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Validating a Remotely Sensed Index of Landscape Leakiness in the Burdekin Dry Tropics, Queensland

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(Healthy Water Ecosystems Theme)

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The work contained in this report is collaboration between CSIRO Sustainable Ecosystems and Mr Robert Karfs and Mr Christopher Holloway, Queensland Department of Primary Industries and Fisheries.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

A previous report (Bastin *et al*. 2007) described how the Leakiness Index (LI) had been used to monitor changes in the condition of grazed lands for sub-catchments of the Fanning River, a major tributary of the Burdekin River in north east Queensland. That report included a small ground validation component where a simple cover index (the 'visible red' band of Landsat TM) was validated with some ground data.

This report documents recent work to more rigorously validate the Leakiness Index in parts of the Burdekin catchment. Ground cover, erosion and PATCHKEY data systematically collected in paddocks at Virginia Park (near Charters Towers) were used to validate leakiness values calculated for the same area from very high resolution satellite imagery and a similarly high resolution digital elevation model. The results confirm that the Leakiness Index reliably indicates landscape function at a larger scale than can be routinely measured on the ground.

Leakiness values calculated from Landsat TM data were then validated for two larger areas in contrasting condition; that is, validation conducted at moderate scale. Both the LI and ground data quantified the condition differences in a consistent manner. Field-based measurement of ground cover suggested that the Queensland Government's Ground Cover Index (GCI) may be over estimating ground cover in this area. If so, then this means that calculated LI values will be conservative. GCI is the preferred cover index for monitoring Queensland's grazed rangelands as it has had both rigorous development and extensive ground validation. Although the index appeared to over-estimate ground cover for the two areas reported here, its performance elsewhere is known to be robust. The index performs consistently through time meaning that changes in landscape leakiness based on GCI will still provide useful information about shifts in landscape function at larger scale.

Finally, we demonstrate how PATCHKEY data can be rapidly collected at 2-3 Ha sites in the field and subsequently processed to an index that characterises landscape function for each area. We were not able to establish meaningful relationships between PATCHKEY-based measures of landscape function for a small number of sites spread throughout the Burdekin catchment and the LI value for a much larger area surrounding each site. This was because the one site at each location inadequately represented the larger area analysed for leakiness.

We anticipate that repeat sampling at a sufficient number of sites, combined with suitable stratification to guide where sampling is conducted, should provide suitable data to validate the leakiness index at larger scales.

INTRODUCTION

The Leakiness Index (LI, Ludwig *et al*. 2007) has been proposed as a suitable method for up-scaling ground-based assessment of land condition in the grazed rangelands of the Burdekin River catchment, north-east Queensland. A previous report, Bastin *et al*. (2007) documented change in calculated leakiness for example sub-catchments of the Fanning River, a major tributary of the Burdekin River. These results showed that sub-catchments dominated by stoloniferous Indian couch (*Bothriochloa pertusa*) had lower mean cover and higher leakiness than sub-catchments retaining native perennial tussock grasses. In particular, indicated leakiness of the Indian couch sub-catchments increased sharply in successive dry years (the mid 1990s) compared with those sub-catchments retaining persistent cover due to the presence of native perennial grasses.

A critical step in avoiding future excessive leakiness following inevitable reduced amounts of wet-season rainfall would seem to be positive actions by pastoralists to retain higher levels of ground cover. A greater density of perennial tussock grasses should also reduce resource loss (leakiness) when rains do occur by slowing downslope flows of water and increasing infiltration. Lower stocking rates and wet season spelling are recommended management procedures for improving land condition. Bastin *et al*. (2007) demonstrated how higher levels of retained cover, and different types of cover (Indian couch cf tussock grasses), in different parts of a sub-catchment (e.g. upper slopes cf lower slopes) affected calculated leakiness.

The Leakiness Index was validated in general terms for a central Australian grazing property when it was first described (Ludwig *et al*. 2007). However, the results reported for Fanning River sub-catchments (Bastin *et al*. 2007) had not been validated (although the cover index used was validated). Here, we confirm the robustness of the Leakiness Index for monitoring landscape leakiness in the Burdekin region based on available ground data. We do this initially at fine scale using very high resolution Quickbird imagery (2.4-m pixels) and then extend the comparison to Landsat TM scale (25-m pixels) that provide the data for more routine monitoring of change over time across large areas.

METHODS

Values of the Leakiness Index have been validated at three scales (Fig. 1):

1. At fine scale for sub-catchments of the Weany Creek on Virginia Park station. Weany Creek is a tributary of the Fanning River. Leakiness was calculated from a December 2003 Quickbird image

2. At moderate scale for sub-catchments of the Fanning River known from ground-based surveys to be in good and fair condition (A-B and C condition respectively using the Queensland Government's ABCD land condition framework, Chilcott *et al*. 2003). Leakiness calculations were based on Landsat TM data and ground data were collected in a similar manner to (1) above.

3. At coarser scale for sample areas in different parts of the Burdekin catchment. Leakiness was calculated from Landsat data as for (2) and ground data were collected along parallel transects using the PATCHKEY method (see Abbott *et al*. 2008).

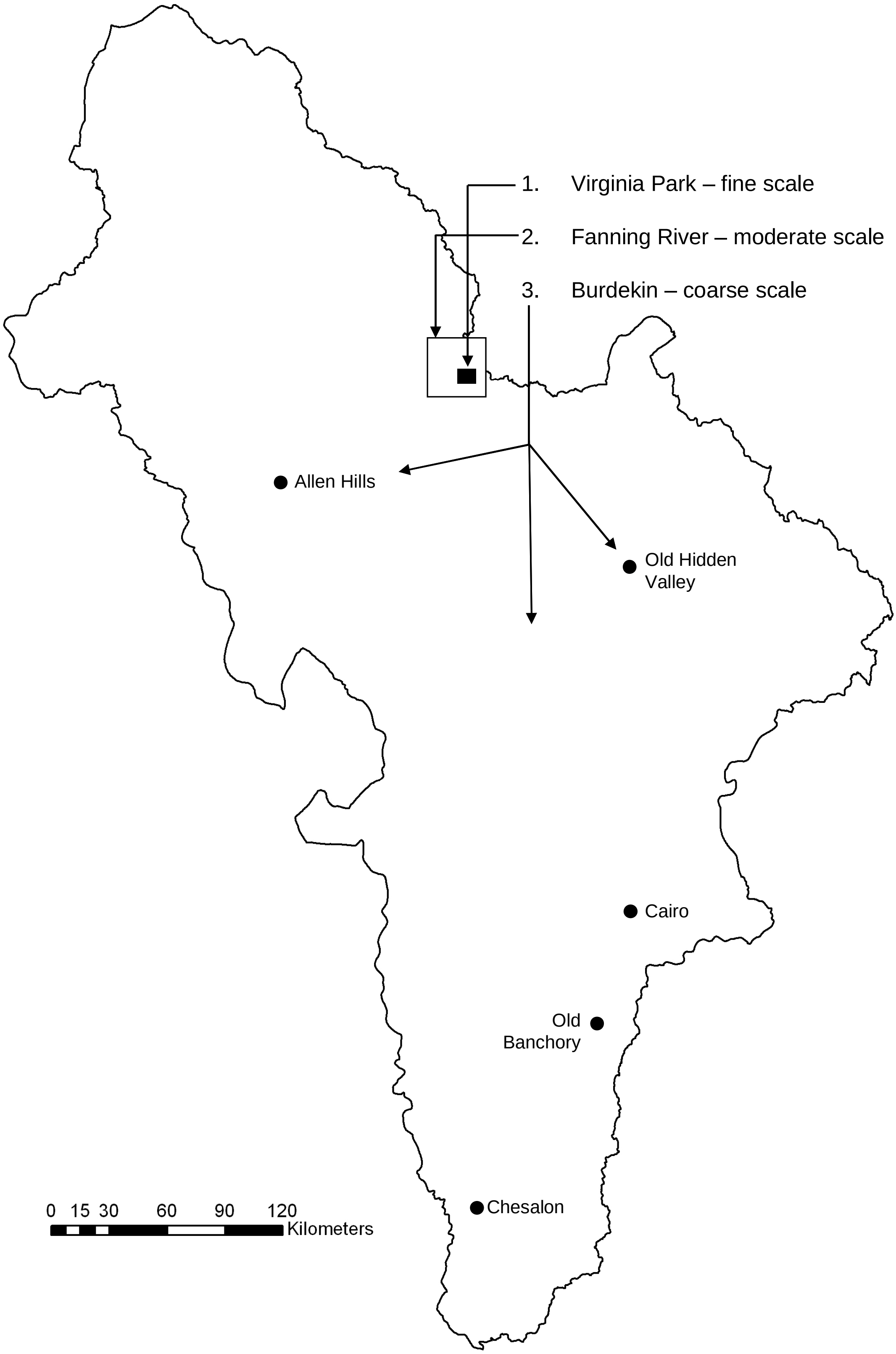

Figure 1. Locations of ground based data of varying spatial resolution within the Burdekin catchment for validating the Leakiness Index.

Fine scale: Virginia Park

Ground cover, litter cover, erosion type and severity, and PATCHKEY scores describing landscape function (Corfield *et al*. 2006) were collected in 4-m^2 quadrats sampled along linear transects in four paddocks at Virginia Park (Fig. 2) in November 2003. The Botanical Analysis (BOTANAL) technique (Tothill *et al*. 1992) was used to collect data. Four sub-catchments were defined for a subset of this area (Fig. 3) based on the 5-m high-resolution digital elevation model (DEM) produced by CSIRO Land and Water. Leakiness of each sub-catchment was calculated (with the Leakiness Calculator) using a cover index derived from a December 2003 Quickbird image (2.4-m pixel resolution re-sampled to 5-m to match the DEM). (The PD54 index (Pickup *et al*. 1993), linearly rescaled between 0 and 100, was used to indicate approximate percentage cover.)

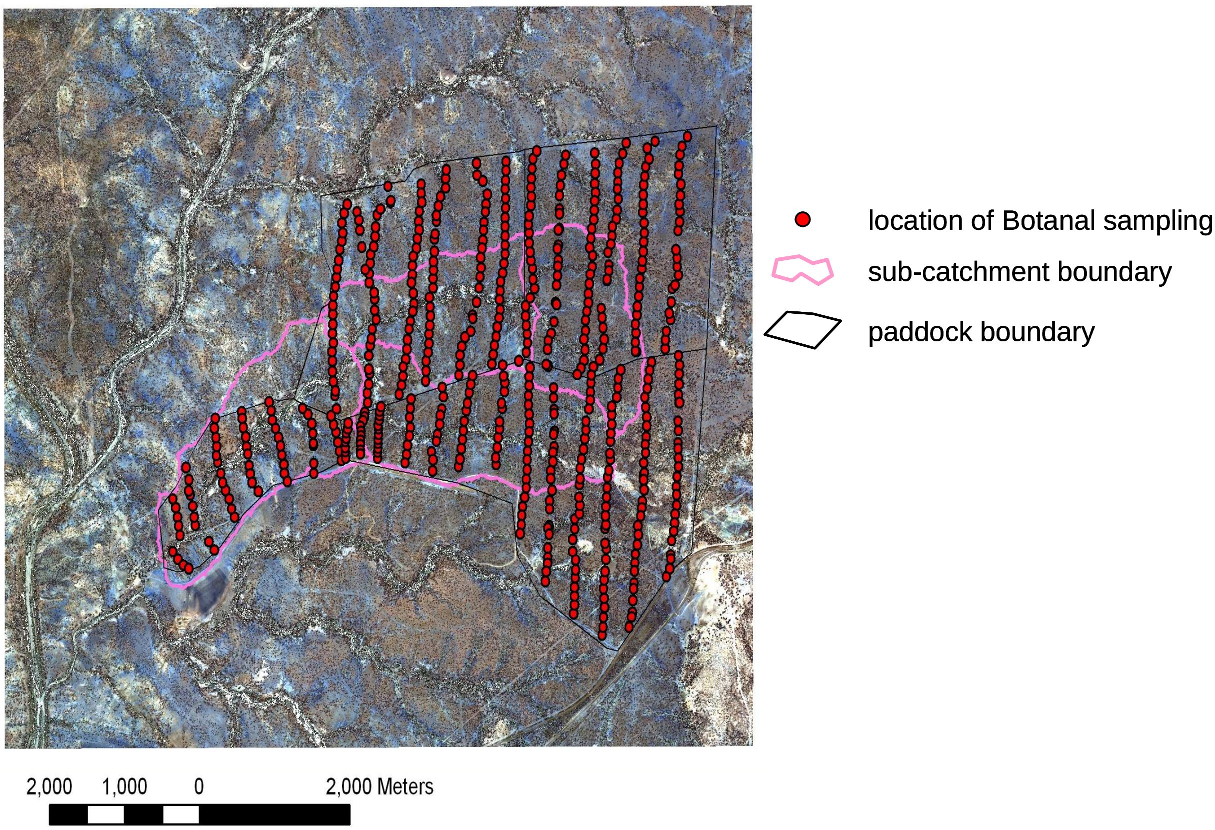

Figure 2. December 2003 Quickbird image of Virginia Park showing the locations of November 2003 BOTANAL samples, sub-catchment boundaries of the Weany Creek and paddocks.

