 6, 125, 268 and 271 respectively.**

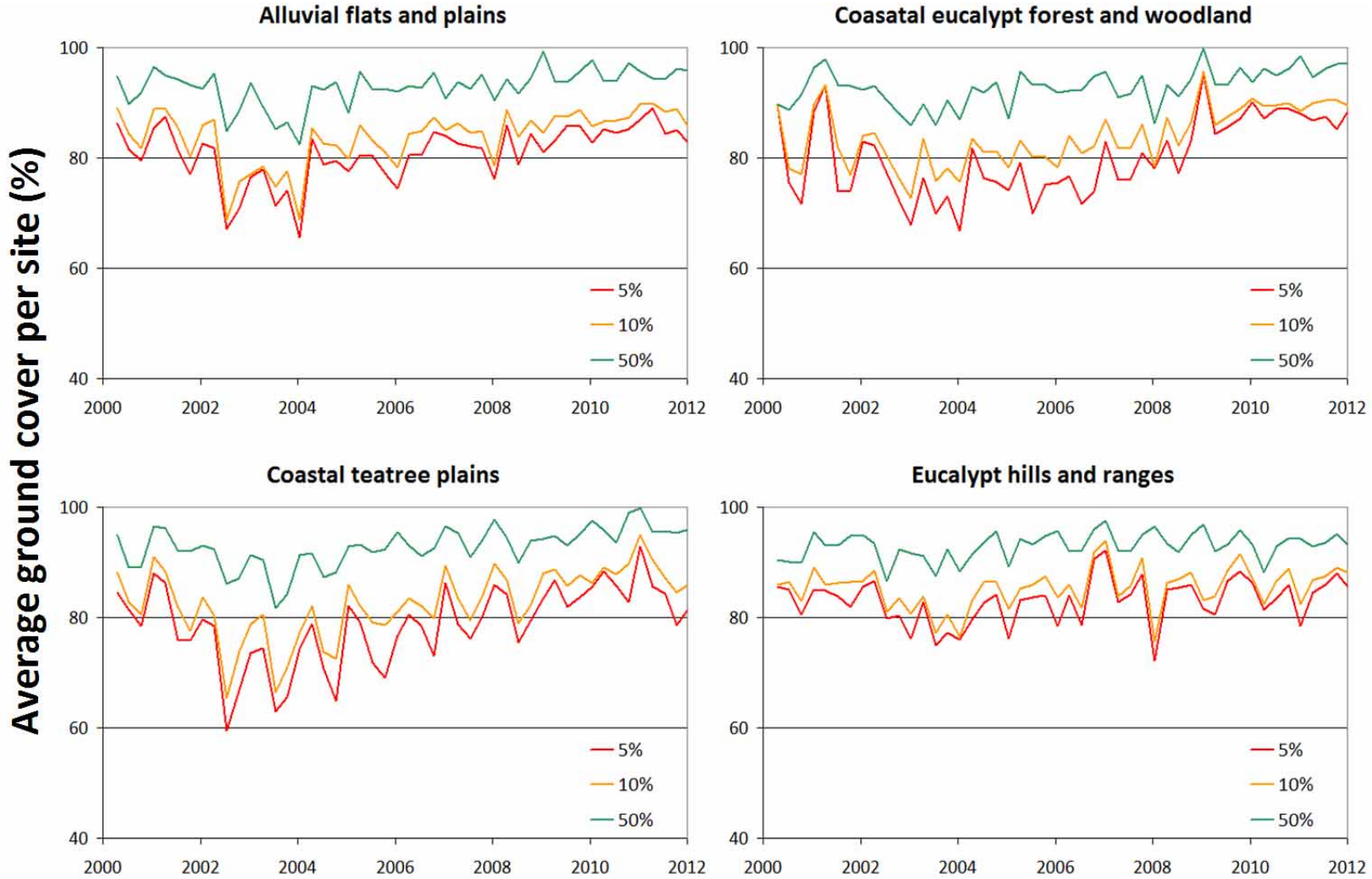


Figure 5: **Percentiles of average ground cover on 670 randomly located sample sites in four land types. Data are based on fractional ground cover data (Scarth et al 2010). Numbers of sites per land type varied annually due to cloud masking, but minimum sample size in Alluvial flats, Coastal eucalypt, Coastal tea tree and Eucalypt hills land types was 186, 220,155 and 109 respectively.**

