Development of a Riparian Condition Assessment Approach for Northern Gulf Rivers using Remote Sensing and Ground Survey

Final Report

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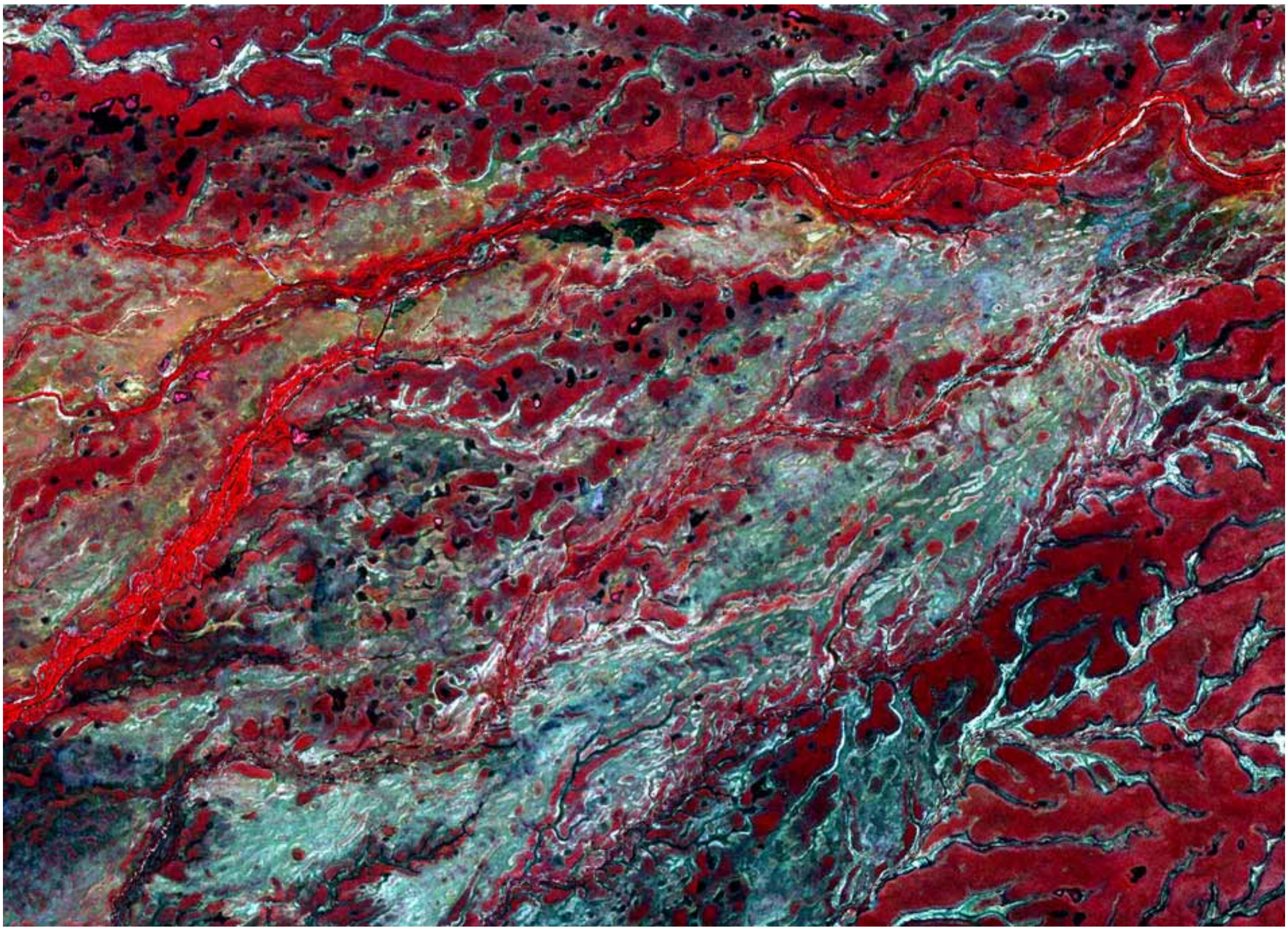

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Cover & inside cover images: ASTER false colour satellite images showing the complex structure of sections of riparian zone in the Mitchell Catchment

Executive Summary

Project Objectives

- To develop a definition of the extent of the riparian zone applicable to the Northern Gulf Region (Mitchell and Gilbert Catchments)
- To develop a broad scale method appropriate for the Northern Gulf region for quantifying riparian condition using remote sensing techniques
- To assess the spatial variability of riparian condition
- To assess the need to modify existing TRARC protocols for Northern Gulf rivers
- To undertake TRARC assessments in selected reaches of the Mitchell and Gilbert Rivers
- To assess the appropriateness of integrating a remote sensing approach for assessing riparian condition in the Gulf Savannah with the existing on-ground survey approach (TRARC).

Definition of the Riparian Zone

Most existing definitions of the riparian zone were found to be too restrictive when applied to the savannah landscapes of the Northern Gulf, given the vast areas of floodplain that are regularly inundated in this landscape, and the fact that a sound case can be made to include entire alluvial plains in the definition. Consequently, we adopted a very inclusive definition of the *riparian zone*, which in total we refer to as the alluvial zone. The broad alluvial/riparian zone is differentiated into three sub-zones: 1) the active channel zone (ACZ) (i.e. the zone which shows geomorphic evidence that it has been occupied by the river channel in the recent geomorphic past); 2) the in-channel zone (ICZ), or the zone encompassing the portion of the current channel that is actively conveying bedload material under the current flow regime; 3) the floodplain (FPZ) – the remainder of alluvial land not encompassed within the other two categories (which as outlined below is not necessarily synonymous with the land that is inundated by the current flood regime – i.e. it may also include alluvial sediments deposited under a former flood regime). The spatial relationship between these three zone is shown in Figure 3.

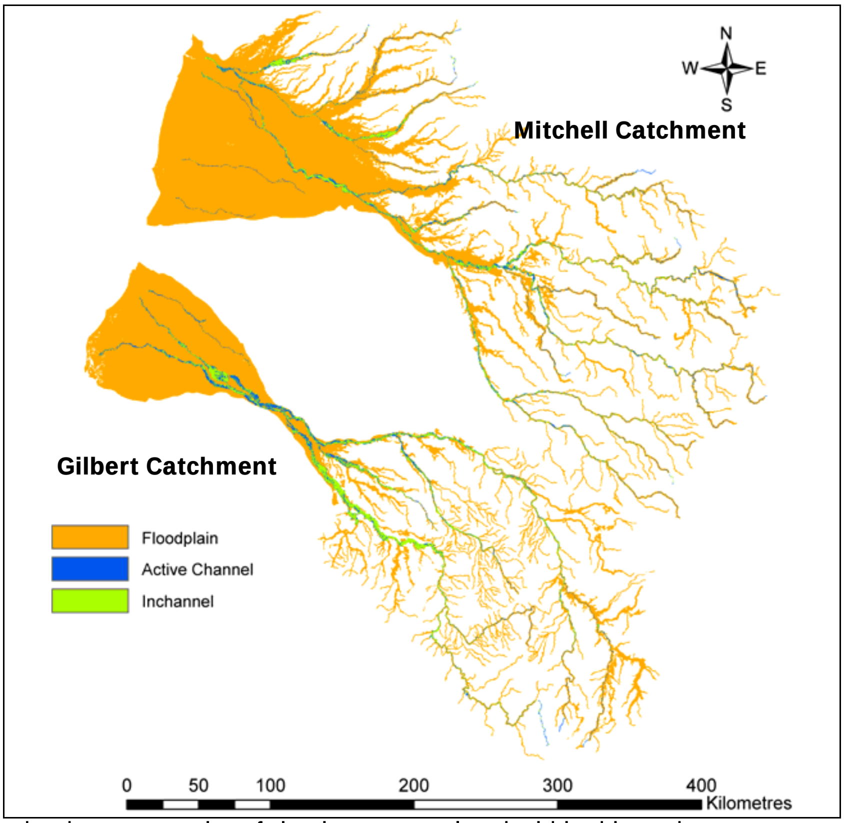

Figure 3 Map showing the three categories of riparian zone analysed within this study.

Land Use Pressure Index

Given that the dominant land use pressures in this region are grazing and mining, with only a locally significant, but spatially confined area of intensive irrigated agriculture in the Mareeba-Dimbulah irrigation area, it is difficult to derive direct measures of land use pressure. Deriving accurate data on actual present day cattle numbers within the region is extremely difficult, while determining total cattle numbers in any one area throughout the period of European settlement is virtually impossible. To get around this problem, we determined that the only measure of land use pressure that can be quantified with a reasonable degree of accuracy, is a measure of road density. We assumed that a greater density of roads, on the balance of probabilities, will equate to more intensive cattle grazing (given that road access is required for the maintenance of stock water points and supplementary feeding). Areas of higher density mining activity are also likely to have more roads. Some caution must be exercised when drawing conclusions from these data at higher resolution, because there are a variety of reasons why roads are located in some areas and not others (i.e. on alluvial ridges as opposed to within the active channel zone.). Nevertheless, we consider at the major sub-catchment scale this is a reasonable measure of relative land-use intensity, which can be broken down into the different riparian zone categories.

It is apparent that road density is slightly greater in the Gilbert catchment than the Mitchell in both the floodplain zone and the channel zone, (average 274 cf 225, and 195 cf 83 (m/km^2) respectively although the difference is not statistically significant (P= 0.395 & 0.363; t-test). The Alice River stands out as having very low road density as does the lower part of the Gilbert fan.

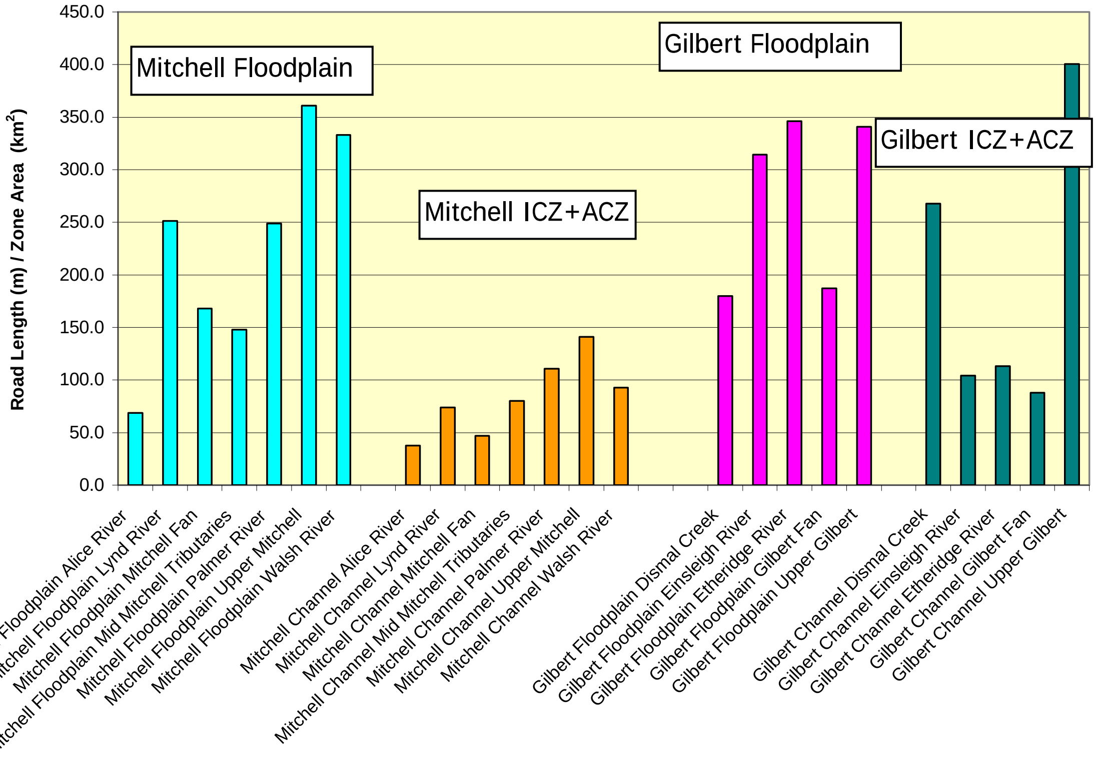

Figure 9 Unit road density by sub-catchment within the Mitchell and Gilbert Rivers

A Remote Sensing based Approach to Riparian Condition assessment at the Catchment Scale

The approach adopted in this component of the study was to look at broad catchment-scale patterns in riparian vegetation, and to establish a baseline against which changes through time could be assessed. We used Landsat TM data from 1988 & 2005 to determine vegetation community types (after Specht, 1970) as well as the extent of in-channel pools and sand deposits, floodplain waterbodies and floodplain bare ground. In total 36120 km^2 of riparian area was analysed across both catchments, comprising 22484 km^2 and 13638 km^2 in the Mitchell and Gilbert catchments respectively.

Having calibrated the 2005 vegetation community structure along with the configuration of in-channel sand bodies, vegetated islands, benches and water bodies with high resolution (1 – 2m resolution) tri-spectral scanner data, it was assumed that the 1988 imagery would reflect the same features on the ground, and a change detection analysis was then carried out using a mosaic of Landsat ETM for the two timeslices (1988 & 2005).

Key Results

Across each of the riparian zone categories, and in all sub-catchments, vegetation density was found to have increased markedly in the period 1988 – 2005.

Mitchell Catchment

ICZ

Vegetation change

There was a net increase of in-channel vegetation (all classes combined) of 6950 ha over the 17 year interval assessed or 13.5% of the total area of the ICZ (51565 ha). This net gain is comprised of a total increase of 11262 ha of in-channel vegetation, which is offset by a loss (via channel erosion) of 4310 ha of in-channel vegetation over the same period. Hence, there has been a considerable turnover of in-channel vegetation during this period. In annualised terms, the net vegetation increase was 409 ha/yr, or 0.79% of the total area of the in-channel zone.

In-channel Sedimentation

Based on the relative areas of in-channel sand, water bodies and vegetation between the two time slices, there is a clear trend towards net accumulation of sediment within the channel in most sub-catchments and minor net scour in others.

The upper Mitchell and the Mitchell fan reach have both experienced considerable net bar deposition between 1988 and 2005, with net increases of 9.23 km^2 and 3.89 km^2 respectively. The Alice and the Lynd Rivers also experienced considerable net sediment accumulation, with sand bar area increasing 3.69 km^2 and 1.89 km^2 respectively. Both the Walsh and Palmer have experienced net increase in pool area of 0.32 and 0.75 km^{2}respectively, suggesting there has been net export of sediment from these streams. Given that these are the sub-catchments that have been subjected to substantial mining pressure, one can speculate as to the role that mining is playing in this pattern.

In total, across the whole Mitchell catchment, there is 17.7 km^2 more bar area in 2005 compared with 1988. In other words, across the Mitchell catchment, there has been an average decline in pool area of 1.04 km^2 per annum over the last 17 years. When converted to a volume, using the moderate 3m estimate of average scour/deposition depth (see Table 9 in main report), this represents somewhere in the order of 3.1 M m^3 of excess sediment deposition within the channel per annum over the study period (or a total of 53 M m^3 over the 17 year period).

FPZ

Vegetation change

Net change towards higher canopy density on floodplains is demonstrated throughout all sub-catchments within the Mitchell. When all the data are aggregated, a total of 2683 km^2 of floodplain (or 13% of the total floodplain area) has experienced a net shift towards a woody vegetation community over the 17 year period 1988 - 2005. If this trend can be independently validated, it represents a significant increase in woody biomass, which could have important implications for ecosystem processes within the Mitchell floodplain.