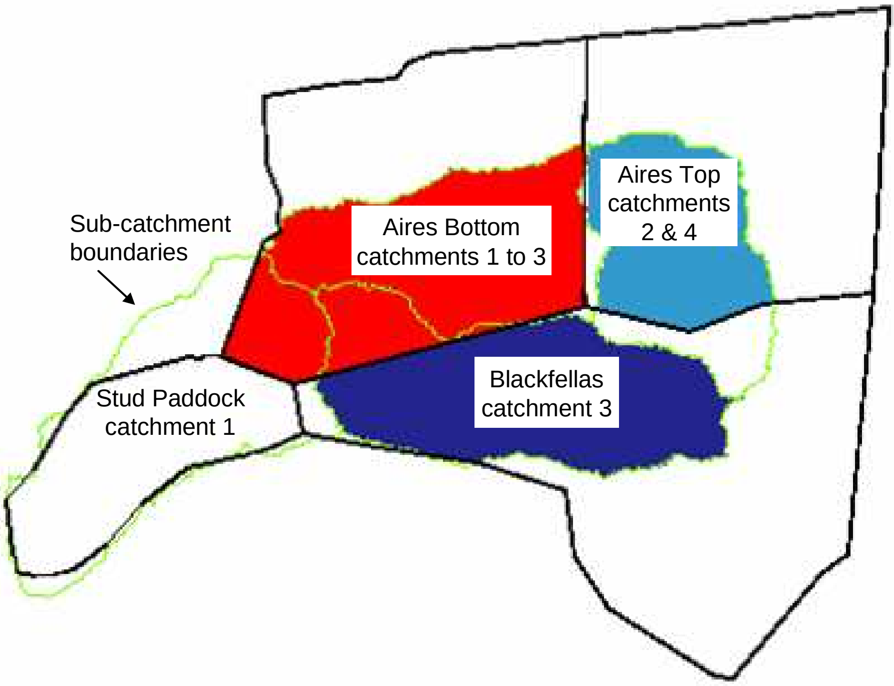

Figure 3. Sub-catchment boundaries within Virginia Park paddocks.

Ground data

Litter cover and total ground cover were estimated within each 4-m^2 BOTANAL quadrat and then calibrated for each observer based on their estimates of cover against measured cover in a set of 'standard' quadrats.

Erosion type and severity were also estimated within each quadrat:

Erosion Type	Erosion Severity
nil	nil
sheet	insignificant
rill	slight
gully	moderate
pedestal	extensive
terracette	
scald	

Sheet erosion was the most common form of erosion (present to some degree in 63% of the 583 quadrats assessed across all paddocks). Sheet erosion is also most relevant to hillslope leakiness in terms of both its spatial occurrence and extent. A 'sheet erosion' index was constructed by weighting the severity of sheet erosion (Table 1). This allowed the descriptive 'severity' classes to be converted to a severity rank (of sheet-erosion) for each quadrat and, in turn, sub-catchment. (Scalding is probably also relevant to hillslope erosion and the Leakiness Index but was only recorded with some degree of severity for ~1% of all quadrats assessed.)

Table 1. Weightings applied to descriptions of sheet erosion severity.

Severity class	Weighting
insignificant	1
slight	5
moderate	10
extensive	20

PATCHKEY

PATCHKEY (Corfield *et al*. 2006) describes patches of vegetation (patch types) according to the ability of each to regulate resources (rainwater, soil nutrients and organic matter) for plant growth. It divides the broad ABCD land condition categories into a number of sub-classes on the basis of their hydrological function. These classes are based on measured infiltration data. Because PATCHKEY is functionally based (as in landscape function), it should provide a logical basis for relating ground data to landscape leakiness estimated from remotely sensed cover.

Patch types are described in Table 2 (left hand side). We grouped classes and assigned weights to provide a numeric ‘functionality’ score for each quadrat and sub-catchment (right hand columns).

Moderate scale: Fanning River and Virginia Park paddocks

A 2,883 Ha paddock on Fanning River station known to be dominated by native 3P (palatable, perennial and productive) grasses and in good condition was sampled several times between July 2000 and May 2002 to estimate litter cover, total ground cover and erosion / deposition status. BOTANAL sampling techniques similar to those used at Virginia Park were applied. However, PATCHKEY assessments were not made at these earlier samplings at Fanning River.

The locations of sampling transects in April 2001 is shown in Fig. 4.

Table 2. PATCHKEY groups and weights.

The three left-hand columns apply to PATCHKEY. Patch numbers, scores and weights in the right hand columns were added to assist validation of LI.

Patch	Dominant species	Description	Patch No	Assigned Score	Patch Weight
A1	3P (palatable, peren	high basal, high foliar, low-moderate litter, no erosion/deposition	1	1	20
A2	3P (& productive)	high basal, moderate foliar, moderate litter, no erosion/deposition	2	1	20
B1	3P+Other Grasses	high/med basal, moderate foliar, moderate litter, no erosion/deposition	3	1	20
B2	3P+Other Grasses	medium basal, mod foliar, low litter , maybe slight erosion/deposition	4	2	10
B3	*B. pertusa*	high basal, high foliar, high litter, no erosion/deposition	5	2	10
B4	*B. pertusa*	high basal, moderate foliar, mod litter, nil-low erosion/deposition	6	2	10
C1	Other Grasses+3P	low/med basal, low/mod foliar, high litter, nil-low erosion/deposition	8	3	5
B5	*B. pertusa*	medium basal, low/mod foliar, low/mod litter, low erosion/deposition	7	3	5
B6	*B. pertusa*	medium basal, low/mod foliar, low litter, low erosion/deposition	11	3	5
D8	Carissa + grass	low-medium basal, moderate foliar, high litter, no erosion/deposition	27	3	5
D9	Carissa + grass	low basal, low foliar, moderate litter, low erosion/deposition	28	3	5
C2	Other Grasses+3P	low/medium basal, low/mod foliar, mod litter, low erosion/deposition	9	4	3.5
C4	*B. pertusa*	low basal, low foliar, high litter, low-moderate erosion, high deposition	12	4	3.5
C3	Other Grasses+3P	low basal, low foliar, low litter, mod-high erosion, low-mod deposition	10	5	2.5
C5	*B. pertusa*	low basal, low foliar, mod litter, mod-high erosion, mod deposition	13	5	2.5
C7	Annuals + OG	low basal, mod/high foliar, mod litter, low-mod erosion/deposition	15	5	2.5
C8	Annuals + OG	low basal, moderate foliar, low litter, low-moderate erosion/deposition	16	5	2.5
C9	Annuals + OG	low basal, low foliar, high litter, low-moderate erosion/deposition	17	5	2.5
D10	Carissa only	no basal, no foliar, high litter, no erosion/deposition	29	5	2.5
D11	Carissa only	no basal, no foliar, moderate litter, low erosion/deposition	30	5	2.5
C10	Annuals + OG	low basal, low foliar, medium litter, moderate erosion/deposition	18	6	1.5
D1	annuals	no basal, low-mod foliar, high litter, low erosion, low-mod deposition	20	6	1.5
D2	annuals	no basal, low foliar, mod litter, low-mod erosion, mod-high deposition	21	6	1.5
D4	Nil	no basal, no foliar, high litter, low-mod erosion, mod-high deposition	23	6	1.5
C6	*B. pertusa*	low basal, low foliar, mod litter, mod-high erosion, low deposition	14	7	1.15
C11	Annuals + OG	low basal, low foliar, low litter, mod-high erosion, low-mod deposition	19	7	1.15
D3	annuals	no basal, low foliar, low litter, moderate-high erosion/deposition	22	7	1.15
D5	Nil	no basal, no foliar, low-mod litter, mod erosion, mod-high deposition	24	7	1.15
D6	Nil	no basal, no foliar, nil-low litter, high erosion, mod-high deposition	25	8	1
D7	Nil	no basal, no foliar, nil-low litter, high erosion, low deposition	26	8	1

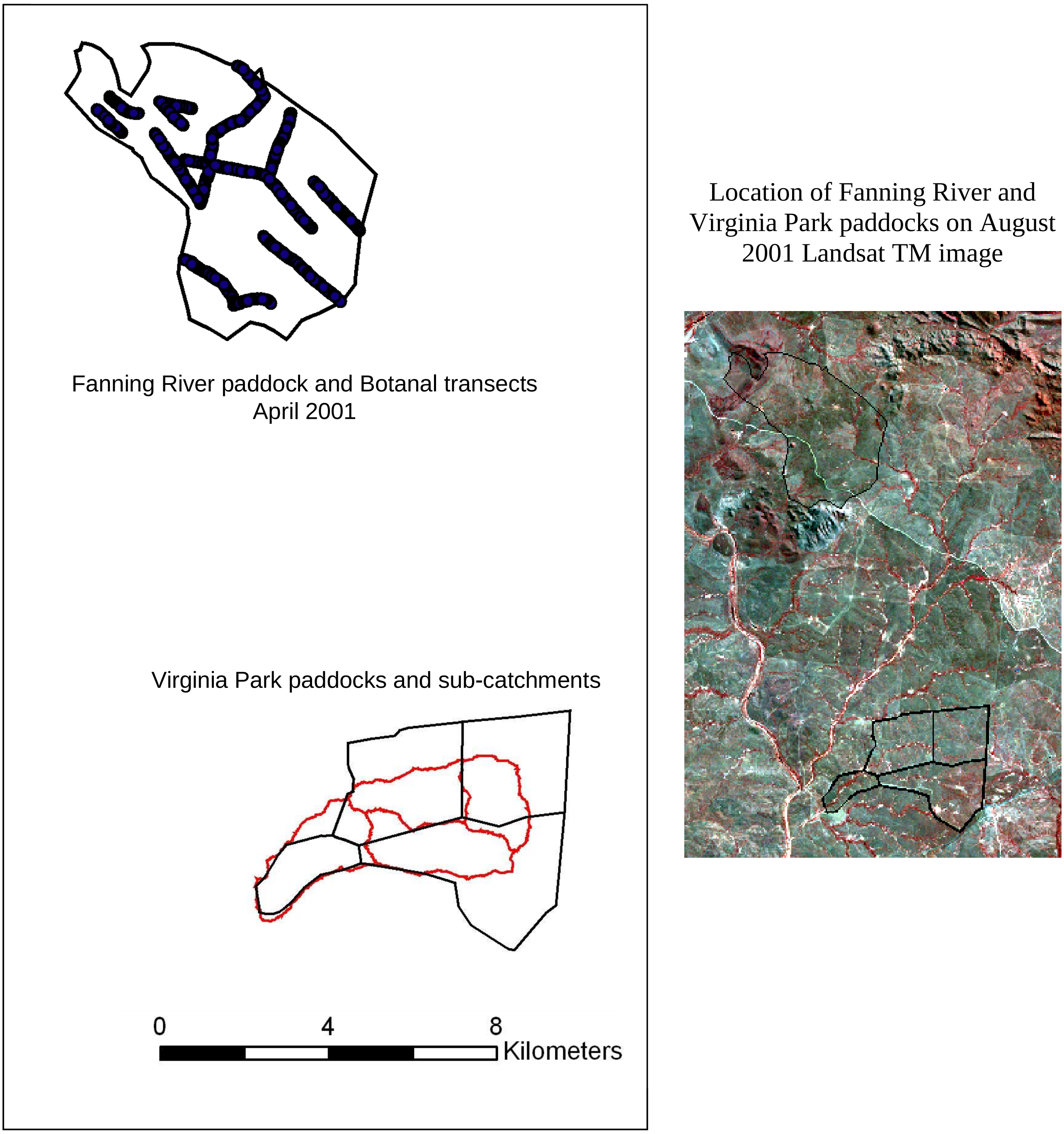

Figure 4. Location of the Fanning River paddock (known to be in good condition) in relation to Virginia Park paddocks and sub-catchments (in poorer condition). The locations of April 2001 BOTANAL transects in the Fanning River paddock are also shown.