Legacy products

Beutel et al (2011, 2012) developed a set of legacy products designed to support ongoing monitoring in the RC region. These products included a database of land condition observations, shape files describing the location of each site, and a Sites book. These products have been used in both subsequent sampling exercises, and greatly reduced time spent in the field. This round of work has seen more changes to the legacy products, in particular the database and a new Sites book. These are outlined below.

The database

The (Microsoft Access) monitoring database contains the monitoring data for all sites and all three samples, including all photos, site descriptions and site location data. The database has four outputs – site, weed, condition summary, and photo sheets. Each is described below.

Site sheets (Figure 6) provide a single page summary all data for a single site at a given sampling date. These sheets contain identical data to the site pages for the Sites Book (discussed below), and provide the simplest means of quickly perusing the data collected at any site. The new database incorporates site data for all three sampling periods.

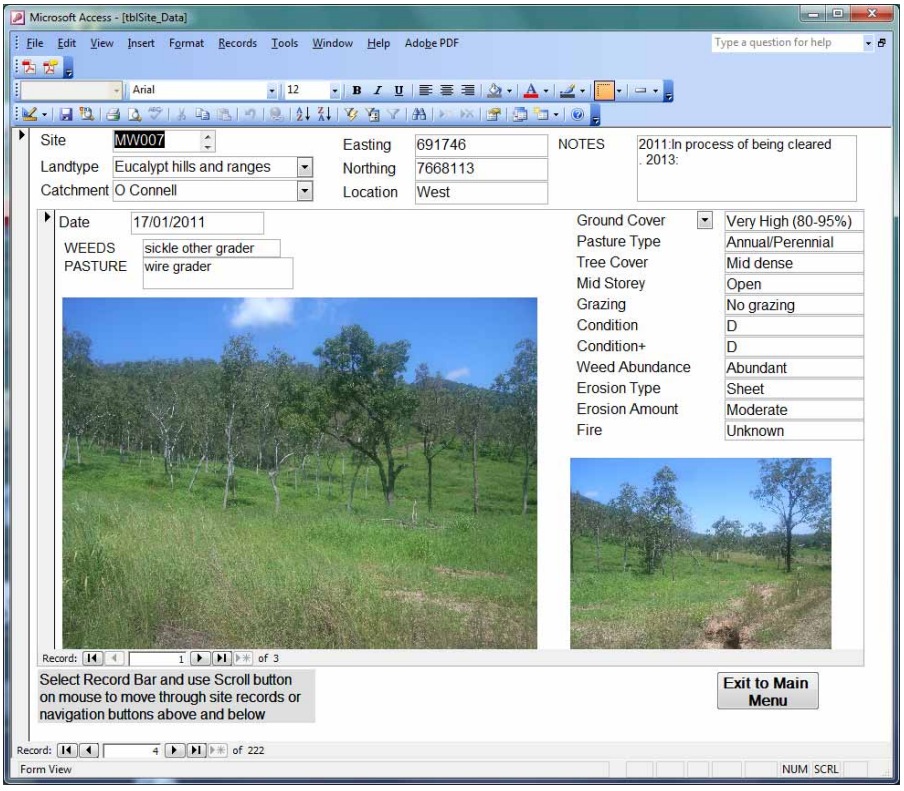
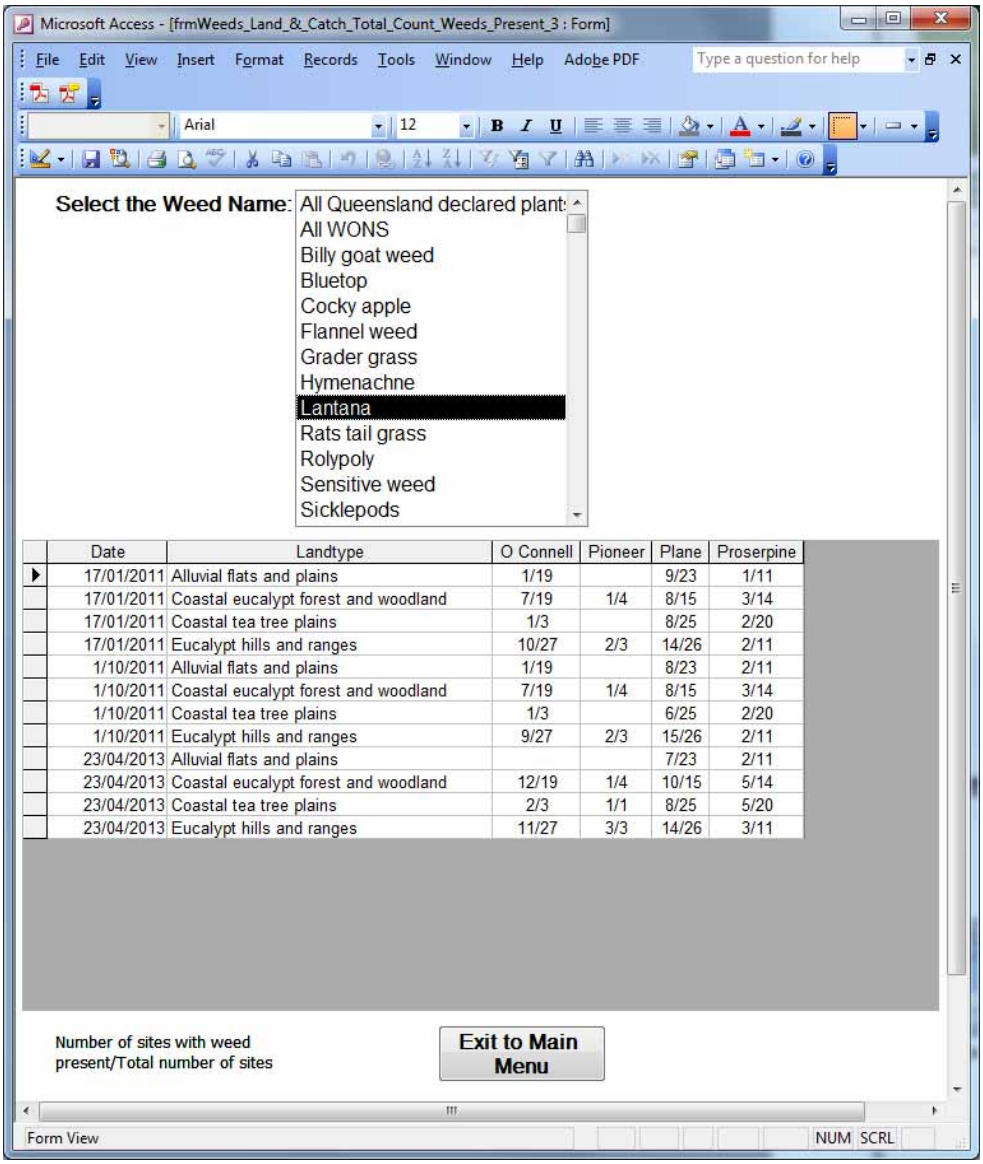


Figure 6: **Screenshot of land condition database site sheet.**

Weed sheets summarise the number of sites in each catchment/land type/date combination where we recorded any identifiable weeds. The data includes 17 different weeds as well as groupings for WONS and Queensland declared weed species. This output format has been included because of the clear importance of weeds in the region. The new database incorporates weed data for all three sampling periods.