Gilbert Catchment

ICZ

Vegetation change

As was the case in the Mitchell, the data indicate there has been a large net increase in the area of in-channel vegetation across all sub-catchments. In terms of absolute area this represents a net increase of in-channel vegetation of 12040 ha over the 17 year interval assessed or 19.4% of the total area of the ICZ (62099 ha). This net gain is comprised of a total increase of 16270 ha of in-channel vegetation, which is offset by a loss (via channel erosion) of 4230 ha of in-channel vegetation over the same period. Hence, there has been a considerable turnover of in-channel vegetation during this period. In annualised terms, the net vegetation increase is 708 ha/yr, or 1.14% of the total area of the in-channel zone.

In-channel Sedimentation

Unlike the situation in the Mitchell where there was a pattern of some tributaries showing an apparent net decrease in the extent of sand bars over the study period, all sub-catchments within the Gilbert catchment demonstrate that they have experienced a net increase in bar area, and by inference sediment accumulation over the study period. Respectively, the upper Gilbert, the Gilbert fan, and the Einasleigh River sub-catchments have experienced net bar area increases of 7.82 km^2, 7.64 km^2 and 4.68 km^2. The two smaller sub-catchments only contribute an additional 0.44 km^2.

In total there is 20.6 km^2 more bar area in 2005 compared with 1988. This represents an annual average increase in bar area of 1.21 km^2. When converted to a volume, using the moderate 3m estimate of average scour/deposition depth (see Table 11 main report), this represents somewhere in the order of 3.6 M m^3 of excess sediment deposition per annum over the study period (or a total of 61.8M m^3 over the 17 year period). As outlined previously, there is a need for field validation of the depth of scour data, but by any measure, even using the most conservative estimate, there appears to have been a substantial volume of net bed material accumulation over the study period.

FPZ

The large changes in floodplain vegetation community density identified in the Mitchell catchment are also apparent in the Gilbert. All sub-catchments experienced increases in canopy cover during the study period, albeit dominated by the more moderate increase/decrease categories. In aggregate, a total of 1090 km^2 of floodplain (or 10% of total floodplain area) has experienced a net shift towards a woody vegetation community during the study period. The same caveats outlined for the Mitchell regarding spatial variability of the trends apply, and hence there is also a clear need for more detailed multi-temporal analysis of the trends to verify the apparent trends summarised here.

TRARC

Summary of TRARC approach

The status of riparian vegetation at 172 sites in the Gilbert River and Mitchell River catchments was assessed based on the Tropical Rapid Appraisal of Riparian Condition (TRARC) method. The TRARC method provides data on a number of measurable ecological attributes, such as regeneration of native species, weed distribution and intensity, litter distribution, and ground-cover composition. These attributes can subsequently be isolated and examined with regard to their individual effects on Condition. The method provides a quantified score (0-100) with a higher score implying better Condition. As outlined in Milestone 2 (Brooks et al., 2007), the relationship between these scores and some independent measure of "condition" has yet to be established in the Gulf catchments, and as such we will not use the term condition within this report (notwithstanding the fact that the TRARC method implies we are assessing condition). Instead the raw scores alone will be presented. This is not to say that a higher score may not equate to a better "condition", rather that more work is required to clearly establish this relationship against an agreed definition of ecological condition (or indeed some other type of condition). The allocation of scores, however, does allow for comparison between sites, individual streams and catchments. The TRARC method is organized into 24 measurable indicators which are arranged into the four sub-indices of Plant Cover (7 indicators), Regeneration (5 indicators), Erosion (5 indicators) and Weeds (7 indicators). Either a single indicator, a group of indicators or a sub-index can be statistically analysed to estimate their effect on the overall score. In other words, the score of a particular site can be analysed to see which indicator, or indicators, are having the most impact on the overall score, either as a positive or negative aspect.

This project had two primary aims associated with assessing riparian status:
to estimate riparian status at a number of specific sites using the TRARC method (Dixon *et al*. 2006) for 172 headwater sites in both the Gilbert River (72 sites) and Mitchell River (100 sites) catchments and provide a rating and analysis of those sites.

to test the variability of the TRARC scores for different vegetation cover types [closed forest, open forest, woodland, open woodland] as defined by the remote sensing methodology. Vegetation cover types were determined at 78 sites within the Gilbert River catchment, with 16 closed forest sites, 37 open forest sites, 13 woodland sites and 6 open woodland sites. These vegetation cover class sites will be further developed with regard to spatial analysis independently of the TRARC but with attention to riparian characterisation based on remotely sensed methods.

TRARC Results

Riparian status, as estimated by the TRARC method at the 72 sites in the Gilbert River catchment, scored in the 50-79 range at 90% of sites. It was estimated using a Least Square Fit statistical analyses, that scores of the four sub-indices were influencing the TRARC Condition in a statistically significant manner at all 72 sites combined, and therefore no single sub-index could be identified as the primary influence on the TRARC Condition score. However, within the 16 closed forest sites in the Gilbert River catchment, two sub-indices, namely Plant Cover and Regeneration, had a statistically significant effect on the TRARC Condition score, whilst one, Erosion, had a significant effect but otherwise of a lesser impact than the former two sub-indices, and the third, Weeds, had no statistically significant impact on the TRARC Condition score. On the face of it these results appear to suggest that "condition" can be determined simply on examination of Plant Cover and Regeneration factors, whereas Erosion and Weeds are less likely to have an impact on the Condition score. On the basis of the data collected and analysed thus far, such a conclusion, would be an extremely dangerous one to draw from the overall study, given that it is based on a small subset of the overall data, specifically designed to test the variability of a single vegetation class, as defined from the remote sensing data. Furthermore, there are some major issues of scale that are yet to be sorted out regarding the appropriateness of the erosion indices in the savannah environment. If further work was to establish the broader validity of this conclusion, one implication of it is that remotely sensed data, which can only determine Plant Cover with any acceptable accuracy, may therefore be a cheaper and similarly accurate substitute for ground survey Condition assessment such as that provided by the TRARC method.

The TRARC method records the presence and abundance of weeds at a site: The most prevalent dominant weeds recorded at the Gilbert River catchment sites were Rubber Vine (*Cryptostegia grandiflora*) which was recorded at 27 of the 72 sites, Hyptis (*Hyptis suaveoloens*) (6 sites) and Noogoora Burr (*Xanthium occidentale*) (6 sites).

For the 100 sites assessed in the Mitchell River catchment, TRARC Condition scores were calculated in the 50-79 score range for 85% of sites. The Mitchell River catchment sites were in somewhat more heterogeneous habitats than the Gilbert River sites, and the area can be divided into three distinct areas based on rainfall, soil types, topography and land-use regimes. These different conditions are reflected in the allocation of TRARC scores, the distribution patterns of weeds and the varying impact of the indicators used to derive the TRARC Condition score. The most widespread weed was Guinea Grass (*Megathrysus maximus*) which was recorded at 76 of the 100 sites and distributed throughout the catchment study area. Other significant weeds included Noogoora Burr (*Xanthium occidentale*) at 36 sites, Hyptis (*Hyptis suaveolens*) at 32 sites, and Rubber Vine (*Cryptostegia grandiflora*) at 24 sites. These latter weeds were mainly confined to the Walsh River sites. Both Weeds and Regeneration scores were variable across all sites.

For the 16 closed forest sites in the Gilbert River catchment, riparian status scores fell within the 65-100 range. Canopy cover was recorded as approaching 100% thus confirming the prediction by remotely-sensed data that the sites were indeed closed forest. The dominant canopy tree species were She Oak (*Casuarina cunninghamiana*) and Broad-leaved Paperbark (*Melalueca leucadendra*), which together accounted for about 86% of total canopy cover. Other widespread canopy species included River Red Gum (*Eucalyptus camaldulensis*), Narrow-leaved Paperbark (*Melaleuca trichostachya*) and Swamp Oak (*Lophostemon grandiflorus*). Despite the wide-spread distribution of these latter species, they accounted for less than 8% of total canopy cover because of their smaller stature or narrow crowns, or were otherwise very scattered within the catchment. The TRARC scores for the closed forest sites were all within the 65-100 score range [average of 77.15/100] , and were within the upper 40% of scores for the total 72 sites in the Gilbert River catchment [average of 65.87/100].

General Conclusions

The vegetation changes detected via the remote sensing analysis are larger than we would have anticipated in this landscape, given the relatively short interval between the snapshots analysed.

It is acknowledged that the remote sensing analysis carried out as part of this study is a first cut at quantifying riparian status within the Northern Gulf region, and requires further research to verify the findings from this initial, relatively simplistic analysis.

Nevertheless, the fact that we have observed such dramatic changes in woody vegetation cover both in the channel zone and across floodplains, warrants much more detailed investigation to establish: a) whether the trends elucidated in this study are real; and b) what the drivers of the changes are (i.e. is there a clear trend through time or is there some variability that is a function of inter-annual climatic variability).

Our initial assessments of the drivers of change highlight a number of issues:

- Rainfall may be an important driver in the Mitchell catchment, but in the Gilbert the influence of rainfall variability through time is less clear.
- More fire data (i.e. a longer time series) is required to determine the relative influence of the fire regime on patterns of vegetation community change.
- There appears to be a fairly strong correlation between land use intensity (as measured by a derived road density index – Fig 14) and in-channel sedimentation. Whether there is a causal link here is yet to be determined, but it would be consistent with relationships established in other regions.
- The two different approaches to riparian condition assessment trialled in this project complement one another well, but individually are applicable at entirely different scales and resolutions and for different purposes.
- TRARC's strengths are in repeat sampling of sites that are known to be relatively geomorphically stable, but which may be experiencing local or upstream cumulative impacts (or improvements), and where data on trajectories of change are needed. Ideally the TRARC approach is more appropriate in smaller headwater streams, but it does have some

application on larger high order rivers, at strategic (geomorphically stable) locations where it is deemed desirable to track changes in weed invasion, recruitment success, or pasture composition/health.

- The strength of the remote sensing approach is that it can be applied over large areas, and unlike a field monitoring program, can be used to assess historical changes in riparian zone status.
- The obvious weakness of the RS approach is that at the resolution applied (~ 25m pixels) much of the finer detail of the ecosystem processes are not detectable.
- On its own, TRARC is not an appropriate method for undertaking regional assessment of riparian condition in large areas like the Northern Gulf.
- The TRARC protocol in its standard form is not an appropriate ground validation method for a broader scale remote sensing (RS) analysis. A ground validation method tailored to the needs of the RS approach is required.
- TRARC is, however, a valuable tool for site specific monitoring, and for assessing ecosystem processes that can't be observed via a moderate resolution remote sensing exercise.

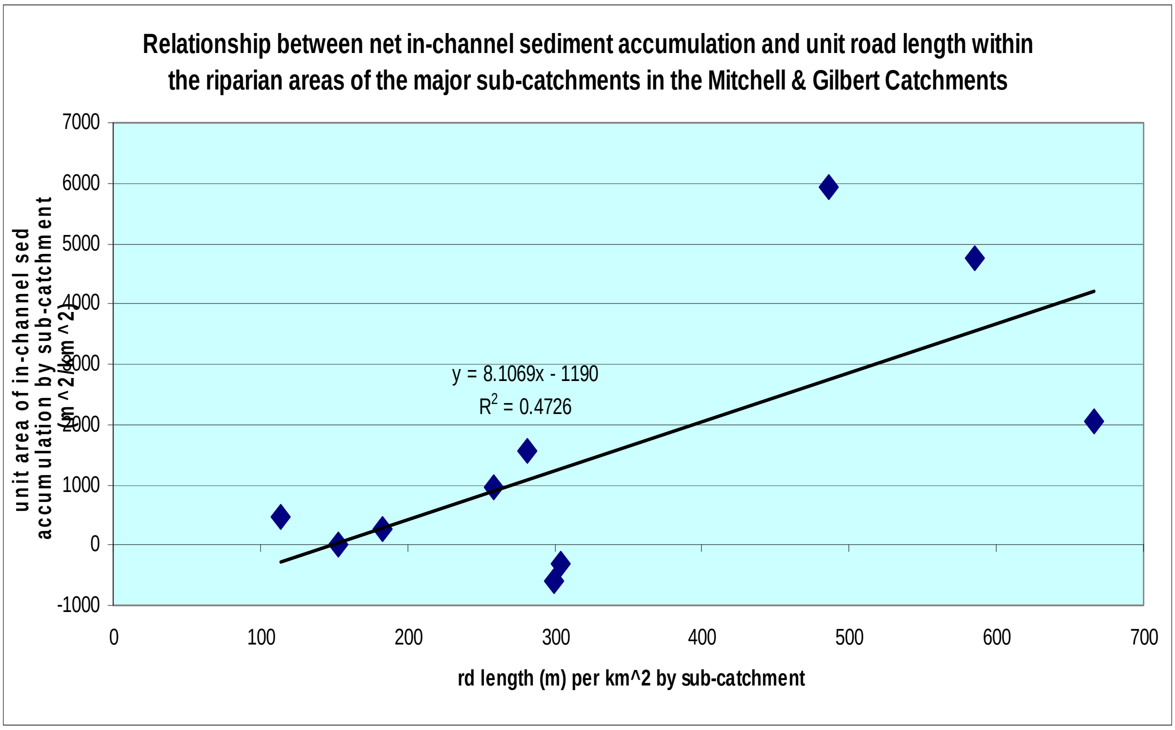

Figure 14 Relationship between unit road length (i.e. land-use proxy) within each sub-catchment, and net change in pool/bar extent (per unit sub-catchment area) for all subcatchments in the Mitchell and Gilbert Rivers. Note that the Mitchell & Gilbert Fans have been left out of the analysis, as it was assumed that these receive the cumulative impacts of the upstream contributing sub-catchments, and a direct relationship between fan land-use intensity and channel change, would not be expected.

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1 Project background:

1.1 The Importance of Riparian Zones

Riparian ecosystems are those vegetation and other biological communities associated with rivers, creeks and other riverine or lacustrine habitats. Numerous definitions exist for the precise extent of the riparian zone, and as outlined below we cannot find any that have been derived specifically for savannah landscapes. Nevertheless, it is generally considered to comprise the alluvial landforms and their associated ecosystems that are regularly inundated by floodwaters, and are dependent on river flows for at least part of their life cycle (Malanson, 1993). This definition must include the in-channel zone (although this is rarely stated explicitly) as well as the channel margins and the floodplains. Thus in some parts of the Northern Gulf, the riparian zone can represent a large proportion of the landscape. Even where a precise theoretical hydro-geomorphic definition of the riparian zone is arrived at, in the savannah landscapes of the Northern Gulf it is often very difficult in practice to accurately designate the area encompassing the riparian zone. This is in part due to the sparse hydrologic gauging network in the region, and hence the incomplete knowledge of flood magnitude and frequency throughout the landscape, but is also a function of the complex hydrologic processes producing flooding in this region. Furthermore, the limited availability of accurate digital terrain data, coupled with the incomplete hydrologic data, limits our ability to constrain the relationship between flow and inundation extent at any one site. In some instances, riparian zones define themselves by the suite of vegetation that is adapted to the hydro-geomorphic conditions within the fluvial landscape, but in the majority of cases lateral zonation of the riparian zone is indistinct.