Analyses

The following analyses were made:

1. BOTANAL-type estimates of total ground cover were compared with contemporaneous estimates of remotely-sensed average ground cover for the Fanning River and combined Virginia Park paddocks based on the Queensland Government's Bare Ground Index (BGI) (Scarth *et al*. 2006). Rather than report levels of 'bare ground', we have subtracted pixel values of the index from 100 to produce ground cover; i.e. Ground Cover Index (GCI) = 100 – BGI.

2. The BOTANAL-based estimates of ground cover and sheet erosion (based on extent and severity using the weights in Table 1) were also compared with similar data collected in the Virginia Park paddocks (note however that sampling dates between the two sites were separated by a year or more).

3. Ground-based estimates of cover for the Fanning River and combined Virginia Park paddocks were compared with LI values of the same area calculated from GCI and the DEM used by Bastin *et al*. (2007).

Coarse scale: Parts of the Burdekin catchment

Five sites used by Abbott *et al.* (2008) in September 2007 to validate their mapping of 'D condition' lands in the Burdekin catchment were selected (Fig. 1) to demonstrate how ground cover and PATCHKEY data can be rapidly collected on the ground and can then provide a viable method for validating leakiness results at larger scale. These sites are briefly described in Table 3.

Note that the data presented (in Results) do not validate particular LI values; they merely serve to demonstrate the method.

Table 3. Characteristics of sites selected to demonstrate use of PATCHKEY data for validating landscape leakiness at coarse scale.

Site	Description	Photo
Allen Hills	Gentle hillslope merging to flat lower slope adjacent to creek. Bleached sandy loam, sodic on lower slope areas. Surface crusting and very hard underneath. Silver leaf ironbark on upper slopes merging into *Eremophila* spp dominated areas on the lower slope sodic areas. Large scalds present. Ground cover mainly *Aristida* spp and annual grasses.	

Site	Description	Photo
Cairo	Long gentle slope with some gilgais. Gravelly clay loam. Surface quite hard and pedestalling apparent in places (i.e. obvious erosion). Cleared eucalypt woodland with minor regrowth. Ground cover mainly buffel grass with clumps of *Aristida* species and other native grasses.	
Chesalon	Cleared eucalypt woodland. Long gentle slope. Clay loam soils with sand deposition in places. Patches of eucalypt regrowth (particularly silver leaf box). Sown to buffel grass – with evidence of sheet erosion around tussocks (i.e. pedestalling). Quite large patches of *Aristida*. Scattered other native perennial grasses (e.g. *Themeda* and *Heteropogon*).	
Old Banchory	Eucalypt woodland (not cleared) on a very slight slope. Clay loam soil with little evidence of surface disturbance. A variety of native perennial and annual grasses. Buffel grass in places.	

Site	Description	Photo
Old Hidden Valley	Gentle hillslope near top of ridge. Sandy clay loam. Eucalypt woodland (bloodwood and box). Pasture layer almost exclusively Indian couch with some *Aristida* species and forbs present (following winter rain).	

At each site depending on patch complexity, three pre-defined parallel transects of either 100-m or 200-m were navigated using a differential global positioning system (GPS) (Figs. 5 and 6). The start and end location of each patch type and PATCHKEY characteristics associated with the patch type were recorded to a hand-held computer. Transects were typically separated by 50-m such that 1 to 2 Ha were sampled at each site.

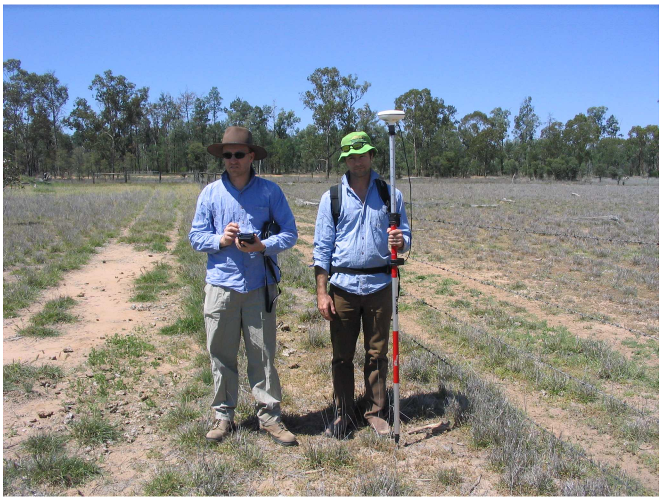

Figure 5. Brett Abbott (left) and Justin Perry (right) collecting PATCHKEY data in an area cleared and sown to buffel grass. Differential GPS provides guidance along predetermined transects. Start and end locations of patch types are captured to the palmtop computer held by Brett. PATCHKEY characteristics of each patch type are also recorded.

Data recorded for each patch type included:

- start and end locations (providing patch length);
- estimated basal area (as one of five categories, Table 4);
- percentage cover of litter and bare ground;
- erosion severity, as one of four categories between ‘insignificant’ and ‘extensive’ (Table 4, note that erosion severity is inversely weighted so that ‘no erosion’ has the highest score);
- deposition extent (using similar ranks as for erosion severity); and
- soil hardness (as either deep sand, easily broken, moderately hard or very hard).

Table 4. Weights applied to PATCHKEY categories of basal area and erosion severity.

Score	Basal Area Category & Weight		Erosion Severity & Weight	
	Midpoint	Weight	Description	Weight
1	0	0	Insignificant	6
2	0.25	0.75	Slight	3
3	1	2.5	Moderate	1
4	2.25	4	Extensive	0
5	4	5		

For each site:

- The basal area, erosion severity and PATCHKEY scores assigned to each patch type were weighted (using values in Table 4 and the right hand column of Table 2 (for PATCHKEY)). Each value was then multiplied by the patch length, as a proportion of total transect length for the site, to provide a weighted ‘patch length’ score (e.g. ‘PATCHKEY length’).
- The ‘patch length’ scores for each attribute were summed for all patch types recorded along all transects to provide an overall site score. For example, patch types with better hydrological function had higher weights (Table 4) which translated to higher summed ‘PATCHKEY lengths’ when these patch types were the dominant component of measured transects.
- The PATCHKEY-based score was compared with calculated leakiness (LI) for an enlarged area of similar country surrounding each site (see Fig. 6 as an example). Leakiness was calculated using the same DEM as for Fanning River and the 2006 bare ground index produced by the Queensland Government (analysed as ground cover: Ground Cover Index (GCI) = 100 – BGI).

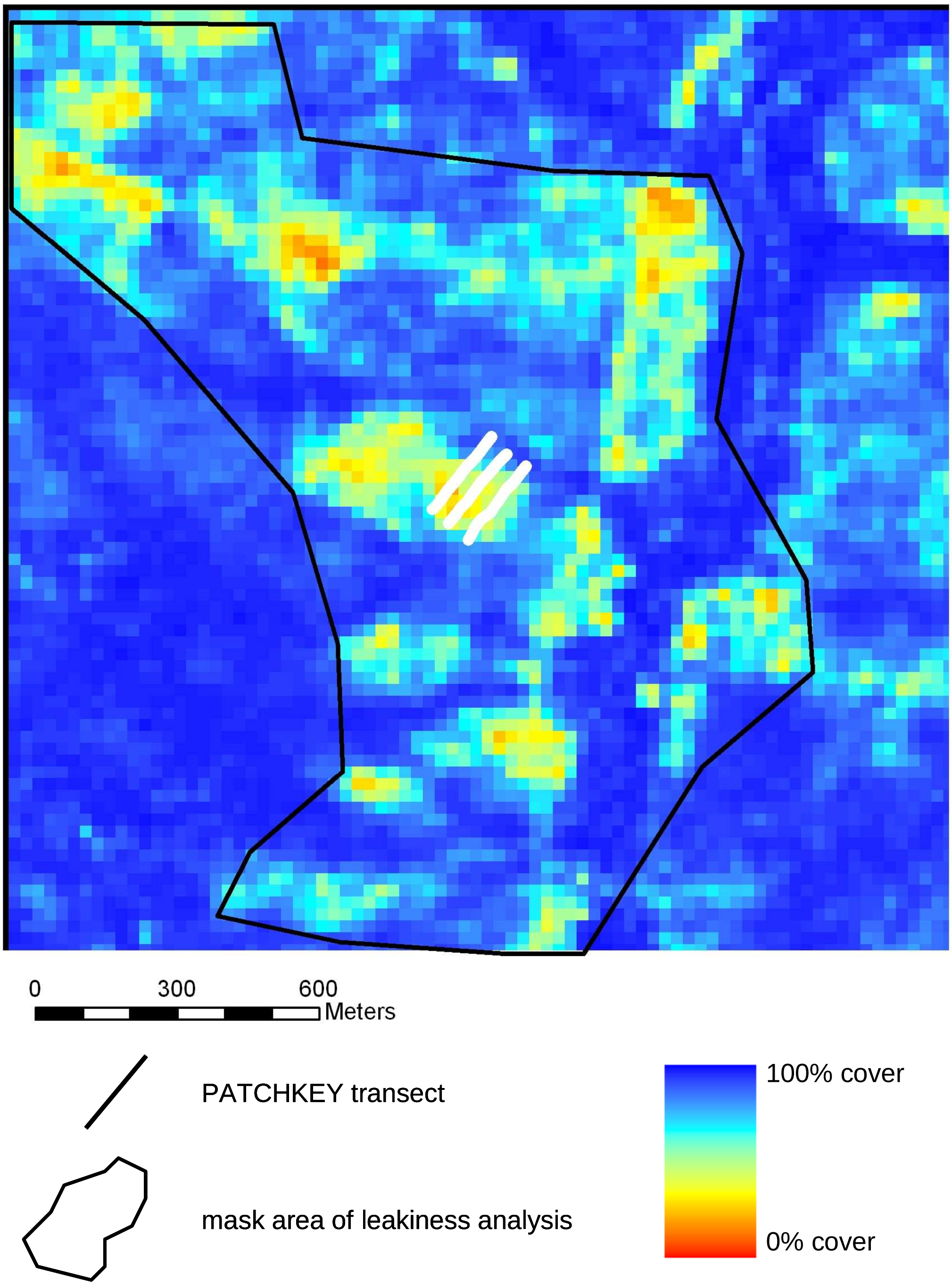

Figure 6. Location of PATCHKEY transects for the Old Hidden Valley site (see Fig. 1) shown on the September 2006 ground cover image. Also shown is the analysis area surrounding the PATCHKEY transects used for calculating leakiness.

RESULTS

Fine scale: Virginia Park

Ground cover: sub-catchment by paddock

The mean level of total ground cover measured in the field in November 2003 differed by <8% (Fig. 7) between sub-catchments within paddocks. These differences were, however, statistically different for sub-catchments in the three main paddocks. There were also small differences in the mean level of litter cover with sub-catchment 3 in Blackfellas Paddock having the highest litter cover. Significantly, litter formed a high proportion of total ground cover in all paddocks: between 57% (in Aires Top, sub-catchments 2 & 4) and 68% (Aires Bottom, sub-catchments 1 to 3). This was probably a result of the dominance of Indian couch which would have mostly senesced to litter at this late stage of the year.