Date	Landtype	O Connell	Pioneer	Plane	Proserpine
17/01/2011	Alluvial flats and plains	1/19		9/23	1/11
17/01/2011	Coastal eucalypt forest and woodland	7/19	1/4	8/15	3/14
17/01/2011	Coastal tea tree plains	1/3		8/25	2/20
17/01/2011	Eucalypt hills and ranges	10/27	2/3	14/26	2/11
1/10/2011	Alluvial flats and plains	1/19		8/23	2/11
1/10/2011	Coastal eucalypt forest and woodland	7/19	1/4	8/15	3/14
1/10/2011	Coastal tea tree plains	1/3		6/25	2/20
1/10/2011	Eucalypt hills and ranges	9/27	2/3	15/26	2/11
23/04/2013	Alluvial flats and plains			7/23	2/11
23/04/2013	Coastal eucalypt forest and woodland	12/19	1/4	10/15	5/14
23/04/2013	Coastal tea tree plains	2/3	1/1	8/25	5/20
23/04/2013	Eucalypt hills and ranges	11/27	3/3	14/26	3/11

Figure 7: **Screenshot of land condition database weed sheet.**

Condition summary sheets summarise important site observations within any combination of date, land type and catchment. These observations include groundcover, tree cover, mid-storey cover, condition, grazing, weed abundance, erosion type, erosion extent, and fire history. They include data for all three sampling periods.

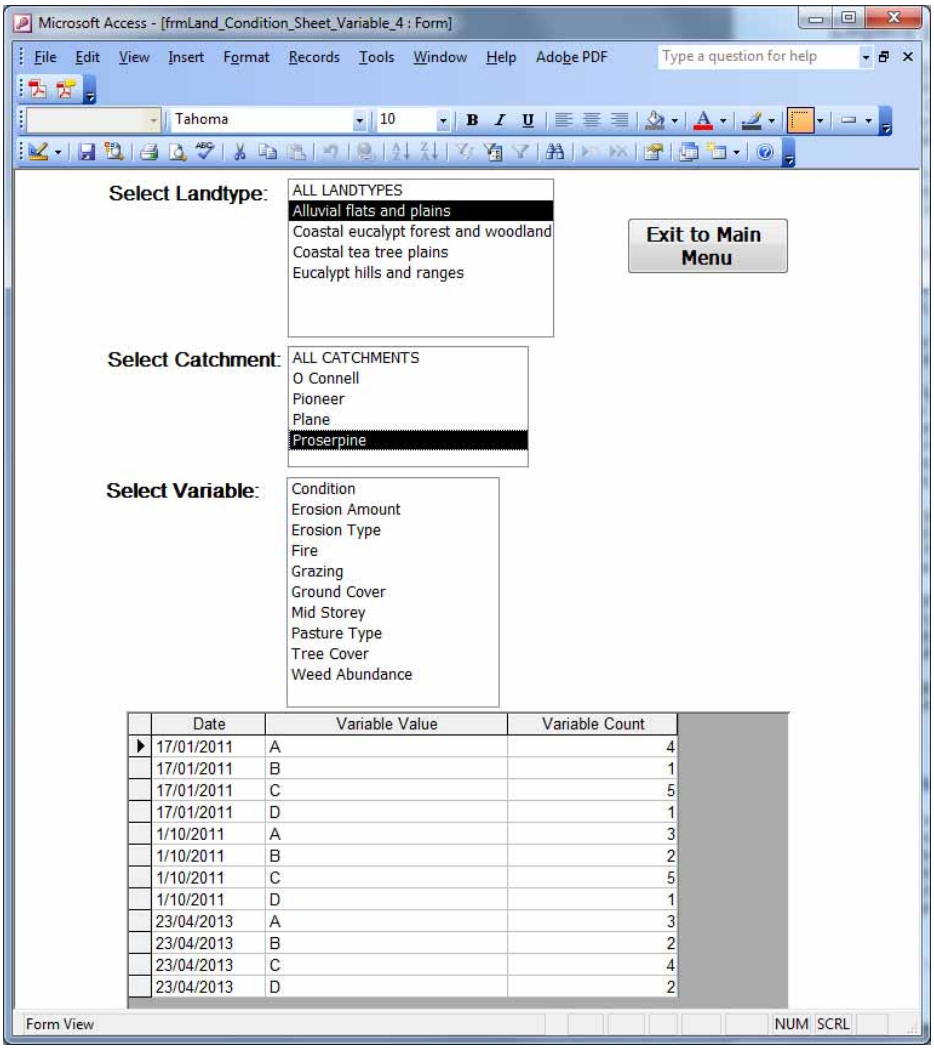


Figure 8: **Screenshot of land condition database condition summary sheet.**

Photo sheets compare the primary photo for each site over the three sample periods. They are a simple means of visualizing change between sample periods.