Riparian zones form the critical interface between riverine and terrestrial systems and have been described as '*the most diverse, dynamic, and complex biophysical habitats on the terrestrial portion of the earth*', because of the multifaceted interactions between fluvial and terrestrial processes, acting across a range of spatial and temporal scales (Gregory *et al*. 1991; Naiman *et al*. 1993, 2000; Pusey and Arthington, 2003). Riparian ecosystems are especially important in the dry and wet-dry tropics where they hold much higher biodiversity and biophysical values than surrounding ecosystems. Riparian vegetation contributes a range of functions to river systems, from bank stabilisation, as a nutrient source for both aquatic and terrestrial ecosystems, as thermal and light regulators through the shading they provide to aquatic and riparian habitats, and through the provision of physical habitat (e.g. for birds, arboreal mammals, as sources of wood to streams etc, Robinson, et al., 2002; Buckton and Ormerod, 2002; Pusey and Arthington, 2003). Riparian zones also tend to be the most ecologically and economically productive parts of the landscape. However, as focal areas for livestock, humans and other threats, these ecosystems are often quite degraded or under threat of degradation, from a variety of sources. As they tend to integrate the combined impacts of upstream disturbances, riparian zones are often heavily impacted by weeds, as well as sediment and nutrient inputs. Indeed riparian ecosystems are thought to be the most highly degraded and/or threatened ecosystems in many parts of the region. However, at present no baseline has been established by which to objectively determine this, nor does an appropriate methodology exist, that has been fully validated, for measuring the ongoing condition of riparian zones in this region. As such it is critically important that an objective methodology is developed for assessing riparian condition, which is suitable for this region, and that accommodates the inherent variability of the region's riverine landscapes.

1.2 Why Monitor Riparian Condition?

Riparian ecosystems hold special values to a large proportion of the community across all stakeholders. They are particularly important for grazing enterprises, but are most neglected in many other areas (eg, irrigation and urban areas); they also hold special social and cultural values (eg, swimming, picnicing, indigenous values), in addition to providing many of the ecosystem services outlined above. Protecting riparian systems, usually through fencing of creeks or springs, is one of the most common activities undertaken through Envirofund and other devolved grants, indicating how highly regarded, and how important these ecosystems are for management.

Knowing that riparian systems are being well managed and not degraded is thus of importance to the whole community. Providing the results of a condition assessment study that covers a considerable area of a catchment is thus a good way of demonstrating this. Other benefits include:

- a means for individual landholders to know the condition of their riparian systems and how they compare to surrounding sites
- demonstrating to the wider community outside of the Northern Gulf that landholders are protecting these important ecosystems
- helping to prioritise sites that would most benefit from funding assistance through the devolved grant scheme
- locating outliers of existing weed infestations that require treatment and infestations of new weeds (i.e., weed detection system)
- links in with condition assessment of grazing lands undertaken through the Grazing Land Management (GLM) program and its successors (Shaw et al., 2007).
- increases peoples awareness of riparian condition (including over wider areas, not just their own property) and thus makes them likely to adopt better management practices to protect such areas

- Increasing peoples awareness of how connected they are via the rivers, to land management activities occurring upstream

In addition, land management is a major aspect of the Northern Gulf Regional Investment Strategy (RIS), and it is incumbent upon the NGRMG to demonstrate, as part of Monitoring and Evaluation, that these investments have resulted in tangible on-ground improvements. Just as the GLM program, among other goals, provided a baseline assessment of pasture land condition to demonstrate future improvements, riparian condition assessment is also required to demonstrate their changing (hopefully improving) condition.

The benefits and rationale of riparian condition assessment (RCA) are similar to those of assessing the condition of grazing lands as has been done under the GLM programs in the Northern Gulf. It is a fundamental tenet of natural resource management that you can't manage what you don't assess and monitor!! The existing GLM program does not provide adequate assessment of riparian ecosystems as the attributes of good condition for riparian systems are quite different to those of pastures. However, riparian condition assessments will complement GLM land condition assessments. A critical difference between RCA and GLM – is that GLM tends to be about managing land at the individual enterprise level, largely for the benefit of that enterprise (although obviously also contributing to the collective health and prosperity of the region). Riparian zone management, however, has implications that cut across enterprises and indeed the whole region, due to the connective nature of river systems. The benefits of best practice riparian management in the upper parts of the Mitchell River catchment, for example, have implications for all downstream riparian landholders, the Kowanyama Aboriginal community at the bottom of the system, and potentially commercial fishers in the Mitchell estuaries and the Gulf itself. Hence it is critical to get the management of these areas right!

1.3 Original Project Aims

Given the importance of riparian zones to regional ecosystems and economies (through the ecosystem services they provide) the aims of this project were as follows:

- To develop a robust definition of the extent of the effective riparian zone for different river reach types (i.e. geomorphic reach classes) in the Northern Gulf Region
- To identify a small set of metrics for quantifying riparian condition, that can be measured using remotely sensed data (e.g. 4 – 6 parameters)
- To develop a broad scale method appropriate for the Northern Gulf region for quantifying riparian condition using remote sensing techniques
- To assess the extent to which these metrics vary with geomorphic river reach type
- To assess the applicability of a reference reach approach in the Northern Gulf region
- To assess the need to modify existing TRARC protocols for the different river reach types found in the Northern Gulf region
- To undertake TRARC assessments using a spatially stratified sample design based on reach geomorphology in the Mitchell and Gilbert Rivers
- To provide an example of a fully integrated remote sensing/on-ground survey approach for assessing riparian condition in the Gulf Savannah.

As outlined in this report and interim milestone reports (Brooks et al., 2007a; Lymburner et al., 2007), some of these original aims were found to be unachievable given the current state of knowledge about riparian zone functioning and dynamics in the wet/dry tropics. Hence, it is not possible to develop definitive metrics for measuring riparian "condition", until we have a better understanding of baseline riparian dynamics and functioning. For this reason t*he* ***focus of the analysis shifted towards establishing a baseline from which future changes can be measured, and towards developing a remote sensing based approach for measuring structural riparian vegetation changes through time***. A refined and refocused set of objectives were subsequently defined:

- To develop a definition of the extent of the riparian zone applicable to the Northern Gulf Region (Mitchell and Gilbert Catchments)
- To develop a broad scale method appropriate for the Northern Gulf region for quantifying riparian condition using remote sensing techniques
- To assess the spatial variability of riparian condition
- To assess the need to modify existing TRARC protocols for Northern Gulf rivers
- To undertake TRARC assessments in selected reaches of the Mitchell and Gilbert Rivers
- To assess the appropriateness of integrating a remote sensing approach for assessing riparian condition in the Gulf Savannah with the existing on-ground survey approach (TRARC).

1.4 What is Riparian Condition in Savannah Environments?

At the project outset it became readily apparent that there is insufficient baseline understanding of the biophysical dynamics of rivers within the Northern Gulf to define what represents "good" or "bad" condition. There are clearly degrading processes or disturbances that can be identified, such as weed invasion, gully erosion, grazing pressure and human infrastructure like roads and dams, but the extent to which we can emphatically state that any of these are degrading the condition of the rivers is unclear. Some of these disturbances, such as dams and weed infestations, have more readily quantifiable impacts than others (eg. gullying and grazing), albeit at differing scales, but there are questions as to whether some of these pressures can be adequately mapped across whole catchments within the constraints of a project such as this.

There are also some accepted dogmas within the riparian condition literature (most of which has been derived from humid temperate regions) that are unlikely to be directly transferable to Gulf Rivers. For example, vegetation "condition" is generally considered to increase as the areal extent, longitudinal connectivity and density of the woody vegetation component of the riparian zone increases. However, in savannah landscapes there are real questions as to whether some riparian environments ever contained continuous expanses of woody vegetation. Savannah grasslands may well have been the dominant vegetation type in some areas, and this inherent dynamic of the riparian landscape must firstly be understood and appreciated before condition rating can be applied. Furthermore, there may well be some circumstances where an increase in vegetation density and extent represents a degrading condition, particularly where weeds are involved, but also where some native species have been provided an advantage at the expense of grasses, through grazing pressure (*sensu* Crowley and Garnett, 2000, Fensham, et. al., 2005). There are also real questions regarding the extent to which extensive gully erosion that exists throughout large tracts of the northern Gulf landscape are a natural or an accelerated phenomenon. This is an ongoing research question being tackled in a separate project (see Brooks et al., 2007b; Knight et al., 2007), but it is unlikely that we can emphatically state that all erosion is bad. This landscape has a long history in which high sediment loads were a natural part of the landscape dynamic, and indeed the floodplain, estuarine and marine ecosystems may be dependent on certain sediment loads. It was also recognised that riparian vegetation dynamics will vary significantly depending on reach geomorphology and the availability of groundwater or base-flow during the dry season.

The notion of "condition" also implies that one has an appreciation of the trajectory of the change within the vegetation community and the reach geomorphology. Hence, in the absence of historical insights into the pre-existing state of the riparian landscape, it is only really possible to establish the contemporary state, from which future states can be compared and condition subsequently inferred once greater insight is gained into the degrading processes and their impacts on aquatic and riparian ecosystems. Some insights into the former state can be gained through analysis of historical remotely sensed imagery, however, insights into *condition* based on these data can only be inferred based on an understanding of contemporary dynamics. It must also be recognised that the remote sensing data only spans the last few decades, and hence the longer trajectory of change may be masked by the particular climatic, flow regime and land use patterns within this period. Hence, at this stage of the process, it makes sense to devote the majority of resources into the development of the best techniques for establishing contemporary status, as the basis for subsequent condition assessment.

Despite this apparent pessimism, there certainly are some universal truths regarding degrading processes in the riparian zone that will be applicable in the northern Gulf. For example, direct clearance of riparian vegetation is undoubtedly a degrading process wherever you are. Similarly, weed infestations are a degrading process as they compete with and displace native species and alter the terrestrial and aquatic ecosystem dynamics. Evidence for ongoing recruitment of native riparian vegetation species is certainly a *good* sign that the system is resilient, and that natural ecosystem processes are still functioning. However, it is not evidence that the precise balance of ecosystem processes is unchanged from that which has been operating over millennia.

For the purposes of this study, a broad view of the measurement of riparian status has been adopted, in keeping with the broad definition of the riparian zone (below). While most riparian condition assessments focus exclusively on the status of the vegetation, in this analysis we will also consider sediment dynamics within the channel as this has a fundamental bearing on the in-channel riparian habitat, and the associated vegetation dynamics.

Figure 1 A typical section of the riparian zone on the main stem channel of the Mitchell River, showing infrastructure development (not common within the region), extensive gully erosion (very common), and evidence of rubber vine invasion with the channel zone (some of the brighter green tinges – increasingly prevalent). Note how the land down slope of the gully front (to the right) in the bottom left hand corner of the image is dominated by woody vegetation whereas the ungullied land to the left is dominated by grassland. According to the prevailing perceptions of "good condition" riparian land, the area with more trees would be regarded as in better condition – but is it?

1.5 Definition of the riparian zone.

A crucial first step in developing a method for monitoring riparian condition is to define the portion of the landscape that we are concerned with. Developing a universal definition for riparian zones in savannah landscapes, which can be applied in an objective fashion, based on existing data, is not a straight forward task. Hence, a pragmatic approach was required that could be readily applied but that still maintained a relationship with underlying biophysical processes. A review of the literature indicates that there is no generally accepted definition of the riparian zone that can be applied universally to rivers in savannah landscapes. Consequently a definition of the riparian zone has been derived specifically for this project based on a review of the literature and the grey/web derived literature, coupled with our experience from the landscape in northern Australia. As a starting point, a brief overview of definitions draw from the literature is outlined.

Definitions of **Riparian Zone** on the Web:

- The land and vegetation bordering flowing or standing water (streams, rivers, lakes and ponds).
  edis.ifas.ufl.edu/FR063
- A terrestrial area adjacent to, and influenced by, a perennial body of water. Riparian zones provide a functional link between terrestrial and aquatic ecosystems through coarse and fine organic matter input, bank stability, water temperature regulation, sediment and nutrient flow regulation, and maintenance of unique wildlife habitat.
  www.sevenislands.com/General_Terms.htm
- The transition zone between the water and the upland zone. Can be identified by specific types of plants and soils.
  fishandgame.idaho.gov/fish/glossary/
- In hydrologic terms, a stream and all the vegetation on its banks.
  weather.gov/glossary/glossary.php
- The area of land from the shoreline of a river or lake to roughly 30-60m inland. This habitat supports a wide variety of species dependent on water systems including raptors.
  www.cbfishwildlife.org/glossary/index.php

- A strip of land where disturbance is not allowed or is closely monitored to preserve or enhance aesthetic and other qualities along or adjacent to roads, trails, watercourses and recreation sites www.ifdn.com/teacher/glossary.htm
- The channel margins (or banks) which form part of the floodplain. www.heritage.gov.au/anlr/wild_riv/guide/appendix2.html
- The band of land beside a stream or other waterbody. A well-vegetated riparian area is important for a number of reasons. The root systems of stream-side plants provide stability for the soil, helping to prevent erosion. The overhanging plants provide cover for protection, shade to maintain cool water temperatures, and food for fish and wildlife. Stream-side plants also help to filter surface water flows to water bodies, especially sediments.
  www-heb.pac.dfo-mpo.gc.ca/water_quality/fish_and_pollution/glossary_e.htm
- This is the land adjacent to and along a river or stream. When a riparian area has a natural vegetative cover it serves a buffer between the upland and water course.
  www.mass.gov/dfwele/river/rivlow_flow_inventory/glossary.html
- The land area along either side of a waterway, often habitat for plants adapted to wet soils and animals that use the waterway and this zone for their food and shelter.
  www.hamiltonnature.org/habitats/glossary.htm

Many of the definitions summarised here, which probably represent the majority view of managers and many river scientists, are derived from headwater zones of rivers in the humid temperate zones of the northern hemisphere. This view generally assumes that the riparian zone includes only a relatively narrow strip of land along the watercourse, with some also qualifying that it must be a perennial watercourse. The environments from which most of these definitions are derived are entirely unrepresentative of Gulf rivers. So while we can take some of the aspects of these definitions and apply them to the northern Gulf, it makes little sense within the Gilbert and Mitchell fans to apply a definitions that delineate between the "upland" and the aquatic zone, or that confines itself to perennial streams.

In his book on riparian landscapes, Malanson (1993, p 9) adopts a much more inclusive definition of the riparian zone than most of the examples above. Malanson (1993) includes the whole floodplain, inferring that the narrow strip view of the riparian zone is far too restrictive from an ecological point of view. However, he also concludes that the concept is not simply encapsulated by the term "floodplain" as this would leave out the strip of vegetation within bedrock confined rivers, and other channel types that do not possess a "floodplain" in its generally accepted form.

In Australia, and particularly northern Australia, Malanson's view of the riparian zone is far more appropriate than the restricted riparian strip definition. This is underscored by the fact that the Land & Water Australia Riparian Program (LWA, 1998) adopted a definition very much in keeping with Malanson's view. Their definition states that a riparian zone is: "Any land which adjoins, directly influences, or is influenced by a body of water".

This definition includes:

1. the land immediately alongside small creeks and rivers, including the riverbank itself;
2. gullies and dips which sometimes run with surface water (i.e. ephemeral streams);
3. areas surrounding lakes; and
4. wetlands on river floodplains, which interact with the river in times of flood.

So in essence this is an extremely inclusive definition, that includes the land within the channel, a strip of land adjacent to the channel, all the land inundated or potentially inundated by overbank flows adjacent to a river (i.e. the floodplain and the wetlands incorporated within it), ephemeral channels and gullies. While this definition does not explicitly define the lower limit (the smallest component) of the drainage network that should be included in the riparian definition – it implies everything down to the smallest definable drainage line (1st order channels) should be included.