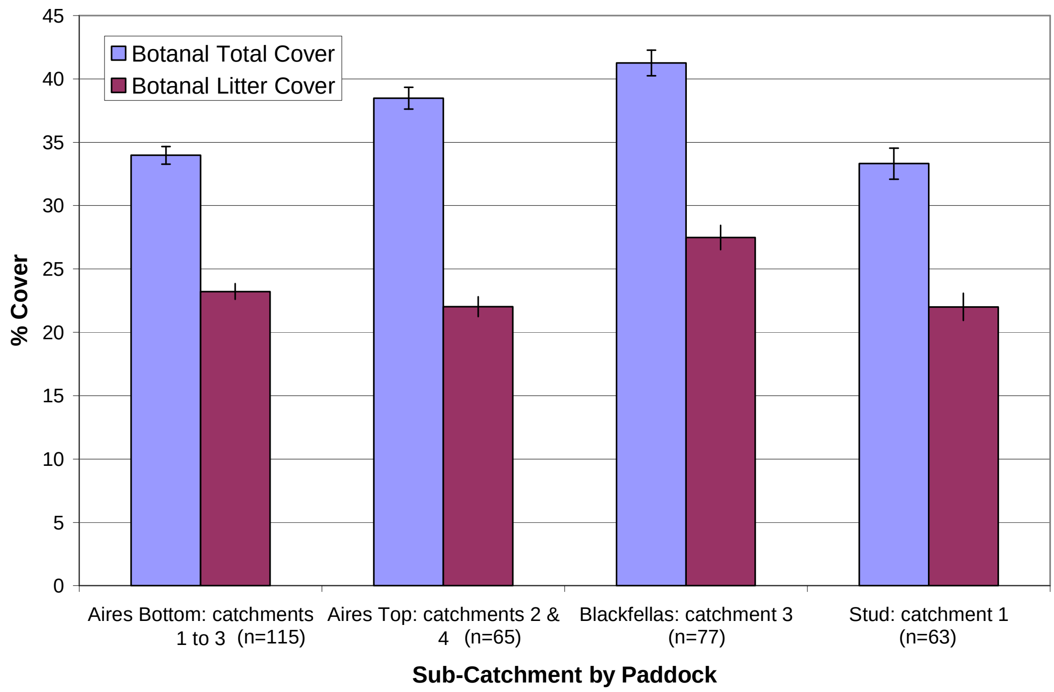

Figure 7. Mean levels of ground cover and litter cover measured within paddock sub-catchments at Virginia Park in November 2003. Bracketed numbers near paddock names show the number of BOTANAL assessments.

Total cover: field and remote sensing measures

The mean level of total cover estimated in the field was marginally lower than the remotely sensed estimate for the same sample locations for three of the four paddock sub-catchments (Fig. 8, remotely sensed cover lower in Blackfellas paddock). Ground cover only was estimated in the field while total vegetation cover (i.e. both woody and ground layer) was estimated by remote sensing. Twenty to forty percent of BOTANAL assessments in all paddock sub-catchments were adjacent to, or under, tree canopies and this probably explains why the remotely sensed estimate was marginally higher then the field-based estimate (i.e. ground cover only). The inclusion of the woody layer also accounts for the mean cover of the remotely sensed index being higher for the entire area of all paddocks compared with just the pixels associated with the locations of BOTANAL assessments (i.e. 'QB polygon cover' cf 'QB Botanal points' in Fig. 8).

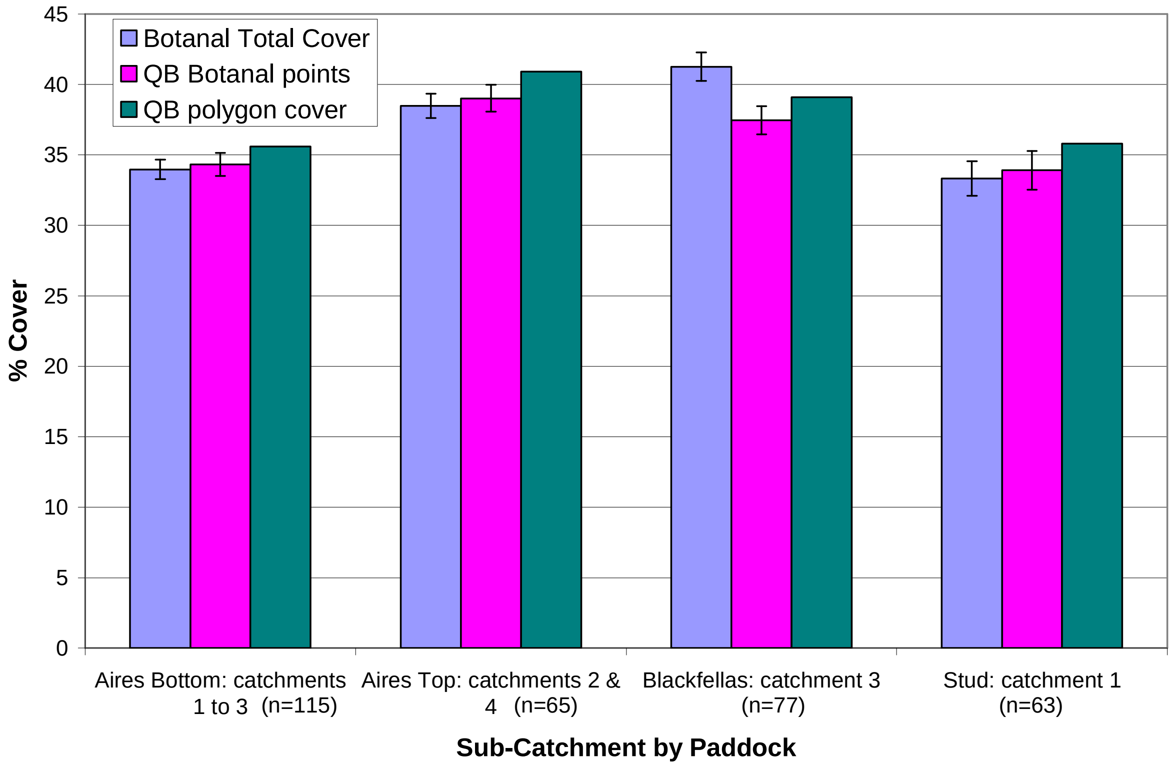

Figure 8. Comparison of field-measured and remotely sensed vegetation cover (QB) within paddock sub-catchments at Virginia Park. Field measurements (BOTANAL total cover) were made in November 2003. Remotely sensed cover is based on the PD54 vegetation index derived from a December 2003 Quickbird image (rescaled to approximate percentage cover). Remotely sensed cover is shown for the pixels corresponding with BOTANAL sampling locations and the entire area of sub-catchments within paddocks. Bracketed numbers near paddock names show the number of BOTANAL assessments.

Part of the reason for the BOTANAL assessment of ground cover being higher than the remotely sensed estimates of total cover in Blackfellas paddock (sub-catchment 3) is that the field collection of data avoided an area that had been recently ploughed (Fig. 9). This area of disturbed (bare) soil was included in the remotely sensed calculations of average cover. A large scald in Aires Bottom paddock (Fig. 9) was also not sampled on the ground but included in remotely sensed analyses of cover.

Ground cover (BOTANAL) and leakiness

The calculated leakiness of sub-catchments within paddocks declined as the mean level of ground cover (as estimated with BOTANAL assessments) increased (Fig. 10, Pearson correlation = -0.976). Leakiness is only shown for paddocks higher in the Weany Creek sub-catchment because these have a larger area of hillslopes (compared with Stud Paddock which is lower in the Weany Creek catchment). The Leakiness Index is more appropriately applied to hillslope landscapes.

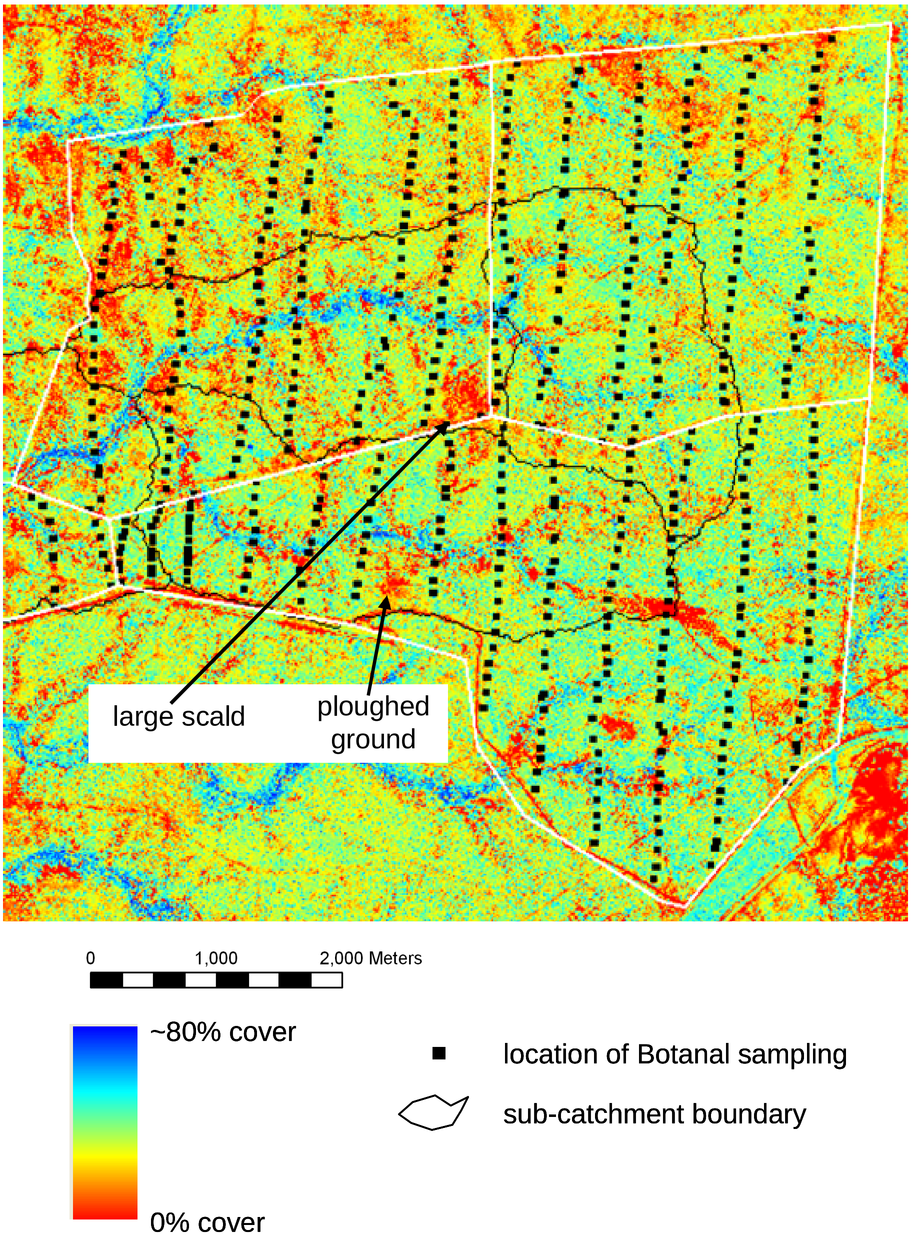

Figure 9. Example areas of low cover that appear to have been under-sampled with BOTANAL estimates of ground cover.

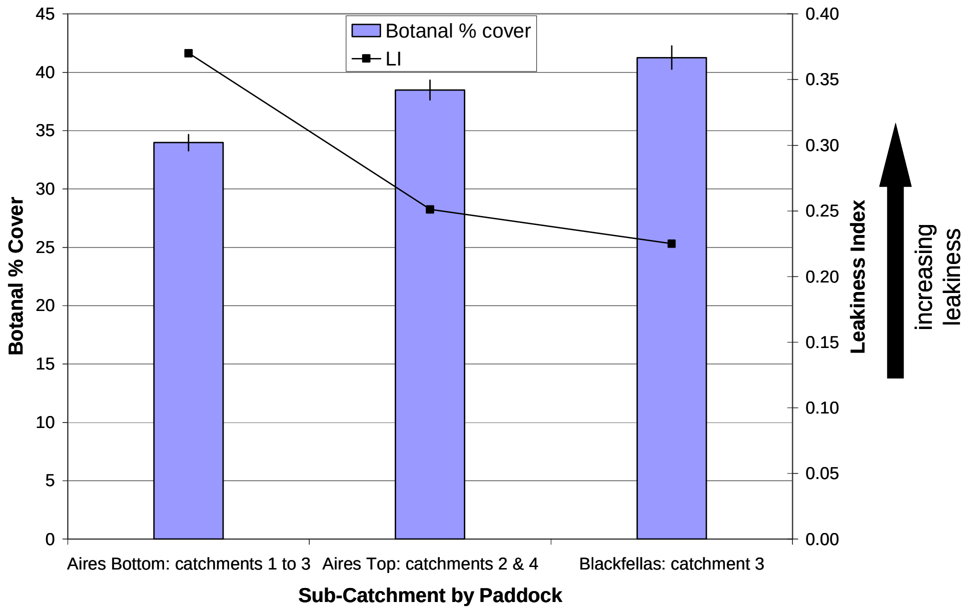

Figure 10. Mean levels of ground cover (from BOTANAL assessments) and calculated leakiness for sub-catchment by paddock.