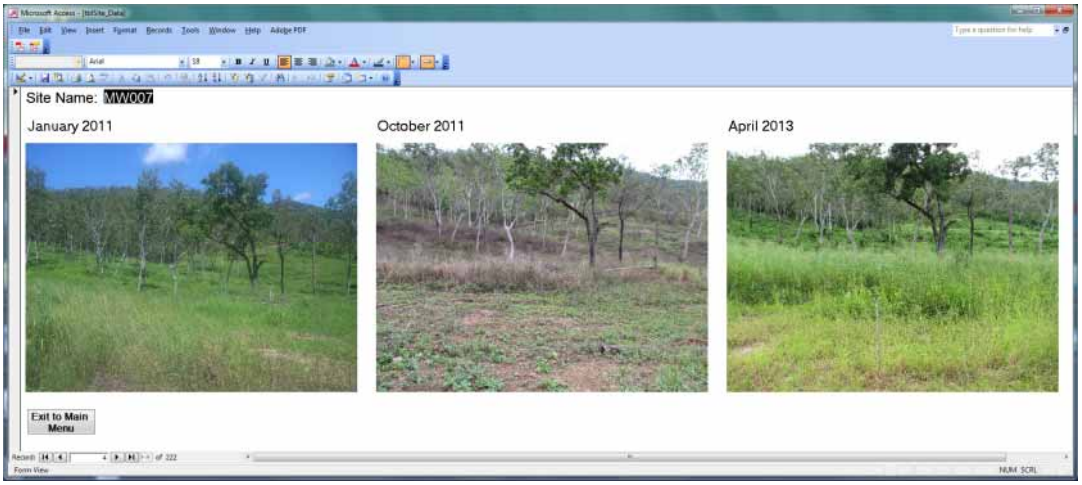


Figure 9: **Screenshot of land condition database photo sheet.**

The Sites book

This round of work has produced a third edition of the Sites book. The Sites book provides a hard copy summary of all site data for the April 2013 sample. Each site is featured on a separate page and includes all data collected at the site including location, photos and site recordings. The page for each site is generated from the site form in the database (above). The Sites book assists field work by calibrating the observer with measurements for the same site in previous sampling, and helping to align photographs along prior line of sight.

Discussion and recommendations

One of the stated benefits of the original phase of this work was the establishment of a system that would facilitate longer term monitoring in the MWRCI region. The most recent sampling continues to demonstrate that benefit, with data now collected over two years and three seasons in an efficient and economical process.

The original sampling in this monitoring system showed that weeds were the strongest negative influence on land condition in RC grazing country. That result was repeated here. Many sites had moderate to abundant coverage of weeds, but relatively good records of ground cover, erosion and pasture type. This result gives RC a stronger basis to target weeds in their grazing land programs into the future.

The data also suggests that lack of ground cover appears not to be an issue in the region, either on our 222 monitoring sites, or the 670 randomly located ground cover sites. This conclusion should be considered though with the caveat that our monitoring focuses on hill slopes and ignores stream bank erosion. Stream bank erosion can produce very high levels of sediment runoff, and this system does not monitor its risk.

The analysis we have used here compares the two wet season samples, and excludes the intervening dry season sample (though the database includes those data). The exclusion of the dry season sample was done on the basis that ongoing sampling would focus on wet season samples, and that the dry season sample was not as comparable with the two wet season samples as they were with each other.

The wet season sample was collected originally to help determine whether a dry or wet season regime would produce greatest benefits for RC. A wet season regime has been selected, but this does not mean that the 2011 dry season sample is of no more value. Beutel et al (2012) suggested that dry season sampling should be considered in very dry years, in which case the 2011 dry season sample would provide a good comparison dataset. This work has demonstrated two tools for identifying those times of potentially very low cover – the relative season imagery (Figure 1) and recent ground cover measurements on representative parts of the catchment (Figures 4 and 5). Use of these tools should give RC sufficient time to arrange a dry season sample if it is required.