1.6 Delineation of the 'Riparian Zone' for this Project

To understand how the riparian zone was defined it is first necessary to give a brief description of the two catchments in which this study is focused. Both catchments can be divided into two broad regions: the uplands, which are characterised by relatively high terrain relief, bedrock or bedrock constrained channels with some alluvial fill valleys upstream of bedrock constrictions; and a megafan (sensu Horton and DeCelles, 2001; Leier et al., 2005) which dominates the lowlands, and which is characterised by a sequence of nested low gradient alluvial fans. Within the megafan there is a network of channels, palaeo-channels, billabongs and wetlands. As outlined above, we have adopted a very inclusive definition of the riparian zone, which in total we refer to as the **alluvial zone**. However, in recognition of the fact that there are some distinct geo-ecological process zones within this broadly defined alluvial zone, we have differentiated the broad riparian zone into three sub-zones: 1) the **active channel zone** (i.e. the zone which shows geomorphic evidence that it has been occupied by the river channel in the recent geomorphic past); 2) the **in-channel zone**, or the zone encompassing the portion of the current channel that is actively conveying bedload material under the current flow regime); 3) the **floodplain** – the remainder of alluvial land not encompassed within the other two categories (which as outlined below is not necessarily synonymous with the land that is inundated by the current flood regime – i.e. it may also include alluvial sediments deposited under a former flood regime). The spatial relationship between these three zone is shown in Figure 3.

1.7 Defining the Alluvial Land Zone

Terrain analysis techniques such as MrVBF (Gallant and Dowling, 2003) have been used in previous studies to identify valley bottoms, which it is assumed are good approximations of floodplains/alluvial deposits. While the MrVBF algorithm can be used reasonably effectively in the upper parts of the catchment to identify the alluvial zone, such techniques do not provide useful information on the alluvial plains in the Mitchell catchment, because of the low gradient and low relief, and the sometimes inverted relief, where the channel is higher than the surrounding landscape. Consequently the outputs from the MrVBF algorithm were incorporated with additional layers to identify the 'riparian zone' for both catchments. The following table describes which map products were used and why they were included.

- **Multi-resolution Valley Bottom Flatness Index (MrVBF)** The MrVBF algorithm described in Gallant and Dowling, 2003 was applied to 90 metre Space Shuttle Radar Topography Mission (SRTM) data. The resulting map identifies depositional valley bottom soils and floodplains. Some of the valley bottom soils may not experience flooding under the current climatic regime, however land use/land cover changes in these areas will impact on fluvial and riparian processes.
- **1:250K topographic series -** A fixed width buffer of 200 metres width was applied to all named streams on the 1:250K topographic series mapping within the Mitchell and Gilbert catchments. Land use/land cover changes within this area are likely to impact directly on the fluvial and riparian processes.
- **Areas inundated during the TC Nelson flood event (Feb 2007)** The extent of post TC Nelson flooding was mapped using daily MODIS 250 metre and 500 metre data. Land use/land cover changes within this area will impact on and be impacted by flooding and sediment transport dynamics.
- **The alluvial/deltaic fans** The bottom, or western half of both catchments are dominated by extensive alluvial/deltaic fans that are subject to complex patterns of inundation due to floodwaters from up-stream as well as locally generated floodwaters (*i.e.* flooding from heavy rain falling directly onto the floodplain). The entire fans for both catchments were included in the overall 'riparian zone'. These fan areas will be broken up into smaller sections for the purposes of analyzing the results but are all included in the overall riparian zone. The fan areas were delineated by using a combination of the geologic mapping (Quaternary alluvium), the 30m DTED DEM , and mapping by Grimes and Douch (1978).

The riparian zone is defined by combining these input layers as shown in Figure 3

1.8 Maximum Fan Extent of Riparian Zone (the alluvial zone)

The ideal approach for understanding the area of maximum inundation within large floodplain systems like the Mitchell and Gilbert Rivers is to use direct observation of flood inundation using satellite imagery. Unfortunately, it is rare in this part of the world to obtain good quality (affordable) cloud free visible imagery when these rivers are in flood. Alternative image sources such as RadarSat tend to be prohibitively expensive. Available visible imagery, therefore, represents an unreliable method for floodplain inundation mapping, but a very good one if the appropriate conditions do occur and cloud free imagery becomes available. Fortunately in February 2007 we were lucky enough to have the combination of a relatively large flood on the Mitchell and to a lesser extent the Gilbert Rivers, and some cloud free conditions during the flood peak. The resulting images (Figure 2) provide good evidence that the Mitchell fan consists of several components, with a more active contemporary flooplain/fan inset within the larger fan complex. However, the imagery also shows that while overbank flows derived from the primary channel will not inundate the entire fan complex, that large areas of the higher elevation segment of the fan (i.e. the section not inundated by sediment laden cyan coloured water) are inundated by locally derived non-sediment laden black water. As such, a floodplain modelling approach that assumed riparian land was only associated with primary channel network derived overbank flows, would not include the higher elevation portion of the fan. Yet this land clearly functions as riparian land, albeit with flows derived from direct floodplain precipitation, and should clearly be included in any broadly defined riparian land.

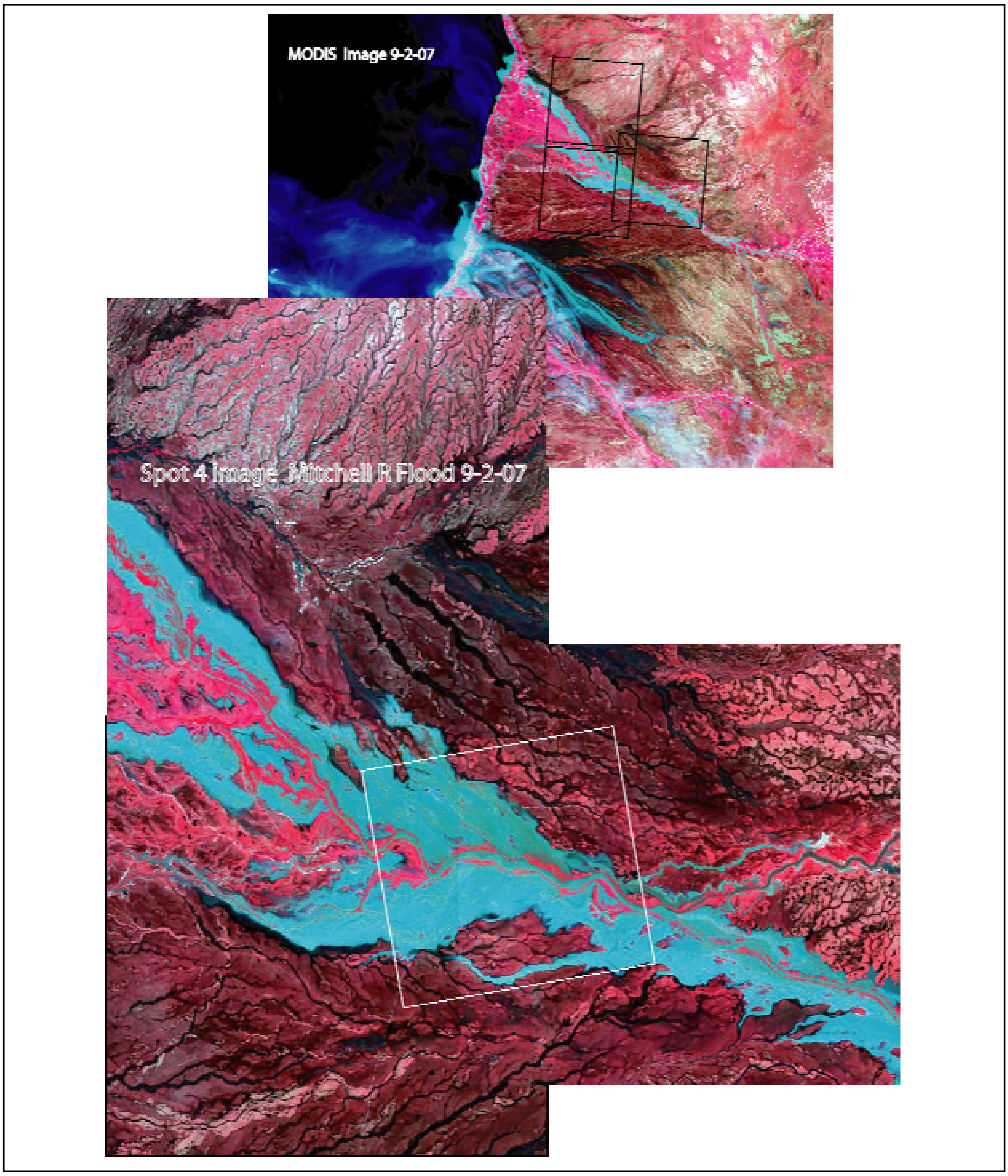

Figure 2 Floodplain inundation associated with T Cyclone Nelson, February 2007. The white box overlying the Spot4 image is approx 40km square. The black boxes on the MODIS imagery shows the approximate location of the Spot4 tiles.

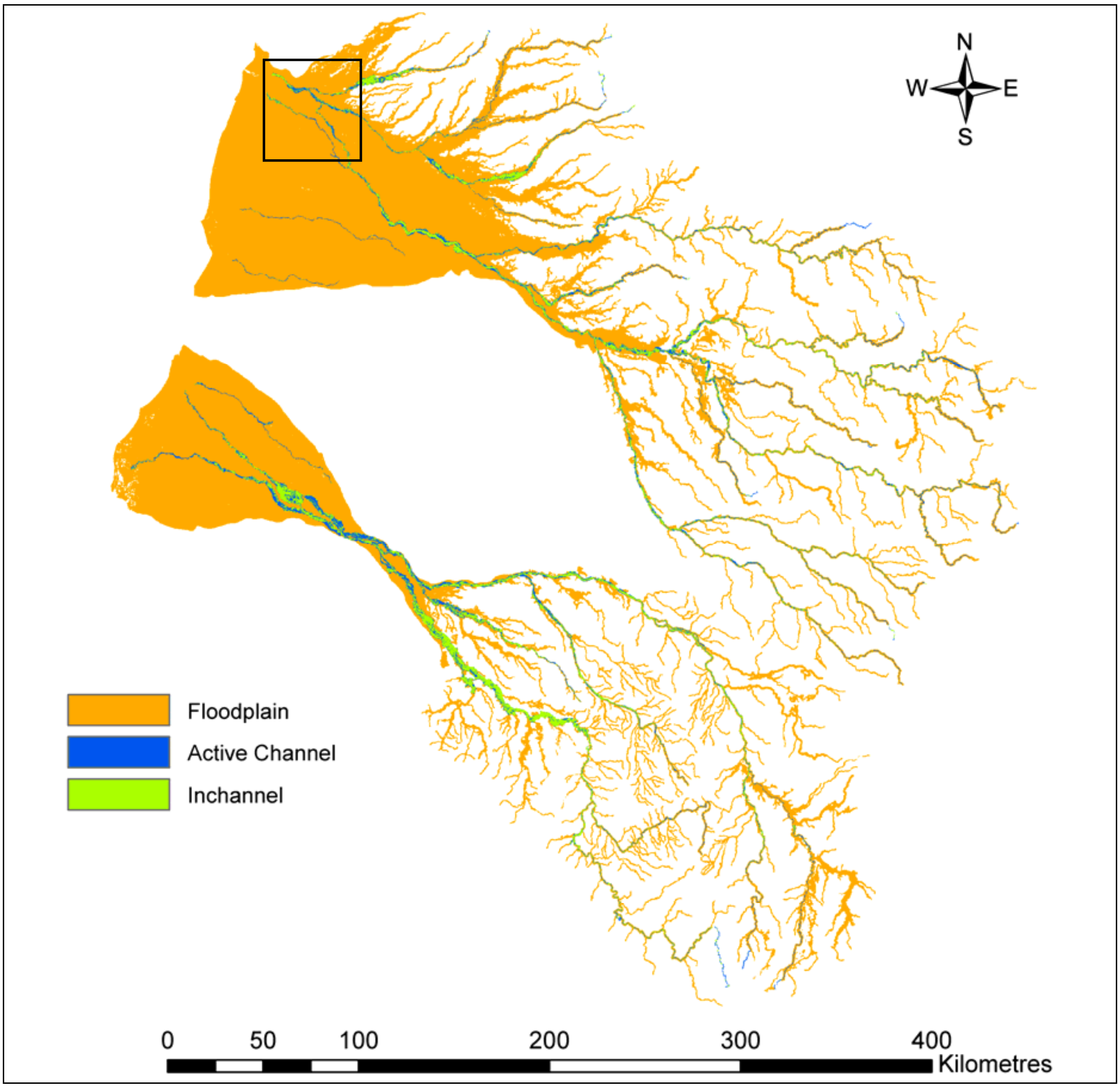

Figure 3 Map showing the three categories of riparian zone analysed within this study. The box indicates the area shown in the blow up (figure 4).

Zone 1) – The Active Channel Zone (ACZ)

The active channel zone encompasses the stream banks and surrounding areas where vegetation is markedly influenced by the availability of river water, and in which there is clear surficial geomorphic evidence that in the recent past (100s-1000s yrs) the active channel has occupied some portion of the land within this zone. This is the zone that landholders may consider to be 'frontage country'. It represents an area that is influenced by fluvial processes, grazing pressure and fire frequency. As a consequence of this isolating the causes of land cover changes that occur in this area can be challenging.

The ACZ was defined based on manual delineation from the Landsat TM mosaic for all channels defined by the 1:5M drainage network. The manual delineation was based on a visual assessment of imagery to identify vegetation with a higher canopy cover than the surrounding landscape, or distinct fluvial forms such as meander bends and palaeo-channels.

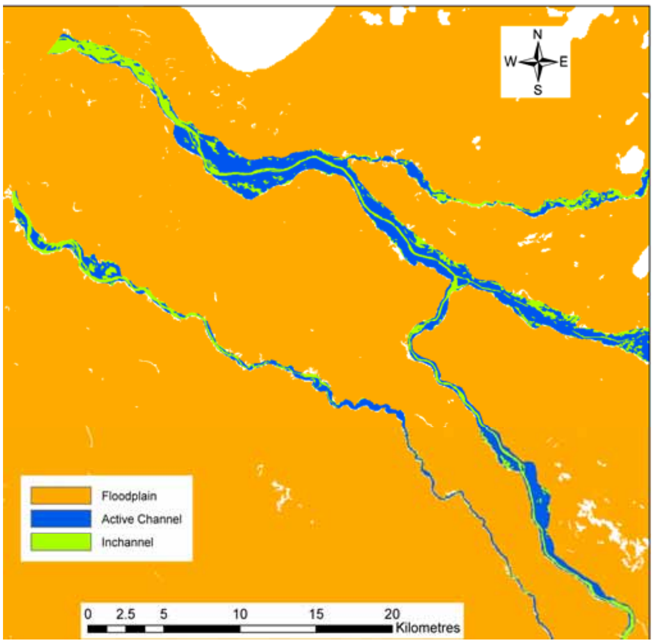

Figure 4 A higher resolution blow up of the box in Figure 3, highlighting the distinction between the in-channel zone (i.e. the portion of the channel that is inundated and reworked every year) and the active channel zone. Note that because this is defined from classified Landsat imagery, there is some ambiguity between the two classes in the area broadly defined by the active channel zone.