Sheet erosion

Sheet erosion was the most common form of erosion recorded (recorded with some degree of severity at 62% of the 320 BOTANAL assessments within paddock sub-catchments). Where sheet-erosion was recorded, 'slight erosion' was the most frequent assessment (Fig. 11) although both Aires Bottom and Stud Paddocks had 14% of assessments in the 'moderate' category and Blackfellas Paddock had the highest incidence of 'extensive' sheet erosion (6% of observations).

Index of sheet erosion and leakiness

Based on the weights assigned to classes of sheet-erosion severity (Table 1), sub-catchments in Aires Bottom paddock had the highest (most severe) erosion score and leakiness (Fig. 12). However the relationship varied for sub-catchments in the other two paddocks where leakiness was calculated: Aires Top paddock was least affected by sheet erosion (based on the index applied) but had leakiness value slightly greater than for sub-catchment 3 in Blackfellas paddock. The location and severity of sheet erosion is not explicitly included in the formulation of the leakiness index because both are difficult to detect rigorously with remote sensing. However, it is likely that increasing extent and severity of sheet erosion reduce vegetation cover and thus increase calculated leakiness. The lack of a consistent relationship between an index of sheet erosion and values of the leakiness index for Virginia Park paddocks and sub-catchments is not unexpected.

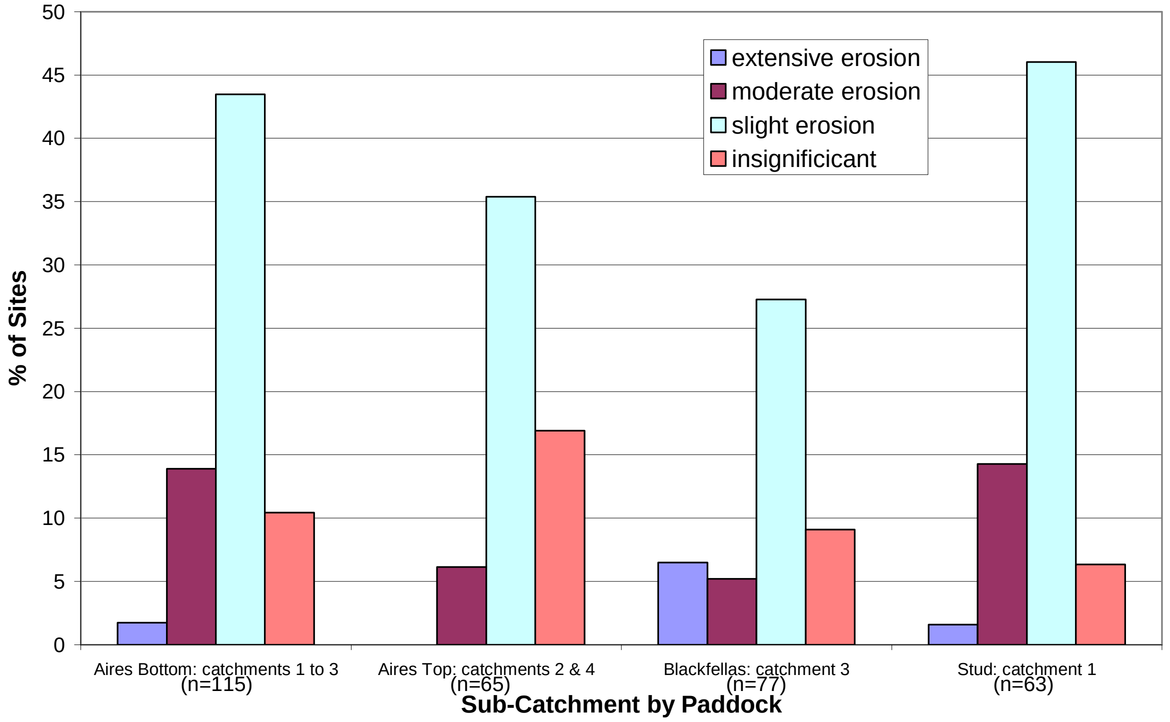

Figure 11. Percentage frequency of recorded erosion severity for sheet erosion in paddock sub-catchments at Virginia Park. Bracketed numbers near paddock names show the total number of BOTANAL assessments.

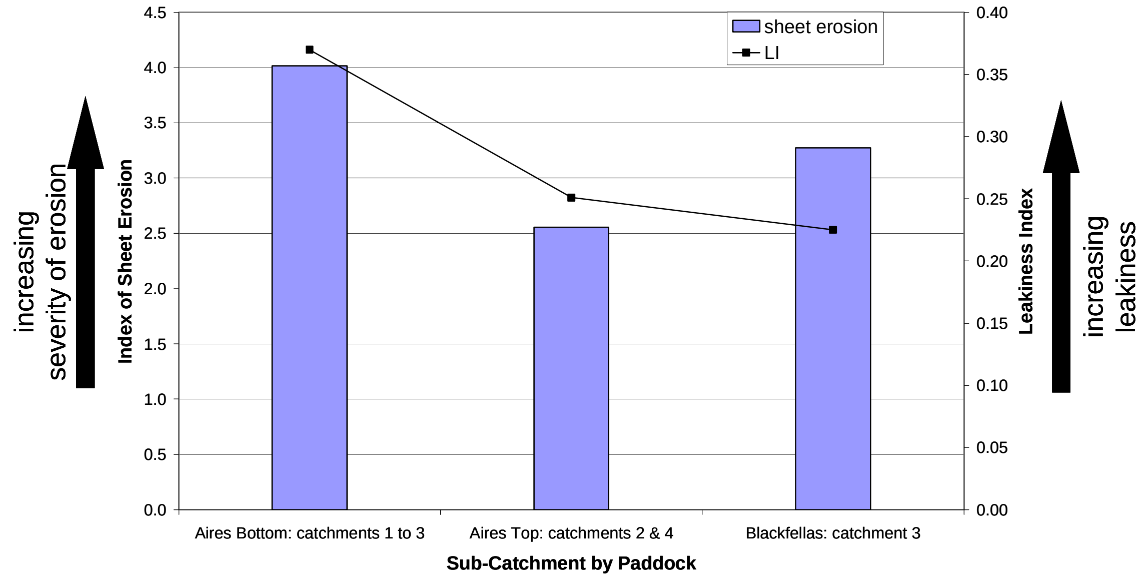

Figure 12. Comparison of an index of sheet erosion severity and Leakiness Index values for sub-catchments within paddocks at Virginia Park.

PATCHKEY landscape function and leakiness

PATCHKEY scores from the November 2003 BOTANAL assessments more clearly indicate landscape function than cover alone. Sub-catchment by paddock leakiness decreased as assessed functionality increased (Fig. 13), based on the patch weights assigned in Table 2 (Pearson correlation = -1.000). This relationship was similar to that demonstrated by ground cover (Fig. 10) but the PATCHKEY data show a bigger difference in functionality between adjacent sub-catchments in the Aires Bottom and Top paddocks than is apparent from the ground cover data.

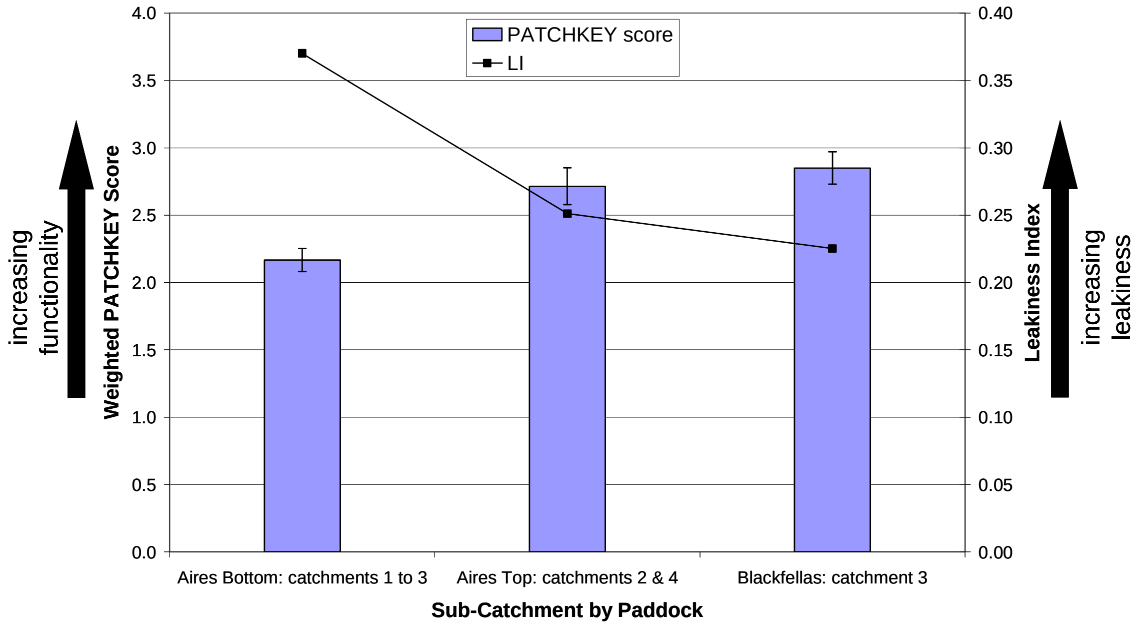

Figure 13. Sub-catchment by paddock functionality (based on weighted PATCHKEY scores from BOTANAL assessments) and calculated leakiness.

Moderate scale: Fanning River and Virginia Park paddocks

Ground cover: field and remote sensing measures

Fanning River

The Queensland Government's Ground Cover Index (GCI) derived from Landsat TM data indicated higher levels of ground cover than was estimated by BOTANAL assessment (Fig. 14). Where cover estimates were time-coincident (May 2002), the field estimate of average cover was ~10% less than the remotely sensed estimate. The ~12% difference in 2001 (for the tree-masked image) was partly attributable to BOTANAL assessments being two months after the satellite image was acquired (image date: August 2001, field data: October 2001).

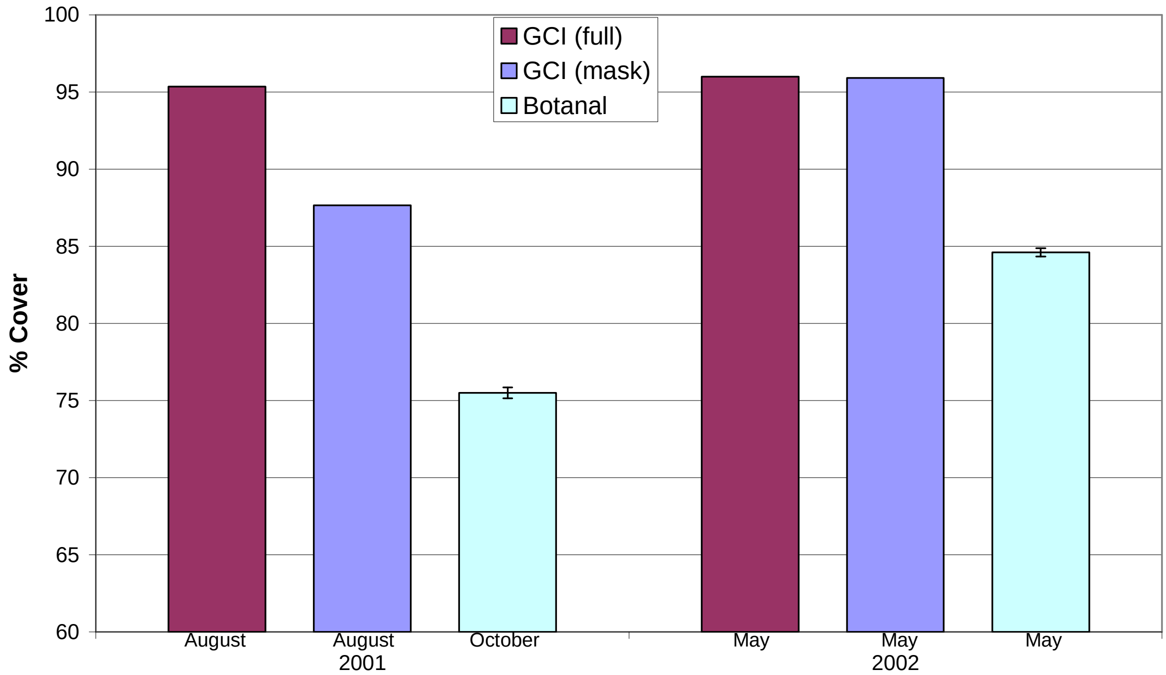

Figure 14. Estimates of ground cover for the Fanning River paddock derived from remote sensing (GCI) and field-based (BOTANAL) assessments. Two versions of the ground cover index are shown: tree-masked, 'GCI (mask)' and non tree-masked, 'GCI (full)'. The standard error of the field-based estimate is shown for both 2001 and 2002.