With two wet season samples now collected, how long should we wait until the next sample? This issue will always be a compromise – sampling too frequently diverts excessive resources into unnecessary data collection, while sampling too infrequently risks missing important changes that the monitoring system should capture. Our recommendation here is to resample in early 2015, and to settle on a two year sampling regime thereafter unless there is a drastic departure from recent seasonal conditions. This is a subjective recommendation, but it seems unlikely, given the nature of the land condition issues identified here, that they will change radically in the next year, and it avoids the risk of the monitoring effort becoming a 'lost' priority as personnel and resources move around within RC.

Given the results, their analysis and discussion, below are our conclusions and recommendations for ongoing monitoring of grazing country in the RC region.

1. *Land condition remains largely static since 2011.* The most recent sample has found much the same patterns in land condition across the region as were seen in January 2011. There have been some small changes in extent of erosion and ground cover levels, but these have not been sufficient to significantly change our assessment of the overall condition of any land types or catchments.

2. *Exotic weeds remain the significant grazing land issue for RC*. This was a key conclusion from both previous samples, and remains in place. More than half of all our land condition ratings in the RC region are below B condition, and weed abundance is the key driver of these poor ratings.

3. *Ground cover is abundant and quite resilient at catchment / land type scales*. Both the field assessments and the ground cover analysis suggest that ground cover is quite high in this region. The ground cover analysis further suggests that ground cover is relatively stable over time, though several higher risk areas have been identified, and should be watched in future monitoring.

4. *Ground cover analysis is now part of the monitoring system*. The ground cover data have given a longer term perspective of ground cover change for RC region both here and in Beutel et al (2012). They can also play a role in identifying for very dry seasons suitable for intermittent end dry season sampling. Though initially brought into the RC monitoring system as an opportunistic addition to the work, it is clear that ground cover data enhance the monitoring system significantly, and should be considered part of the system for future work.

5. *Wet season sampling should occur approximately biannually*. Given all of the above points, we recommend future sampling be based on an end-of-wet season sampling regime. Weeds are the dominant issue around land condition in this region, weeds are probably more visible in the wet season, and there is no competing need to regularly monitor at end-of-dry given generally very high levels of ground cover and the availability of remotely sensed ground cover data for verification. Wet season sampling seems a better monitoring fit for this region.

6. *Maintain and use this land condition monitoring system*. This was a recommendation of Beutel et al (2011) and remains relevant. Monitoring benefits compound with repeated sampling, but this requires organizational commitment, most particularly until the system matures and its long term benchmarking value are better appreciated.

Bibliography

Beutel T, J Fletcher and M Hoffmann (2011) Grazing land condition in the Mackay Whitsunday reef catchments - Final Report. The State of Queensland, Department of Employment, Economic Development and Innovation.

Beutel TS, J Fletcher, M Hoffmann and D Reid (2012) Grazing land condition in the Reef Catchments (Mackay Whitsunday Isaac) region October 2011. Final report to Reef Catchments (Mackay Whitsunday Isaac) Ltd. Department of Agriculture Fisheries and Forestry, Queensland.

Karfs RA, BN Abbott, PF Scarth, and JF Wallace. (2009) Land condition monitoring information for reef catchments: a new era, *The Rangeland Journal* **31**: 69–86.

McCullagh P and Nelder JA (1989) Generalized Linear Models (2nd edition). Chapman and Hall.

Scarth P, A Röder and M Schmidt (2010) Tracking grazing pressure and climate interaction - the role of Landsat fractional cover in time series analysis. In: Proceedings of the 15th Australasian Remote Sensing and Photogrammetry Conference (ARSPC), 13-17 September, Alice Springs, Australia. Alice Springs, NT.

Scarth P, T Danaher, B Henry, R Hassett, J Carter and P Timmers (2006) State of the paddock: monitoring condition and trend in groundcover across Queensland. *The 13th Australasian Remote Sensing Conference*, Canberra.