Zone 2) – The In-Channel Zone (ICZ)

The in-channel zone refers to that portion of the stream/river between the stream/river banks. This area receives flow during most wet season flow events. This is also the area that landholders are likely to consider to be 'the river'. This zone includes the large sand bed features found in the lower reaches of the Mitchell and Gilbert catchments. This zone is dominated by fluvial or 'river-based' processes. As a consequence, changes that occur in this region will be associated with fluvial processes. For example in-channel vegetated islands can be washed away during major flood events, resulting in a change from vegetation to river sand. The amount of sand present in the in-channel zone may have changed as a result of anthropogenic activity further up in the catchment, however any changes that are observed in the in-channel zone are likely to be the result of fluvial (as distinct from fire, grazing or climatic influences).

The ICZ was identified based on the following criteria, the in-channel zone was contained within the active channel zone (defined above). The ICZ was defined by the presence of water in either 1988 or 2005, or the presence of river sand in either time. Islands of vegetation that were surrounded by either river sand or water were included into this definition of the in-channel zone.

Zone 3) – The Floodplain

The floodplain represents the remainder of the riparian zone (i.e. the alluvial zone), and includes all areas that are subject to flooding or have evolved through fluvial deposition. The causes of land cover change in these zones tend to be more complex, often dominated by grazing and fire regime, with flooding playing a smaller, but still important role. The distribution of the three zones is shown in Figure 3. In some upper catchment areas the ACZ and floodplain are difficult to distinguish from one another, and are consequently combined into a single floodplain category. This is the case in the Upper Mitchell River, the Palmer River, Mid Mitchell Tributaries, the Etheridge River, Upper Gilbert River and Dismal Creek.

For the purposes of this study, it has been necessary for practical and logistical purposes to limit the extent of the drainage network that will be assessed in the study – both from the point of view of the constraints imposed by image resolution for undertaking a remote sensing analysis of riparian condition, as well as the practicalities of validating our assessment on the ground. As this type of work has not been previously undertaken at this resolution across large areas in northern Australian, this project has been undertaken as a "proof of concept" over a manageable proportion of the drainage network. Consequently we have limited our mapping and assessment of the in-channel and active channel zones (see below) to just the main stem channels and large tributaries of the Mitchell and Gilbert Rivers. The 1 in 5M drainage network mapping (see Figure 5) provides a good approximation of the main channels in the Northern Gulf.

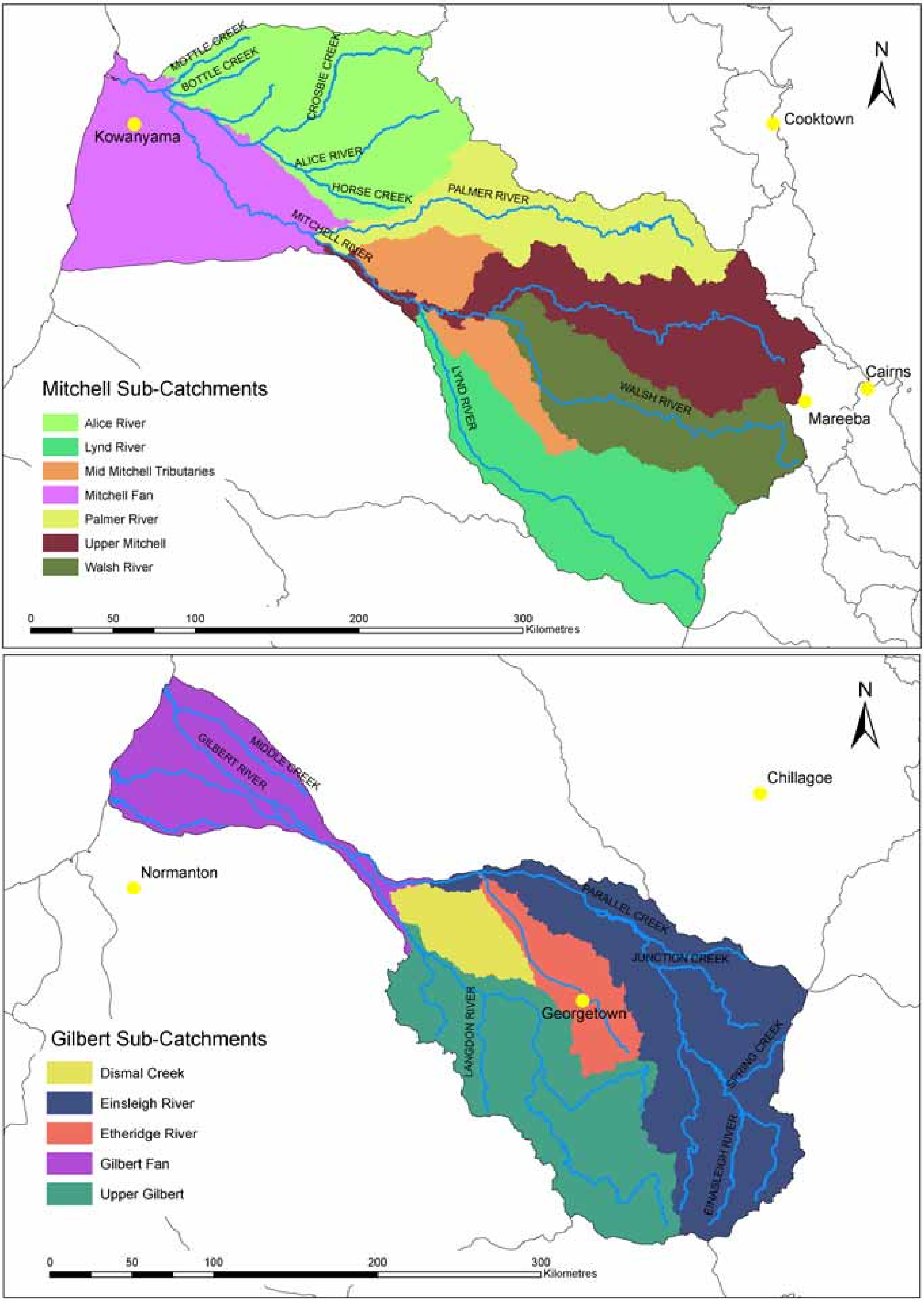

Figure 5 The Mitchell and Gilbert catchments showing the reporting Sub-Catchments and the two large fans which dominate the lower reaches of each catchment. The riparian zone is delineated into three sub-zones within the fans and two zones within the remainder of the catchments.

1.9 Sub-Catchment Delineation

The two focal catchments were divided into a series of sub-catchments for the purposes of reporting, and for delineating the fans from the geomorphically distinct remainder of the catchment that contains bedrock valleys and more confined floodplains (Figure 5). The sub-catchments have been derived using the standard hydrological analysis tools (i.e. the ArcHydro plug-in from the University of Austin Texas) within ArcGIS using the 90m SRTM digital elevation data.

2 Overall Study Design

As originally conceived, this project was to take an existing method for rapid ground assessment of riparian condition in tropical rivers - the TRARC (tropical rapid assessment of riparian condition, Dixon et al., 2005), and to develop a method for extrapolating the on ground point data over a wider area based on a remote sensing analysis (*sensu* Johansen et al., 2007). It soon became apparent, however, that while it may be possible to undertake such an exercise in a relatively confined section of a “well behaved” river, using high resolution Quickbird imagery (e.g. Johansen et al., 2007) that it is an entirely different proposition to scale this approach up by several orders of magnitude using coarser resolution LandSat imagery. The mismatch of scales between an on ground assessment across a 100m x 5m quadrat, and a LandSat analysis across tens of thousands of square kilometers of highly diverse riparian landscape, renders any such integration of these approaches as meaningless.

It had also been hoped at the project outset that the TRARC type field assessment could form a basis for ground validation of the remote sensing data. Again, however, it was found that the scale of the on-ground TRARC assessments, as well as the site selection criteria, was completely mismatched for what would be required to adequately perform a remote sensing ground validation analysis. A different approach was required for this task. Nevertheless, both approaches were still regarded as having their merits, but the sorts of questions one can address varies considerably with each approach.

For this reason, both methods have been retained within the study, and while they are separate analyses of riparian condition, addressing a different suite of questions, we believe they are complementary. The sorts of questions that can be addressed using the two approaches are summarized:

TRARC approach.

- Does a specific site show evidence of riparian ecosystem degradation as a result of weed invasion, clearing, over grazing?
- Does a specific site show evidence for system resilience? Is there new recruitment of native plants?
- Do successive surveys at the same site indicate that the riparian ecosystem is becoming more or less infested with weeds through time?
- Are basic ecosystem functions such as litter production, LWD production, shading etc., changing through time?

Remote Sensing approach

- Does the whole riparian landscape demonstrate there has been a shift over time (i.e. through time series analysis of satellite imagery) in the riparian vegetation community structure or community patch dynamics?
- Is there evidence of increasing/decreasing riparian cover or erosion through time?
- Is there evidence for sustained sedimentation of in-channel pools through time?
- Is there evidence for a change in river channel dynamics within the timeframe of the available data?

Separate analyses are then required to determine the causes of any detected changes at each resolution between successive surveys. Furthermore, identifying the causes of such changes may not be answerable at the scale at which the analysis was performed. The drivers of the change may be operating at broader or finer spatial scales. Hence, it is crucial that multiple scales of analysis are undertaken when assessing riparian condition- not just the plot scale, or the broad scale.

2.1 Limitation of TRARC

Limitations have also been identified as to the scale of catchment and river channel at which the on-ground TRARC assessment can be effectively used. In large river channels, such as the main stem channel on the Mitchell River, where the in-channel zone (see below) may be 2km wide, and highly dynamic, with the low flow channel shifting hundreds of meters in successive years, repeat surveys of transects and quadrats of 100m in length are not going to be of much use for shedding light in trajectories of change, without a bigger picture view as well.

Given this problem, and the need for large numbers of replicate samples for a given channel segment, we concluded that this technique was not very practical in large rivers. It was no longer a “rapid appraisal” technique when 15 or 20 transects were required to adequately represent one channel segment. Nevertheless, multiple transects in a reach can shed light on whether the channel segment is becoming infested with weeds, or provide insights into other higher resolution ecosystem functions that are not detectable from moderate resolution remote sensing data. Hence, we do not rule out this approach altogether in larger river channels. Indeed ongoing monitoring of multiple transects in a few segments of large channels could be very informative. However, as a method for undertaking regional assessment of riparian condition in large areas like the Northern Gulf, TRARC is not a practical approach. Rather, it is best focused in particular parts of a catchment, preferably the lower order streams, where it is scale appropriate, and where repeat samples at a site are likely to detect changes associated with, for example, changing land use pressure.

Figure 6 Examples of a simple savannah riparian zone (left) and more complex ones (centre and right) with hypothetical minimum transect locations that would be required to adequately represent vegetation community dynamics in the respective riparian areas.

2.2 Adopted Strategy

Given the inherent problems outlined above in assessing condition based on a contemporary assessment of the status of the riparian zone, the primary focus of this study was necessarily on the establishment of the baseline state against which future condition trends can be measured, and the development of a robust, repeatable method for undertaking this analysis. This applies at the two scales at which riparian condition is being assessed – i.e. remote sensing across the entire catchment and the detailed ground based survey at specific sites using the TRARC approach (Dixon et al., 2006). The broadscale analysis is fundamentally limited by the resolution of the available satellite data (see below), but for various reasons, we have had to confine ourselves to the use of 25m LandSat imagery. This is primarily due to the fact that this is the only readily available data set with an archive of any length (i.e. two decades +). This will enable us to gain some understanding of the trends in vegetation and landscapes status over this period and hence begin to gain some understanding of condition.

Given this background, the study has been broken into two main parts: 1) A remote sensing based approach using Landsat imagery at two time periods, to detect gross changes in riparian structure between the two intervals. 2) A ground-based assessment of 175 sites throughout the upper Gilbert/Einasleigh Rivers and the upper Mitchell and Walsh Rivers. In this instance the sites were targeting the most intensively utilized portions of the catchments.

2.3 Road density as an indicator of land-use pressure.

Complementing the two primary scales of analysis, an additional GIS analysis of the road network was carried out, as a way of providing a proxy indicator of current land-use pressure. If it is assumed that the ultimate driver of degraded riparian land condition (however that may be defined) is relative land-use intensity, one of the ideal means for assessing the pressure on the landscape is to come up with an independent measure of land use intensity. In this landscape, the ideal measure would be some spatial distributed understanding of grazing pressure, which ideally would include the actual numbers of cattle per unit area within the various riparian zones. Unfortunately reliable data of this nature is not readily available, so an alternative measure was sought.

Road density provides the most readily calculable proxy indicator of anthropogenic disturbance, if it is assumed that the greater the density of roads reflects more intense utilisation of the land, be it through grazing pressure, mining pressure or intensive agriculture. There is also some evidence to suggest that roads are an important initiator of alluvial gully erosion, and they are important corridors for weed distribution and feral animal dispersal. As such, road density was determined from the 1:250K topographic map series and unit densities calculated for each riparian land unit within the delineated sub-catchments. Given that the only roads occurring within the in-channel zone are the designated road crossings, a separate analysis was not undertaken within the in-channel zone. Instead, for the purposes of the exercise the active and in-channel zones were combined into a single class.

2.4 Remote Sensing Approach

Riparian and floodplain systems in tropical savannahs are dynamic environments subject to change over time. Effective management of these landscapes requires an understanding of the climatic, biophysical and anthropogenic drivers of change.

Climatic and seasonal drivers of change:	annual seasonality El Nino, La Nina cycles Cyclonic rainfall events Pacific decadal oscillation

Biophysical drivers of change	Flood dynamics
	    magnitude
	    duration
	    frequency
	Alluvial gullying
	Surface & slope erosion
	Fluvial or river processes
	    Channel migration
	    Bank erosion
	    Floodplain and in-channel sedimentation

Anthropogenic or human-based drivers of change[2]	Grazing pressure (cattle, pigs, horses) Fire regime Flow regulation or water extraction Roads and other infrastructure Cropping & horticulture

To assess these processes at an appropriate scale (*i.e.* catchment scale), necessitates the use of remote sensing data and spatial analysis. The Landsat archive provides the longest historical record ranging from 1972 through to 2005. The dataset for Landsat TM, which has a 25m pixel size[3] covers the period from 1988 to 2005. For the remote sensing component of the Riparian Condition Assessment project the Landsat TM mosaics from 1988 and 2005 were analysed to assess the degree of vegetation and land cover change that had occurred in the Mitchell and Gilbert catchments of the Northern Gulf region during that 17 year period. Interpretation and validation of the Landsat TM data was carried out using airborne tri-spectral scanner data. An archive of MODIS satellite imagery was also used to assess the growth dynamics, inundation dynamics and fire dynamics[4].

The aim of the project was to assess what sorts of vegetation and land cover changes had occurred in the floodplains and riparian zones in the Northern Gulf region and interpret these changes to provide an overview of the change in riparian condition. The same vegetation classes (*i.e.* closed forest, open forest, woodland and open woodland) used to aggregate the TRARC scores were identified in the Landsat imagery. This provides the template for interpreting vegetation changes over time.

Given the 25m pixel resolution of the LandSat base data set, there are a limited suite of indicators that can be derived as the basis for a condition assessment. LandSat imagery can be used to differentiate vegetation community classes in the manner of Specht (1981). A simplified set of six classes are used, which include: closed forest, open forest, woodland, open woodland, grassland and bare ground (including gully and scald erosion as well as river sand deposits). River sand will subsequently be segregated from the remaining bare ground, using LandSat thermal bands, while the gully erosion subset of the bare ground class will be delineated from the output of a separate gully mapping project. In addition to these vegetation classes, water bodies are also quantified.