There were very small differences in estimated average cover between the tree-masked and non tree-masked versions of the GCI in 2002 but a considerable difference in 2001 (ground cover 'GCI (mask)' 7.7% lower than total vegetation cover, i.e. 'GCI (full)'). The reason for the difference between years is not clear. Visual inspection of the GCI images shows that tree-masked areas (i.e. >20% foliar projected cover, ~>40% crown cover) are mainly the (tree-lined) watercourses.

Fanning River and Virginia Park paddocks

The differences between remotely sensed and field-based estimates of ground cover are amplified when the Virginia Park paddocks are considered (Fig. 15). The Virginia Park paddocks are the combined area of Aires East & West, Blackfellas and Stud (i.e. beyond the sub-catchments of the Weany Creek included in the fine-scale analyses reported above).

Fig. 15 compares:

- Tree-masked and non tree-masked versions of the GCI: 'GCI (mask)' and 'GCI (full)' respectively. Data source: 25-m Landsat TM.
- The PD54 index rescaled to approximate percentage cover. Data source: 5-m Quickbird.
- Systematic field assessment of cover (BOTANAL) across the four paddocks. Estimates made in 4-m^2 virtual quadrats.

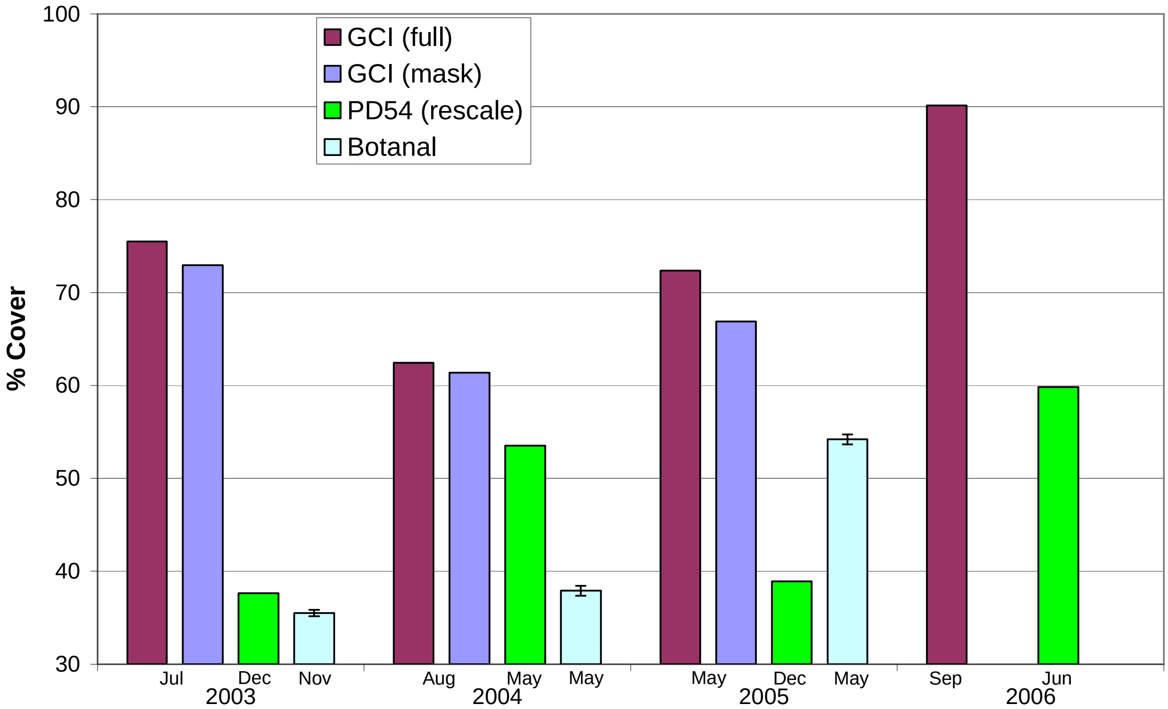

Figure 15. Cover estimates for the combined Virginia Park paddocks derived from Landsat TM (i.e. GCI) and Quickbird (PD54) satellite images, and field-based (BOTANAL) assessments.

In 2003 average cover for the combined Virginia Park paddocks based on the Quickbird-derived and field-based estimates was approximately half that indicated by the Landsat TM GCI. The GCI index preceded the lower estimates of cover by four to five months and it is reasonable to expect that the July remotely sensed estimate of ground cover would be higher than the November field estimate. Additionally, the 2002-03 wet season was much below average (decile 1 rainfall from the long-term record available at the nearby Mingela Post Office). There was evidence that the cover of Indian couch declined substantially as the 2003 dry season progressed. Thus the difference between the July and November-December 2003 estimates of cover shown in Fig. 15 are plausible. However, the elevated estimate of ground cover provided by GCI in following years, compared with field measurement and Quickbird imagery, is more difficult to account for.

- In 2004, the considerably higher GCI estimate of ground cover was obtained three months after the field- and Quickbird-based estimates (i.e. later in the dry season). Rainfall records from the Mingela Post Office show insignificant rainfall (4.5 mm) between May and August 2004 and therefore little prospect of real increase in ground cover. The BOTANAL data suggest that the rescaled PD54 index may have also over-estimated cover, although this remotely sensed cover index should be higher because it includes trees (i.e. total vegetation cover).

- The field (BOTANAL) estimate of average cover in May 2005 was 81% of that estimated by the tree-masked ground cover index (May image). These approximately coincident assessments suggest that GCI is over-estimating ground cover in this part of the Burdekin region.

- The rescaled PD54 index of total vegetation cover in late 2003 was slightly higher than the BOTANAL measure of ground cover a month earlier, at least partly because the former included trees. In 2005, the rescaled PD54 index for December indicated approximately 30% lower cover than measured on-ground in May (a decline expected). Thus the rescaled PD54 index appeared reliable for indicating vegetation cover at Virginia Park (the difference in cover in May 2004 was partly due to trees and the PD54 index may have also been unduly influenced by residual greenness in the vegetation). Thus given that there was some parity in cover as measured in the field and indicated by the rescaled PD54 index, the September 2006 GCI estimate of ground cover also appears to be an over-estimate.

One reason for the differences between the GCI and BOTANAL / rescaled PD54 estimates of cover may be data scaling. The latter estimates were made at very high resolution: 2-m (linearly) for BOTANAL and 2.4-m for Quickbird PD54. These assessments were at the scale of small vegetation patches and interpatches. GCI, derived from Landsat TM at 25-m pixel size, is at the scale of multiple patches and larger areas of bare ground. The patch-interpatch discrimination possible with BOTANAL and Quickbird is subsumed as mixtures within these larger Landsat TM pixels. It may be that GCI (and remote sensing in general) over-estimates the ground cover of pastures dominated by Indian couch because it is difficult to discriminate sufficient of the bare ground amongst the runners (stolons) that cover much of the surface. This problem may increase in dry years when the basal area of Indian couch is reduced, runners provide a higher proportion of the reduced ground cover and field-based assessment would regard much of the ground cover as litter.

If GCI has over-estimated ground cover for the Virginia Park paddocks (and Fanning River, see above), there is a high degree of confidence that it has done this consistently over time (from the evidence here and also because of the systematic and rigorous way in which Landsat TM data are processed to produce GCI). Where suitable ground-cover data are available, it may be possible to better calibrate GCI to the local environment being analysed. If it is not possible to better calibrate GCI to local conditions, over-estimates of cover will translate (non linearly) to reduced estimates of leakiness (reported in following sections). Although these estimates may be conservative, differences between catchments in their time traces of LI still provide a valuable record of change over time and allow inferences to be drawn about differences in catchment condition.

Sheet erosion: Fanning River and Virginia Park paddocks

The weights for sheet erosion severity (Table 1) applied to the field data collected in combined Virginia Park paddocks (November 2003) produced a much higher index value than for Fanning River (May 2002 data) (Fig. 16).

Calculated leakiness (LI) was very low for both locations (Fanning River and combined Virginia Park paddocks) on all occasions of available Landsat imagery because of high (and probable over-estimated) GCI cover values (Fig. 17). Leakiness was calculated for the Fanning River paddock using the ‘tall tussock grass’ function and for the combined Virginia Park paddocks using the ‘mat forming grass’ function (see Bastin *et al*. 2007). For the same level of average cover, pastures dominated by stoloniferous mat forming grasses (such as Indian couch) are relatively much leakier than if native tussock grasses occur. Thus we apply separate 'decay' functions between cover and potential soil loss for these two locations in calculating LI values. This amplifies LI differences according to known land condition.

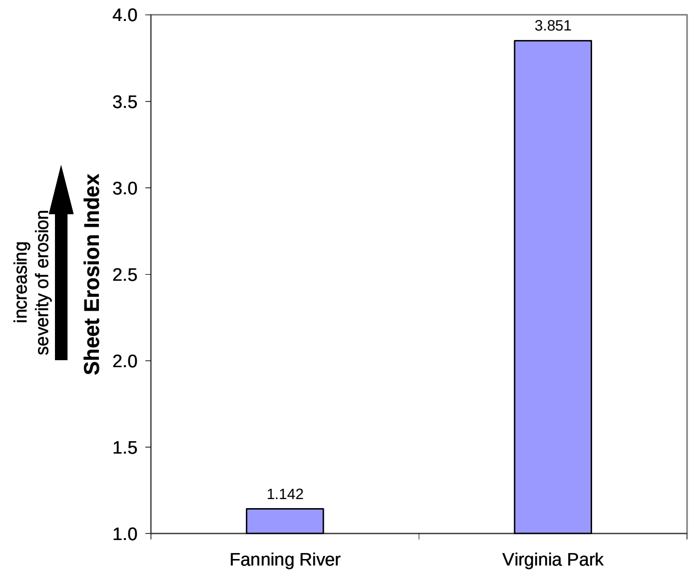

Figure 16. Sheet erosion index values for Fanning River and combined Virginia Park paddocks. An index value of 1 equates to no sheet erosion recorded at any of the BOTANAL assessments.

Landscape leakiness: Fanning River and Virginia Park paddocks

Differences in indicated leakiness were most pronounced in August 2004 when average cover for both paddocks was relatively lower. However, it is likely that actual LI values were much higher for the combined Virginia Park paddocks (and less so for Fanning River) because ground cover was over-estimated with the ground cover index.

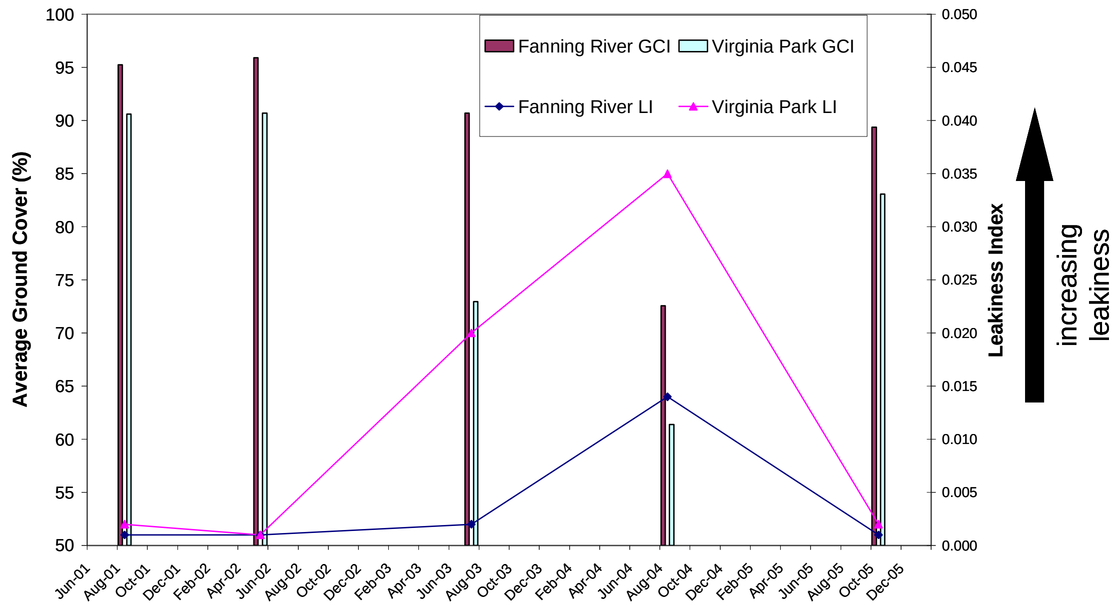

Figure 17. Landsat TM-derived estimates of average ground cover, as indicated by GCI, and calculated leakiness for the Fanning River and combined Virginia Park paddocks.