With this set of relatively simple land and vegetation classes, patterns in their changing relative distribution were determined for the various riparian zone classes. Various indicators were derived, such as the aerial extent of vegetation classes, relative changes in the extent of certain vegetation classes, sand and water bodies within a specified reach (an indicator of sediment accumulation or evacuation), or aerial extent of infrastructure such as roads. As more data becomes available at a higher resolution (either remotely sensed or ground based), it may be possible to link temporal changes in the relative proportions of vegetation community classes in a given area, to some of the degrading processes. For example, if a given river segment records an increase in the proportion of the channel occupied by bare sand bodies,

[2] This includes both indigenous and non-indigenous land use practices for change.
[3] As distinct from Landsat MSS (1972-1988) which has a 80 metre pixel size, which made this earlier imagery unsuitable for this analysis
[4] Fire frequency analysis was carried out by Peter Thompson from the Cape York Peninsula Development Association

and concomitantly a change in the relative proportion of woodland and closed forest over say a 20 year period (i.e. overall there is less vegetation within this section of channel, but there is more closed forest than woodland). With some additional evidence, we may be able to link the changes in vegetation community composition to weed infestation, and the increased extent of in-channel sand bodies to increased sediment supply at the catchment scale. On their own, however, these metrics would not tell us these things, but they would alert us to the fact that something has changed, which would then raise a flag that a more detailed investigation is required. As we start to build a body of knowledge about some of these changes, our ability to highlight particular problems and their potential causes will increase.

2.5 Integration of TRARC and a remote sensing approach to riparian condition assessment

At the outset of this project it was assumed that TRARC would form the basis for undertaking the ground validation, and that the insights gained from on ground TRARC surveys would provide a basis for extrapolation of these site-specific findings to much larger areas. Following extensive discussion it was decided that the initial assumption that we could effectively marry these two approaches to riparian assessment was flawed – or at least constrained by the huge complexity of the riparian landscapes in the northern Gulf. The variability of the landscape means that huge numbers of TRARC sites (e.g. thousands) would have been required to make it statistically rigorous enough to use these data as a basis for extrapolation across the whole landscape. Furthermore, it was decided that it was probably not the most appropriate method for ground validating the remote sensing analysis at the resolution at which this was carried out. In short, there was a fundamental mismatch in the scale, resolution and objectives of the two approaches. TRARC is primarily designed for establishing the baseline condition at a specific site and monitoring the change through time at that same location. In rivers that are relatively homogeneous, this site transect may be assumed to be representative of the reach. In more complex river reaches that are typical in the northern Gulf, numerous transects would be required to gain a representative snapshot of the state or condition of a relatively small reach (Figure 6). This is not to say that the two approaches cannot complement one another, and improve insights gained from each strategy in isolation.

2.6 The Solution:

To maximise the benefit to the Northern Gulf – a strategic decision was made to target our on-ground TRARC assessments in headwater areas that are at a scale more in line with the scale of river for which the procedure was designed, but in the case of the upper Walsh and Mitchell Rivers, also perceived to be at greatest risk from development pressure over the short to medium term. The sites selected will act as a pilot study as to the applicability of this rapid riparian assessment method in the northern Gulf, but in addition would be used to test some of the assumptions regarding the variability of particular vegetation classes in the northern Gulf, as mapped in the remote sensing component.

Three areas were targeted for relatively intense on-ground assessment, the upper Walsh River irrigation area, the upper Mitchell wet tropics area, and the upper Einasleigh (see Section 6). The upper Einasleigh TRARC sites were selected from the initial land unit mapping (section 5).

In moving away from using TRARC as a method for undertaking ground validation of the RS analysis, a more appropriate ground validation methodology was then designed that better matched the resolution of the remote sensing and enabled more ground to be covered, albeit in less detail. In addition, resources were directed towards the collection of high resolution airborne remote sensing data to augment the ground survey data (see section 5), and ultimately provide one of the best data sets for validating the remotely sensed information, across a large enough sample of the landscape to make it statistically viable.

3 Remote Sensing Approach

3.1 METHODS

Processing and Analysis of the Landsat TM data

The process of assessing change in the riparian zones of the Mitchell and Gilbert catchments consisted of a number of steps. The first step was to use airborne scanner imagery to understand what the trees, shrubs, grasses, river sand, bare ground and water looked like in the Landsat TM data. The second step was to establish a relationship between the combination of grasses, trees and bare ground etc. and the way these areas reflect sunlight (as measured by the Landsat TM sensor). The third step was to assess whether this relationship was stable, in other words, did a mix of 30% trees and 70% grass in one area of the catchment look the same as an area with 30% trees and 70% grass elsewhere within the catchment? The fourth step was to make the assumption that an area with 30% tree cover and 70% grass cover would reflect sunlight the same way in the mid dry season of 1988 as it did in the mid dry season of 2005. The fifth step was to examine how much the land cover had changed between 1988 and 2005 *i.e.* Did the area that contained 30% tree cover and 70% grass in 1988 now contain 20% tree cover and 80% grassland? Or 50% tree cover and 30% grass and 20% bare soil. The final step was analyze these land cover changes to gain insight into how different drivers may be influencing land cover change.

Step 1 Understanding the relationship between land cover and Landsat TM reflectance

The image processing package was used to segment up the Landsat TM data into image objects or polygons. These polygons represent discrete objects such as a stand of trees, a small in-channel island, or a large sand bar. A polygon based classification was used in preference to a pixel based classification because land cover types such as woodland, which is characterized as a mixture of trees and grass has quite variable reflectance at an individual pixel scale (because each pixel may contain a different mixture of trees and grass), however when viewed at a larger scale *i.e.* as a area of woodland rather than an individual pixel, these areas of woodland have similar reflectance characteristics.

The 2005 Landsat TM mosaic prepared by the QDNRW SLATS team was input into Definiens eCognition. The image segmentation was run using a scale setting of 5 (the smallest object or minimum mapping unit is 5 pixels (3125m^2). The shape constraints were turned off, which means that the polygons were formed based on reflectance characteristics only (this reflects the random shape characteristics of riparian vegetation and land cover types). This segmentation was only applied to the riparian areas of the Mitchell and Gilbert catchments.

The polygons generated from the Landsat TM data were overlayed on top of the tri-spectral scanner data collected by Jorg Hacker and his team from Airborne Research Australia during August 2006. Details of the tri-spectral scanner dataset are contained in Milestone report 1 (Brooks et al., 2007a). However, these provide a high resolution (~1m pixels) NDVI data set which is used to calibrate the coarser resolution Landsat data. Classes were assigned to each polygon as shown in Figure 7 The classes used were, closed forest, open forest, woodland, open woodland, woodland with bare background, open woodland with bare background, grassland, grassland/bare soil mix, bare soil and water. A detailed definition of these classes is contained in Specht (1981). Several attempts were made to automate the polygon assignment process based on classifying the tri-spectral scanner data, however these attempts were confounded by misregistration between the polygons derived from the Landsat TM data and the tri-spectral scanner data.

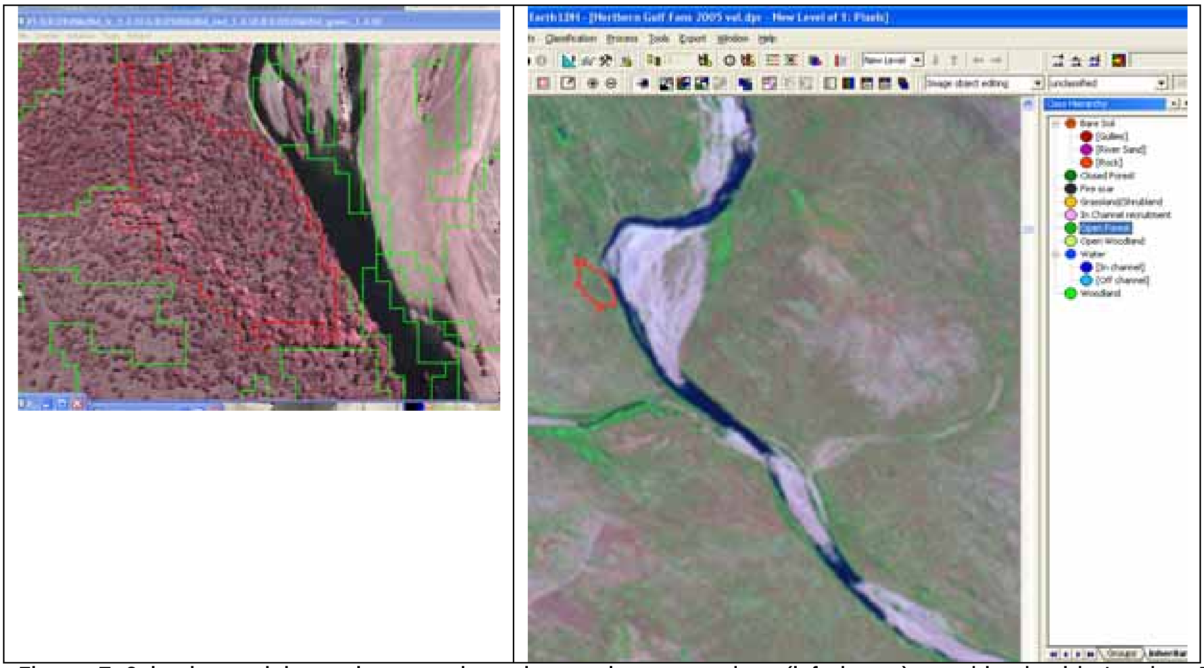

Figure 7 Selecting training polygons using trispectral scanner data (left image) combined with Landsat TM derived polygons (right image). The polygon outlined in red is the same in each image.

Step 2 Training the classification of the 2005 Landsat imagery using trispectral scanner data

The technique shown in Figure 7 was applied to 14 strips of tri-spectral scanner data and 824 training polygons were collected. The 14 strips covered the alluvial fans, and riparian zones of the major subcatchments.

Table 1 The distribution of 824 training samples across different land cover types.

Land Cover	No. of Samples
Bare Soil	69
Closed Forest	28
Grassland	108
Grassland/Bare soil mix	47
Open Forest	85
Open Woodland	69
Open woodland with bare background	77
Rock	17
Water	96
Woodland	186
Woodland with bare background	42

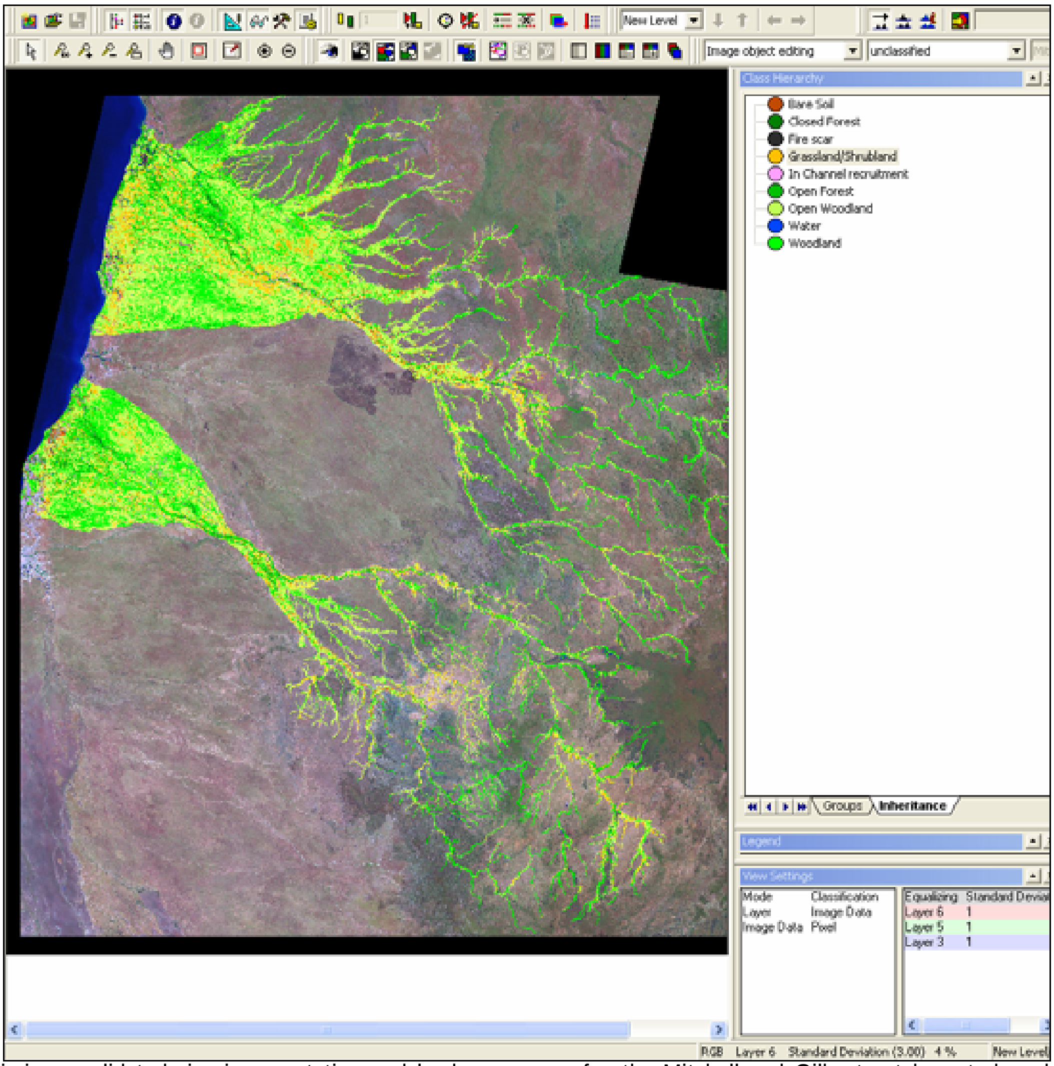

Figure 8 Preliminary validated riparian vegetation and land cover map for the Mitchell and Gilbert catchments based on the 2005 Landsat mosaic.

The 824 polygons listed in Table 1 were used to seed the nearest neighbour classification algorithm within eCognition. The classification threshold was set to 0.8 ensuring that polygons were either classified with a high degree of confidence (spectrally similar to the training areas) or were identified as unclassified. The nearest neighbour algorithm was used to classify every polygon based on their reflectance characteristics in all 6 bands of Landsat data.

Step 3 Assessing the accuracy of the 2005 image classification

To assess whether the map generated from the 2005 Landsat imagery was accurate, 16 strips of tri-spectral scanner data were examined, and an additional 1183 polygons were selected to assess the accuracy of the classification. This was done using the same process as for the training data. However it is important to note that these 1183 polygons were collected from different strips of tri-spectral scanner data than that used to train the classification. This means that the validation polygons are completely independent of the input training data. This ensures a rigorous accuracy assessment (Table 2, Table 3 and Table 4).

Table 2 Error assessment matrix for all classes

		Tri-spectral scanner validation polygons											
2005 Landsat TM classification	User Class \ Sample	CF	OF	WL	OW	GL	BS	WA	RO	WLB	OWB	GLB	Sum
	Closed Forest (CF)	32	2	0	0	0	0	0	0	0	0	0	34
	Open Forest (OF)	1	177	10	0	0	0	0	0	1	0	0	189
	Woodland (WL)	0	5	262	14	1	0	0	0	6	1	0	289
	Open Woodland (OW)	0	1	6	73	9	0	0	0	1	3	1	94
	Grassland (GL)	0	0	1	17	105	0	0	0	1	7	3	134
	Bare Soil (BS)	0	0	0	0	1	113	0	4	0	0	3	121
	Water (WA)	0	1	0	1	0	0	56	3	0	0	0	61
	Rock (RO)	0	0	0	0	0	14	0	24	0	0	0	38
	Woodland with bare soil (WLB)	0	0	2	0	0	0	0	0	59	0	0	61
	Open Woodland with bare soil (OWB)	0	0	2	8	10	1	0	0	6	99	1	127
	Grassland/Bare soil mix (GLB)	0	0	0	0	1	1	0	0	0	3	28	33
	unclassified	0	0	0	0	0	0	0	2	0	0	0	2
	Sum	33	186	283	113	127	129	56	33	74	113	36	
	Overall Accuracy 86.9%												

The error assessment matrix, Table 2, shows a high (86.9%) overall accuracy for the classification. The shaded cells on the diagonal represent accurate classification, whereas values away from that main diagonal represent classification errors. Many of the errors are considered to be ‘acceptable’ errors from a fuzzy classification point of view. This is because the errors are often between adjacent canopy cover classes. For example a dense woodland will reflect sunlight in a similar way to an open forest, so a small degree of confusion between these two classes is to be expected. There are some ‘unacceptable’ errors for example woodland being misclassified as grassland or open woodland with bare soil. However these errors occur infrequently. They occur in less than 1% of cases for the woodland example, and in 2.3% of cases overall.

Table 3 and Table 4 examine certain areas of the overall error matrix, and show the accuracy assessment for two areas of interest to this project, the accuracy of the overall vegetation classification, and the accuracy of the important gradient between open woodland grassland and bare soil. Both matrices show high overall accuracies (>80%). However it is worth noting that there is an increase in the number of unacceptable errors (9%) for the Open Woodland-Grassland-Bare Soil gradient.

Table 3 Error assessment matrix for the vegetation classes

		Tri-spectral scanner validation polygons								
	User Class \ Sample	CF	OF	WL	OW	GL	WLBS	OWBS	GLBS	Sum
2005 Landsat TM classification	Closed Forest(CF)	32	2	0	0	0	0	0	0	34
	Open Forest (OF)	1	177	10	0	0	1	0	0	189
	Woodland (WL)	0	5	262	14	1	6	1	0	289
	Open Woodland (OW)	0	1	6	73	9	1	3	1	94
	Grassland (GL)	0	0	1	17	105	1	7	3	134
	Woodland with bare background (WLBS)	0	0	2	0	0	59	0	0	61
	Open Woodland with bare background (OWBS)	0	0	2	8	10	6	99	1	126
	Grassland/Bare soil mix (GLBS)	0	0	0	0	1	0	3	28	32
	unclassified	0	1	0	1	1	0	0	3	6
	Sum	33	186	283	113	127	74	113	36	
	Overall Accuracy 86.5%									

Table 4 Error assessment matrix for the Open Woodland-Grassland-Bare Soil gradient

		Tri-spectal scanner validation polygons					
2005 Landsat TM classification	User Class \ Sample	Open Woodland	Grassland	Bare Soil	OWB	GLB	Sum
	Open Woodland	73	9	0	3	1	86
	Grassland	17	105	0	7	3	132
	Bare Soil	0	1	113	0	3	117
	Open Woodland with bare background (OWB)	8	10	1	99	1	119
	Grassland/Bare soil mix (GLB)	0	1	1	3	28	33
	unclassified	15	1	14	1	0	31
	Sum	113	127	129	113	36	
	Overall Accuracy 80.7%						

Step 4 Classifying the 1988 Landsat imagery

Having established the reliability and shortcomings of the 2005 Landsat classification, the same classification was applied to the 1988 imagery. This is based on the assumption that the way grass, trees, bare soil and water reflected sunlight reflected light in the mid dry season of 1988 is the same way they reflect sunlight now. This is a reasonable assumption given that a). the scenes that make up the mosaics have been radiometrically and atmospherically corrected, and b). the mosaics are made up of mid-dry season (July-September) scenes from both years.

Step 5 Defining the change detection classes

To understand what sorts of changes had occurred in the riparian zones of both catchments it was necessary to come up with some way of characterising change. For example an area that contained woodland in 1988 and has changed to forest in 2005 has undergone an increase in canopy cover, whereas an area that contained woodland in 1988 but had changed to grassland/bare soil mixture in 2005 has undergone a change from woody to non-woody vegetation. If we consider the class of a polygon in 1988 to be it's initial class, and its class in 2005 be it's final class, then there are 100 different initial class->final class combinations (assuming that rock is constant). Interpreting the 100 different class combinations individually is more confusing than enlightening, consequently a change assessment matrix was established to group these class combinations into process based groups (Table 5 and 6).

Table 5 Change analysis matrix for the active channel zone and floodplain. BS=bare soil; CC=canopy cover; NW=non-woody; LC=land cover

		2005 Vegetation/Land Cover									
1988 Vegetation/Land Cover		**Closed Forest**	**Open Forest**	**Woodland**	**Woodland BS**	**Open Woodland**	**Open Woodland BS**	**Grassland**	**Grassland BS**	**Bare Soil**	**Water**
	Closed Forest		Decrease in CC	Big Dec in CC	Big Dec in CC	Vbig Dec in CC	Vbig Dec in CC	Woody 2 NW	Woody 2 NW	Woody 2 NW	Water/LC dynamics
	Open Forest	Increase in CC		Decrease in CC	Decrease in CC	Big Dec in CC	Big Dec in CC	Woody 2 NW	Woody 2 NW	Woody 2 NW	Water/LC dynamics
	Woodland	Big Inc in CC	Increase in CC		Decrease in GC	Decrease in CC	Decrease in CC	Woody 2 NW	Woody 2 NW	Woody 2 NW	Water/LC dynamics
	Woodland BS	Big Inc in CC	Increase in CC	Increase in GC		Decrease in CC	Decrease in CC	Woody 2 NW	Woody 2 NW	Woody 2 NW	Water/LC dynamics
	Open Woodland	Vbig Inc in CC	Big Inc in CC	Increase in CC	Increase in CC		Decrease in GC	Woody 2 NW	Woody 2 NW	Woody 2 NW	Water/LC dynamics
	Open Woodland BS	Vbig Inc in CC	Big Inc in CC	Increase in CC	Increase in CC	Increase in GC		Woody 2 NW	Woody 2 NW	Woody 2 NW	Water/LC dynamics
	Grassland	NW 2 Woody	NW 2 Woody	NW 2 Woody	NW 2 Woody	NW 2 Woody	NW 2 Woody		Decrease in GC	Woody 2 NW	Water/LC dynamics
	Grassland BS	NW 2 Woody	NW 2 Woody	NW 2 Woody	NW 2 Woody	NW 2 Woody	NW 2 Woody	Increase in GC		Woody y 2 NW	Water/LC dynamics
	Bare Soil	NW 2 Woody	NW 2 Woody	NW 2 Woody	NW 2 Woody	NW 2 Woody	NW 2 Woody	NW 2 Woody	NW 2 Woody		Water/LC dynamics
	Water	Water/LC dynamics	Water/LC dynamics	Water/LC dynamics	Water/LC dynamics	Water/LC dynamics	Water/LC dynamics	Water/LC dynamics	Water/LC dynamics	Water/LC dynamics	

To read this table, first identify the row that represent the land cover in 1988 then move across the columns until you find the land cover that that polygon has changed to. For example, if an area of open forest in 1988 has changed to open woodland then it has undergone a big decrease in canopy cover. Another example would be from bare soil in 1988 to open woodland in 2005, which would be represented by a change from non-woody (NW) to woody vegetation.

There are two main processes represented in Table 5. These two processes are increasing (green tones) vs decreasing canopy cover (yellow-red tones) and changes from woody to non-woody vegetation (purple tones) vs the change from non-woody to woody (blue tones). The other processes are increases and decreases in ground cover (pale yellow and pale blue). The ground cover dynamics are not analysed in detail because ground cover changes are very seasonal, whereas shift between woody and non-woody vegetation take place over longer timescales. The other process shown in Table 5 is the water/land cover (LC) dynamics typically associated with wetting and drying perimeters of floodplain waterbodies.

Table 6 Change analysis matrix for the in channel zone

		2005 Vegetation/Land Cover							
		Closed Forest	**Open Forest**	**Woodland**	**Woodland BS**	**Open Woodland**	**Open Woodland BS**	**River Sand**	**Water**
1988 Vegetation/Land Cover	**Closed Forest**	Veg to Veg	Increase in CC	Big Dec in CC	Big Dec in CC	Veg to Sand	Veg to Sand	Veg to Sand	Veg to Water
	Open Forest	Increase in CC	Veg to Veg	Decrease in CC	Decrease in CC	Veg to Sand	Veg to Sand	Veg to Sand	Veg to Water
	Woodland	Big Increase in CC	Increase in CC	Veg to Veg	Decrease in GC	Veg to Sand	Veg to Sand	Veg to Sand	Veg to Water
	Woodland BS	Big Increase in CC	Big Increase in CC	Increase in CC	Veg to Veg	Veg to Sand	Veg to Sand	Veg to Sand	Veg to Water
	Open Woodland	Sand to Veg	Sand to Veg	Sand to Veg	Sand to Veg	Sand to Sand	Veg to Sand	Veg to Sand	Veg to Water
	Open Woodland BS	Sand to Veg	Sand to Veg	Sand to Veg	Sand to Veg	Sand to Veg	Sand to Sand	Veg to Sand	Veg to Water
	River Sand	Sand to Veg	Sand to Veg	Sand to Veg	Sand to Veg	Sand to Veg	Sand to Veg	Sand to Sand	Sand to Water
	Water	Water to Veg	Water to Veg	Water to Veg	Water to Veg	Water to Veg	Water to Veg	Water to Sand	Water to Water

Step 6 Interpretation of the change detection classes

There are a number of geomorphic and ecosystem processes for the in-channel zone represented in Table 6, which can be synthesized down to three fundamental geomorphic changes as indicated in Table 7, channel erosion or bed turnover, in-channel deposition, or no net change. Of course the observed changes only reflect a two dimensional change, and so it is only by inference (and knowledge of processes on the ground)that we can attribute these geomorphic responses to the observed changes in the Landsat data. Field experience in both catchments tells us that for a pool to be a pool one year and a sand bar the next, somewhere in the order of 3 – 10m of deposition has taken place at that particular site. The converse is obviously true for the situation where there is a sand bar one year and a pool the next (or within 17 years). On this basis we can make assumptions about the minimum depth of bed material that has been turned over to either deposit a bar or scour a pool, and hence derive an estimate of minimum sediment turnover within the channel. The assumption is also made that in the status quo category, on average there has been not net change in sediment storage. However, what we do not know is the extent to which the sand bar category has been turned over between the consecutive images. A sand bar will still look like a sand bar at the two time intervals, but it may have been scoured and redeposited every year of the intervening period between images.

Table 7 Summary table showing the underlying geomorphic implications of the observed changes indicated by the remote sensing data.

Physical Interpretation of Detected change	**Nature of Change**	**Interpretation from Table 6**
Status quo (i.e. no net change) although vege density may have changed	(Veg to Veg, Sand to Sand, Water to Water)	pale green, pale yellow and pale blue.
bar formation (deposition)	(water to sand)	orange.
bar scour (bed turnover)	(sand to water)	dark blue.
Island formation /sand bar stabilisation	(Sand to Veg)	mid green.
Island scour (bed turnover)	(Veg to Sand)	mid yellow.
Erosion of vegetation (bed turnover)	(Veg to Water)	mid blue.
Deposition + Island formation /sand bar stabilisation	(Water to Veg)	dark green.

3.2 Results

Road Density

Road density (i.e. road length per unit area) is calculated here as a proxy indicator of relative land use intensity within similar land types across the region. Clearly the indicator should not be used to draw inferences about relative land-use intensity between riparian land categories, given that most roads are likely to be located on the higher ground within floodplains, compared to the channel zones. However, we believe it is a valid approach for measuring relative land use pressure between catchments within either the floodplain or channel zones. From the results presented in Figure 9, it is apparent that in both the channel zone and the floodplain zone, road density is slightly greater in the Gilbert catchment than the Mitchell, although the result is not significant (P= 0.395, and 0.363 for the floodplain and channel zones respectively). Within the Mitchell catchment it is evident that the Alice river catchment is substantially less impacted by roads than the other tributaries. In both catchments the roading pressure is lower within the channel zone in the fan portion of the catchment. This is unsurprising, given that wet season inundation makes these areas inaccessible for 3-4 months of the year at least, and permanent settlement very difficult. These data provide some broad indicators of the likely relative land pressures within the different sub catchments comprising the study area.

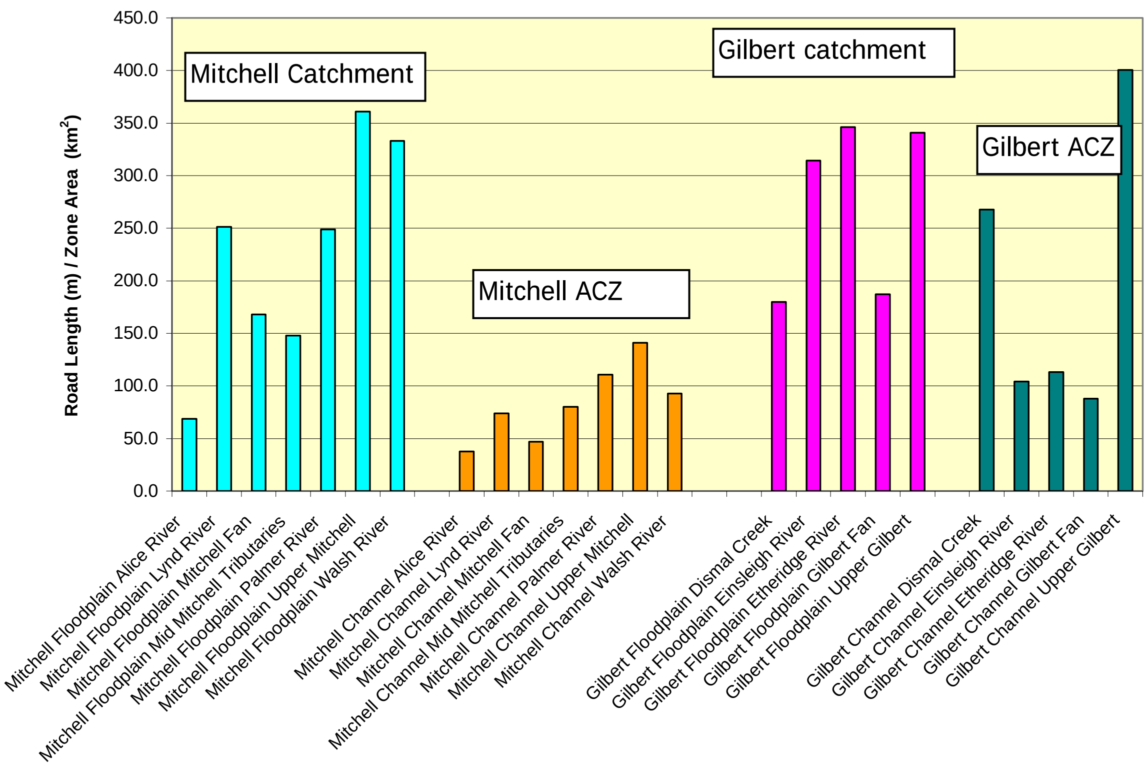

Figure 9 Relative road density derived from the 1:250 K topographic data for the floodplain zone and a combined active and in-channel zone.