Coarse scale: parts of the Burdekin catchment

PATCHKEY transects: cover and erosion indices

The Allen Hills site (see Fig. 1) had the lowest levels of basal area, litter and total ground cover (Fig. 18) and the most severe erosion (Fig. 19). Chesalon and Old Hidden Valley were better sites in terms of cover (Fig. 18) while Old Banchory and Old Hidden Valley were least affected by erosion (Fig. 19). Note that the sites presented here were selected from those sampled to validate mapping of 'D-condition' land (Abbott *et al*. 2008) and are not intended to represent land condition across the grazed rangelands of the Burdekin catchment.

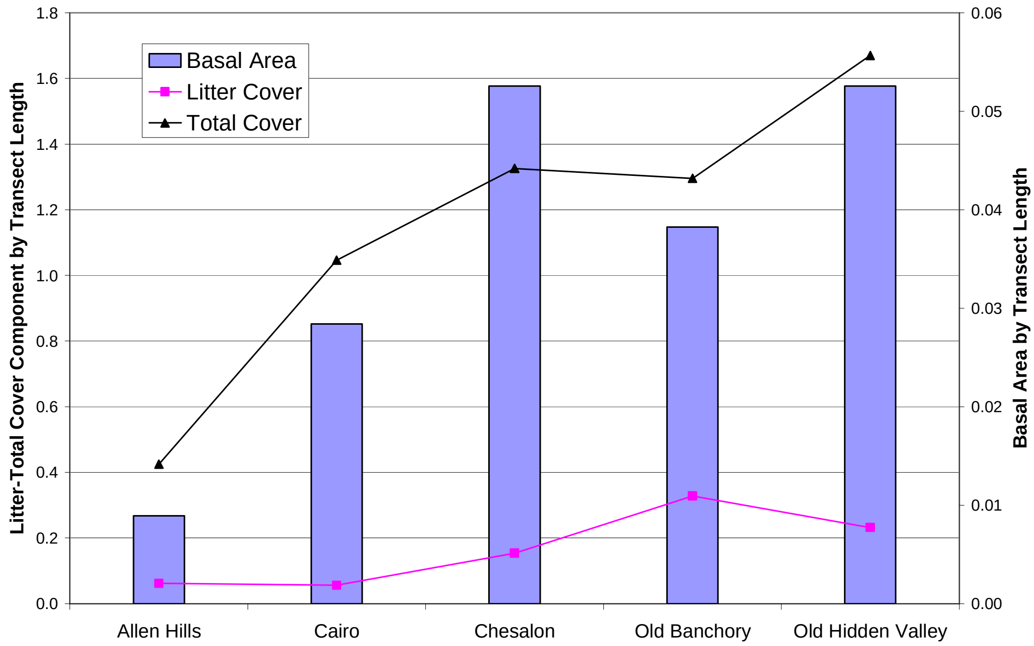

Figure 18. Levels of basal, litter and total cover weighted by proportional patch length and then summed for PATCHKEY transects assessed at five locations in the Burdekin catchment.

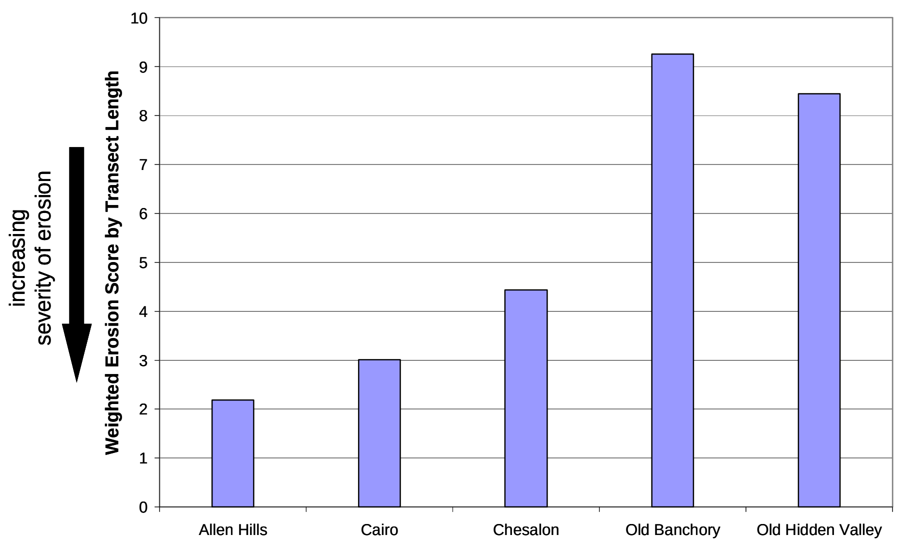

Figure 19. Weighted index of erosion severity from PATCHKEY transects at five locations in the Burdekin catchment.

Landscape function: PATCHKEY scores

The PATCHKEY score assigned to each site, to indicate its landscape function, combined the various forms of cover data and erosion severity. Basal area is particularly influential in the weights assigned (Table 2) and thus the magnitude of site functionality scores (and their ordering) (Fig. 20) was similar to that for site basal area (Fig. 18).

The Chesalon, Old Banchory and Old Hidden Valley sites had moderate functionality, despite considerable differences in pasture composition (Table 3) while Allen Hills with its very low basal area and litter cover and quite severe erosion had the lowest level of landscape function. This site was purposefully selected to characterise 'D-condition' (i.e. degraded) country.

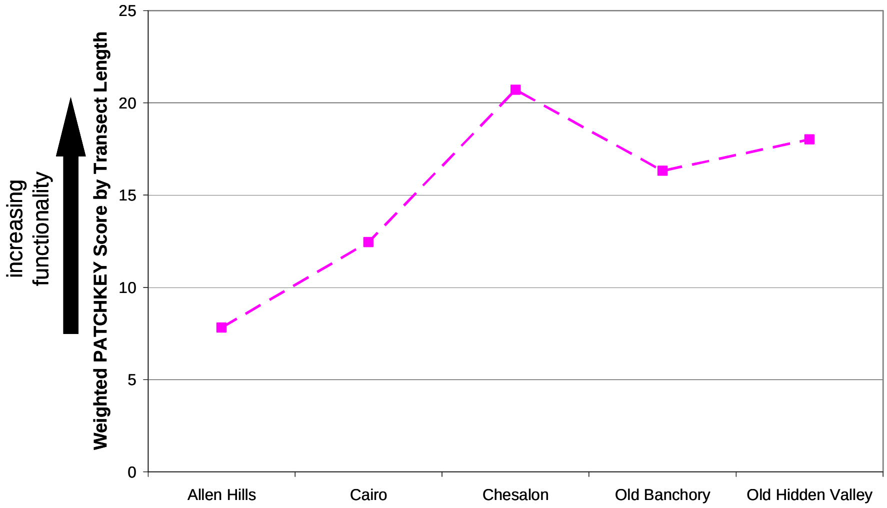

Figure 20. Weighted index of landscape function from PATCHKEY transects at five locations in the Burdekin catchment.

The direct contribution of site basal area and, in turn, total ground cover to weighted PATCHKEY score is further illustrated in Fig. 21. These scatter plots confirm that:

- The Allen Hills site, deliberately selected to represent a degraded area of D-condition land, was most affected by erosion and had the lowest cover measures.
- Significant erosion and low litter cover offset higher basal and total (ground) cover at the Cairo site to produce a moderate PATCHKEY condition score (among the five sites). This area had been cleared and sown to buffel grass.
- The Chesalon site (another cleared area with buffel grass) had low litter cover but relatively high basal area and total (ground) cover. These factors produced the highest PATCHKEY condition score of the five sites despite the presence of considerable erosion.
- Old Banchory, a relatively intact (undisturbed) site, had the highest litter cover and moderately high basal area and total cover. Erosion was least amongst the five sites and overall PATCHKEY condition score was moderately high.
- The Old Hidden Valley site had moderate litter cover and relatively high basal area and total (ground) cover. This pasture layer was dominated by Indian couch and all cover levels probably vary considerably with different seasonal conditions. There

was minimal erosion and the resultant PATCHKEY score was the second highest of the five sites.

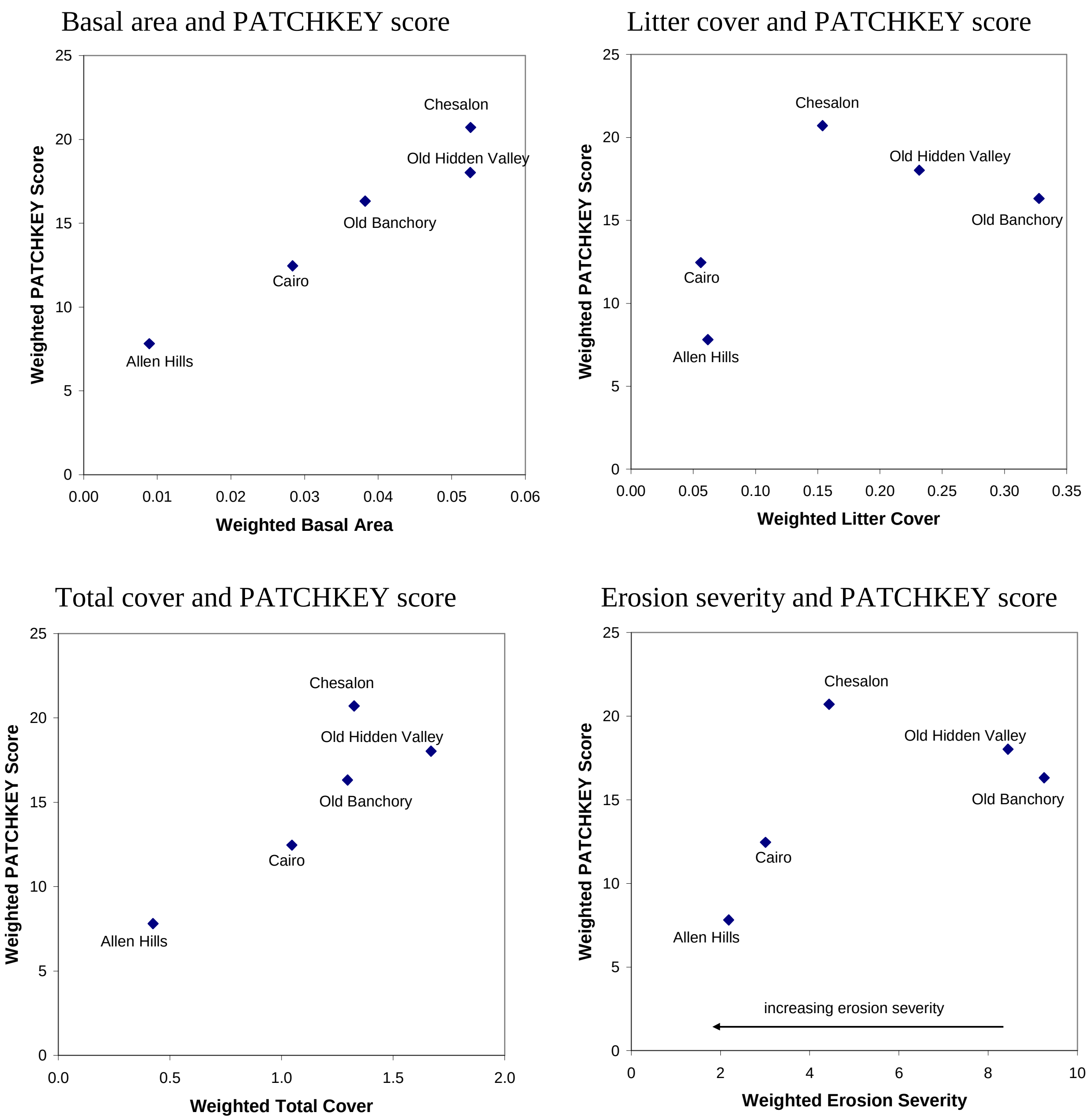

Figure 21. Scatter plots showing the arrangement of sites with respect to condition (based on weighted PATCHKEY score) and basal area (top left), litter cover (top right), total (ground) cover (bottom left) and erosion severity (bottom right).

PATCHKEY and landscape leakiness

Leakiness (LI) values were very low for the enlarged areas of 53 to 264 Ha surrounding sites (Fig. 22) indicating all landscapes were non leaky (leakiness calculated using the late 2006 Ground Cover Index). This was because of generally high cover despite the presence of variable areas of poor (D) condition land surrounding the locations of some ground transects. Despite the very low leakiness values, LI was inversely related to the average level of cover present on each area analysed (as expected).

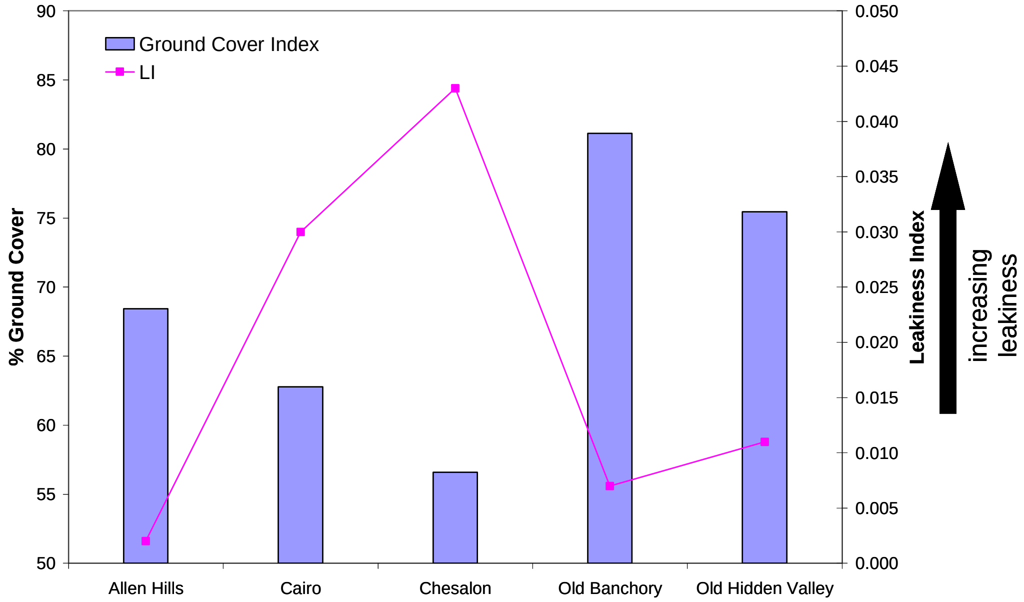

Figure 22. The mean level of cover indicated by the Ground Cover Index and calculated leakiness for enlarged areas surrounding five sites selected to demonstrate ground validation of the leakiness index.

There was no sensible relationship between PATCHKEY condition score of the five sites and calculated leakiness of the larger area (Fig. 23). For example, the Allen Hills site was in the poorest condition but had the lowest LI value because of higher cover on much of the enlarged 53 Ha area analysed to calculate leakiness.

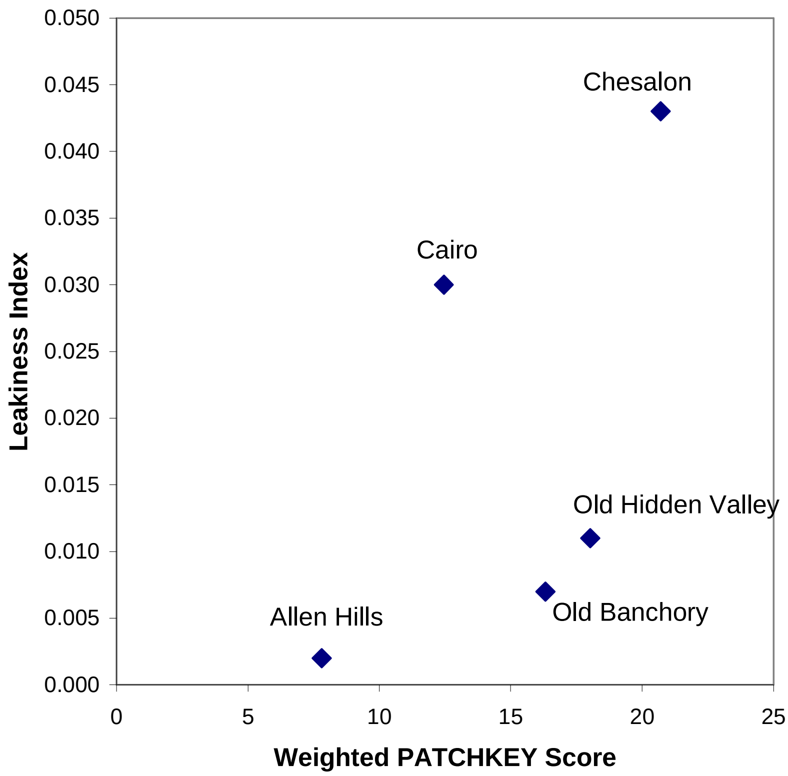

Figure 23. Scatter plot of sites based on their weighted PATCHKEY score and calculated leakiness for a considerably enlarged area surrounding each site.

DISCUSSION

Earlier work funded by the Water for a Healthy Country Flagship demonstrated that the Leakiness Index was useful for monitoring change in land condition at sub-catchment scale in parts of the Burdekin catchment (Bastin *et al*. 2007). The results of this work received favourable comment when presented to QDPI&F staff involved in grazing land management at a workshop in Charters Towers in April 2007. At that time, key QDPI&F staff were provided with spatial datasets used for analysis, the LI calculator (a computer program) and basic instruction material allowing them to repeat, or extend, these analyses. Contact has been maintained with these staff but as yet, they have had limited opportunity to extend regional analysis of leakiness or to discuss results with individual landholders because of their other work commitments.

The results from analysis of remotely sensed data require ground validation to determine their level of precision and, from there, confidence in what is being reported. However, such validation is often difficult because of scale issues. Remote sensing allows large areas of spatially complex landscapes to be assessed (and monitored over time) thereby overcoming the considerable difficulties of adequately sampling such landscapes on the ground. However, these same spatial complexities and large areas can mean that it is quite difficult to obtain sufficient suitable ground data to verify the results of remote sensing.

For the validation process reported here, we used a stepped approach of:

1. Fine-scale analysis

   (i) Validating a remotely sensed index of cover (at very high spatial resolution) with ground data that involved the systematic estimation of cover components across sub-catchments within commercially grazed paddocks (i.e. at a management-relevant scale).

   BOTANAL estimates of total ground cover estimated in 4-m^2 quadrats averaged for paddock sub-catchments showed good agreement with the PD54 index of total vegetation cover rescaled to approximate percentage cover.

   (ii) Testing the relationship between ground cover measured in the field and landscape leakiness calculated for paddock sub-catchments using the very high resolution cover index from step one.

   There was a consistent relationship of decreasing leakiness with increasing mean cover for each area.

   (iii) Examining the effect of assessed sheet erosion on leakiness. The various forms and severities of water erosion are important determinants of landscape function but are difficult to directly assess from remotely sensed data. The effects of sheet erosion are captured to some extent in the Leakiness Index (although not explicitly so) because sheet erosion is common to hillslopes and it affects the spatial arrangement and level of cover seasonally present. That is, it is likely that persistent cover is reduced as the extent and severity of sheet erosion increases.

   A sheet-erosion index showed that the indicated leakiness of paddock sub-catchments broadly increased as the frequency and severity of recorded sheet erosion increased. However, this was not a consistent (monotonic) relationship across the limited range of sub-catchment by paddock data values examined.

(iv) Making a direct comparison between ground-based assessment of landscape function and landscape leakiness by assigning functionality weights to recorded PATCHKEY scores recorded at BOTANAL points and averaging these for sub-catchments within paddocks.

There was a consistent relationship of decreasing leakiness with increasing PATCHKEY functionality score for sub-catchments within the three paddocks analysed.

These results demonstrate that values of the Leakiness Index derived from a very high resolution DEM and satellite imagery can be validated with ground data for sub-catchments within smaller grazed paddocks of the Burdekin catchment. Estimates of ground cover and PATCHKEY functionality provide the best data for validation. The results provide confidence that the leakiness index is reliably indicating landscape function at the sub-catchment scale within these paddocks.

2. Moderate-scale analysis

(i) Analyses were conducted using Landsat TM (25-m pixel) data for two areas of the Fanning River sub-catchment known to be in contrasting condition. The Queensland Government's Ground Cover Index (GCI) appeared to over-estimate ground cover for both areas compared with field-based data.

Over-estimation of cover will result in conservative calculation of landscape leakiness. GCI provides a convenient database of multitemporal change in ground cover at 0.0625 Ha resolution for most of Queensland and this is a potentially valuable resource for broader scale analyses of landscape leakiness. Although ground cover appeared to be over-estimated for the two areas examined, there is good evidence that GCI has improved reliability elsewhere (Scarth *et al*. 2006). The robust correction factors applied to the SLATS database (from which GCI is derived) means that any errors in cover estimation are consistent over time. Thus, although indicated leakiness may be conservative for the two areas examined, the magnitude and direction of change in LI values over time will still convey meaningful information about landscape-scale changes in functionality.

(ii) Condition differences between the two areas indicated by field-based estimation of ground cover and sheet erosion (quantified by a sheet-erosion index) were discriminated by the Leakiness Index. Differences in LI values between the two areas were subdued in years of higher average cover and amplified in drier years when average cover was lower.

In this validation component, landscape leakiness was calculated for larger (moderate sized) paddocks (or groups of paddocks) using Landsat TM-derived GCI to indicate ground cover. The successful scaling up of ground-based validation provides evidence that the leakiness index reliably indicates landscape function at this larger scale. Confidence in calculated LI values should be increased where it is known that GCI accurately indicates actual levels of ground cover.

3. Coarse-scale analysis

(i) PATCHKEY provides a viable method for rapid ground collection of important components of landscape function (plant basal area, litter and total ground cover, extent and severity of erosion etc). These components combine in a structured way to provide a PATCHKEY score that represents the functionality of each vegetation patch type recorded (Corfield *et al*. 2006).

Weights were assigned to each PATCHKEY score to numerically indicate the functionality of each patch type. These weights were then adjusted by the proportional length of each patch type and summed to provide an overall site functionality score.

There was no consistent relationship between site PATCHKEY functionality score and calculated leakiness for a much larger surrounding area for five areas selected throughout the Burdekin catchment to demonstrate the method. This occurred because none of the sites adequately represented cover or its distribution across the broader area analysed to indicate leakiness.

The lack of any sensible relationship was not surprising as the ground transects were located to characterise and validate ‘D condition’ land (Abbott *et al*. 2008), not to validate leakiness results. To satisfactorily achieve the latter, it would seem necessary to compute the leakiness of required areas (e.g. sub-catchments) and then conduct multiple PATCHKEY assessments at selected sites so that the landscape characteristics of each analysis area are adequately sampled. An appropriate stratification scheme is necessary for deciding where to sample on the ground, e.g. based on the spatial arrangement of cover combined with elevation (landform) characteristics. Visual inspection of Landsat imagery and landscape features derived from the DEM (e.g. slope length and steepness) should assist this stratification and site selection. Access constraints of course further limit where PATCHKEY data can be collected on the ground.

Overall assessment

We have shown through a scaled approach to ground validation that the Leakiness Index does reliably indicate landscape function of sub-catchments within commercially grazed paddocks of the Fanning River sub-catchment (a significant tributary of the broader Burdekin catchment). We were less successful in validating leakiness for other areas of the Burdekin due to the lack of suitable ground data. However this work, combined with the mapping of ‘D-condition’ land by Abbott *et al*. (2008), has demonstrated that the PATCHKEY method provides a viable means for rapidly collecting ground data suitable for validating leakiness at larger scales. Suitable replication of this method at a sufficient number of sampling locations should provide the necessary ground data for validating landscape leakiness at other sub-catchments in the Burdekin (and elsewhere in the grazed rangelands where it is appropriate to monitor landscape function with the Leakiness Index).

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