3.3 Remote Sensing Results - Mitchell Catchment

Overview

As a means of better understanding the varying patterns in land cover change within the Mitchell and Gilbert catchments, the results have been analysed within the different riparian zone classes, and have been simplified to highlight the key responses that have been detected over the 17 year time interval between the two time slices analysed (i.e. 1988, 2005). Our initial feeling was that the changes over this relatively short time interval would be too subtle to detect with the 25m pixel resolution Landsat TM data. As outlined below, the results indicate that substantive changes have been detected, changes far greater than we would have anticipated. The results for each zone are presented graphically, with a summary of the implications from each analysis.

In-channel zone

In-channel Vegetation Dynamics

The data in Figure 10 indicate there has been a net increase in the area of in-channel vegetation across all sub-catchments within the Mitchell River within the in-channel zone (ICZ). In terms of absolute area this represents a net increase of in-channel vegetation of 6950 ha over the 17 year interval assessed or 13.5% of the total area of the ICZ (51565 ha). This net gain is comprised of a total increase of 11262 ha of in-channel vegetation, which is offset by a loss (via channel erosion) of 4310 ha of in-channel vegetation over the same period. Hence, there has been a considerable turnover of in-channel vegetation during this period. In annualised terms, the net vegetation increase is 409 ha/yr, or 0.79% of the total area of the in-channel zone.

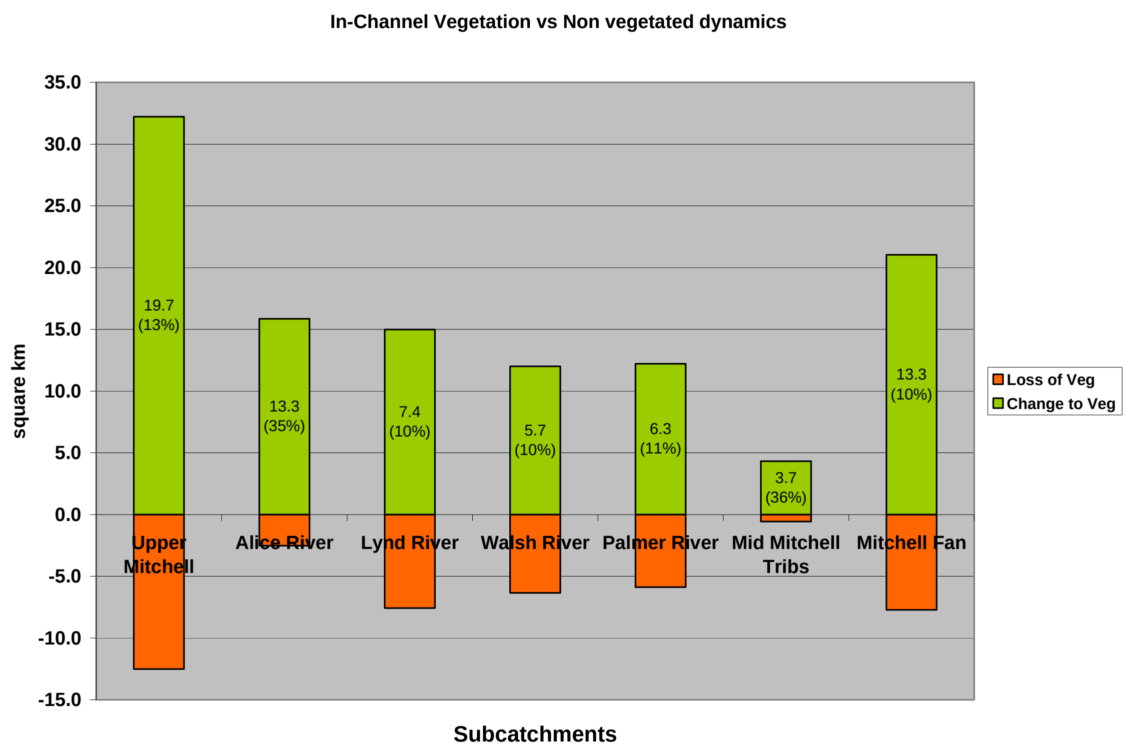

Figure 10 Relative change in vegetation cover within the ICZ combined between 1988 and 2005 within the Mitchell catchment. The “change to vegetation” class represents the sum of the polygons that have changed from either sand to vegetation or water to vegetation between 1988 and 2005. The loss of vegetation class represents polygons that have changed from vegetation to water or vegetation to sand. Values shown above each bar are the net change of canopy cover (in km^2) within the ICZ in each sub-catchment. Values in brackets show the percentage of the total ICZ area in each sub-catchment that has experienced a net increase in canopy cover.

Implications

The net increase in vegetation detected in this analysis represents a very significant increase in the total area of in-channel vegetation over the 17 year period between 1988 and 2005. Undoubtedly some of the trend could be explained by measurement error or indeed methodological error. The fact that a standard polygon mask derived from the 2005 imagery was used for detecting changes betweem 1988 and 2005 could have contributed to some systematic error in the detection of vegetation change This is possibly exacerbated by the fact that for the purposes of this exercise all vegetation polygon categories have been lumped into a single “super class” of vegetation. The method tends to overestimate the polygons classified as “vegetation” at the expense of bare sand, because a minor increase in vegetation within a sand bar will shift that polygon from a bare sand class to a vegetation class, even though the polygon is still predominantly sand. Hence the observed trends could be biased towards detecting vegetation polygons.

Despite this potential measurement problem, the trend is so large that it is unlikely it can all be explained away by measurement error. It would appear that there has been a real and significant increase in the extent of vegetation within the in-channel zone. Part of the reason that we can be reasonably confident about these results, is the fact that, leaving aside the issue raised above, the spectral signatures of the three key classes, sand, water and vegetation are so distinct that it is a relatively straight forward remote sensing exercise to separate them. Hence, of all the riparian zone changes, we can have most confidence in the ones within the ICZ.

So what does this mean? There are a number of potential explanations, and of course it may be a combination of causal factors. However, without further field and remote sensing evidence it is difficult to determine conclusively the key mechanisms.

- There has been an increase in the available substrate within the channel upon which the dominant in-channel Melaleuca forests can establish. Hence, the increase in vegetation could be masking an increase in sediment deposition within the channel.
- The flood regime within the period between 1988 and 2005 has been particularly conducive to vegetation colonisation rather than stripping. We would expect this to be the case had there not been any major floods that would tend to strip vegetation.
- The increased vegetation cover reflects an increase in invasive species colonising the ICZ (e.g. rubber vine, bellyache bush etc.).
- There has been some other environmental change (e.g. CO^2 driven global warming that has made the environment more conducive to in-channel riparian vegetation colonisation).
- There are some internal system dynamics yet to be fully identified, and this analysis is simply detecting a particular part of some cyclical trend.

Further research is required to determine which, if any, of these potential mechanisms is responsible for the observed change.

With regards to option 2, the evidence from the flood regime at Gamboola (Figure 11) on the lower Mitchell River, would tend to suggest that if anything, one might have expected the opposite response. The wet seasons of 1999 and 2000 produced the 2nd and 3rd largest floods on record, which would have been expected to cause significant scour of vegetation. Indeed anecdotal evidence from the hydrographers gauging during these events suggest large amounts of vegetation were removed during these events (Steve Parker, pers. comm., 2007). However, a counter to this assumption is that the decade prior to these two extreme wet seasons (i.e. the ten years immediately following the 1988 Landsat image that forms the baseline for this analysis) was relatively benign, potentially providing sufficient time for in-channel vegetation to establish and then to reach sufficient size to be able to resist removal by large floods.

A higher resolution multi-temporal analysis is required to conclusively establish the relationship between floods and vegetation colonisation/removal.

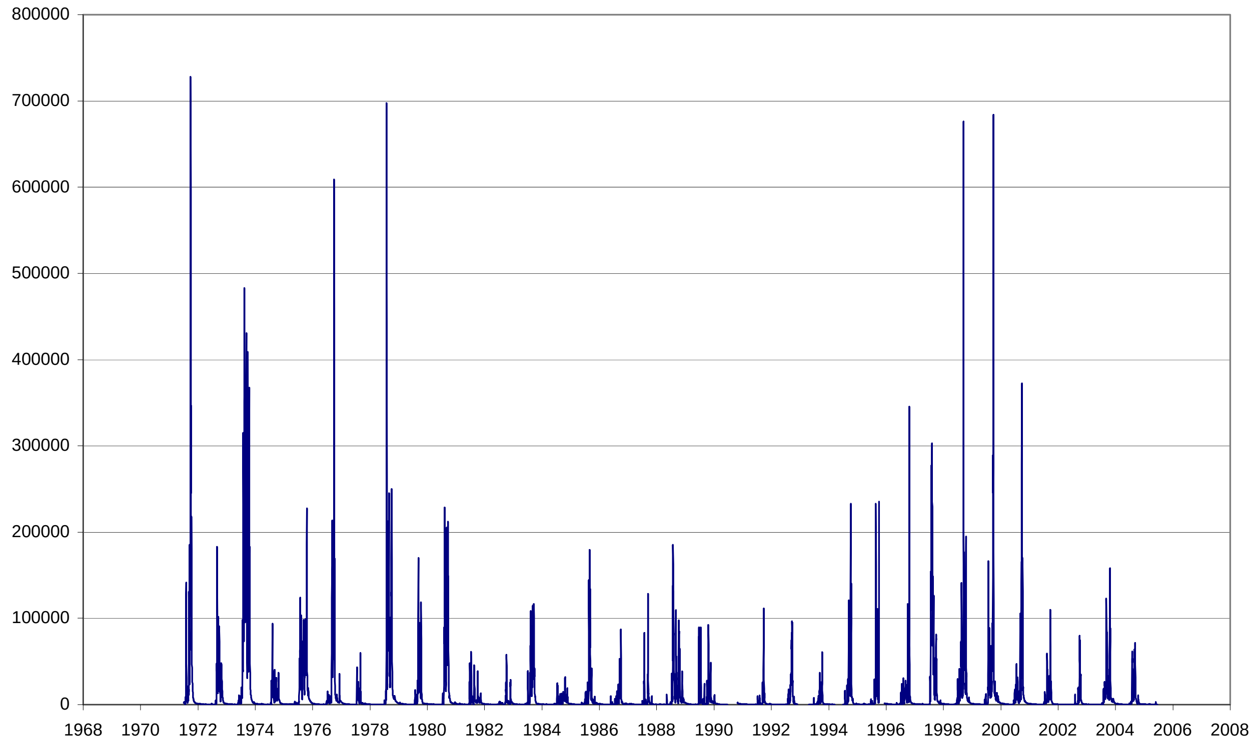

Figure 11 Daily discharge record for the Gamboola gauge (ML/Day) on the lower Mitchell River (stn #. 919011A)

Spatial Variability of Change

One aspect of the catchment wide change in vegetation dynamics that is masked by the sub-catchment averaged analysis presented above, is the extent to which there is spatial variability in the trend within any one tributary or sub-catchment. As can be seen in Figure 12 while there has been an overall increase in the extent of in-channel vegetation between the two time slices, there are some notable hotspots where the trend has gone the opposite way. Further work to improve our understanding of the drivers of vegetation change would be best focused in reaches with highly contrasting patterns of change.

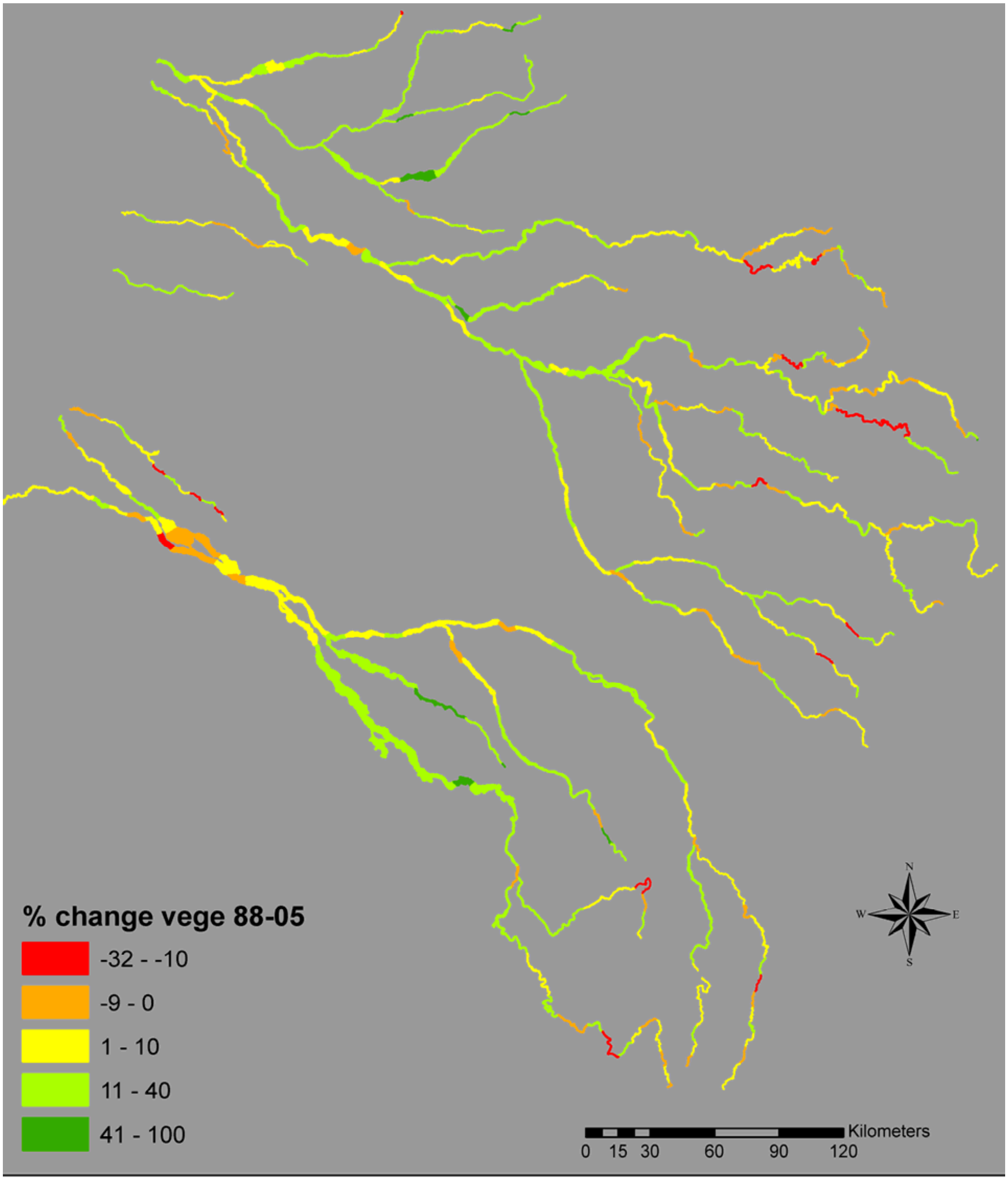

Figure 12 Map of both the Mitchell and Gilbert River catchments showing the spatial variability of in-channel vegetation change between 1988 and 2005 within the ICZ and ACZ combined.

Net Scour and Deposition – Evidence for Sediment Accumulation

Given that the channels mapped in this study are predominantly sand-bed channels with highly mobile beds in which the locations of pools and bars are relatively dynamic between years, it is not surprising that we can observe significant dynamism in the extent of sand bodies and pools over the seventeen year interval examined in this study. Apart from demonstrating that the different sections of the channel network are highly dynamic (an important point in its own right –particularly if one is the business of monitoring the habitat and/or aquatic ecosystem dynamics of individual water holes), these data can also tell us whether the system is roughly in equilibrium, or whether it is trending towards bed material accumulation or bed scour (i.e. increased pool area).

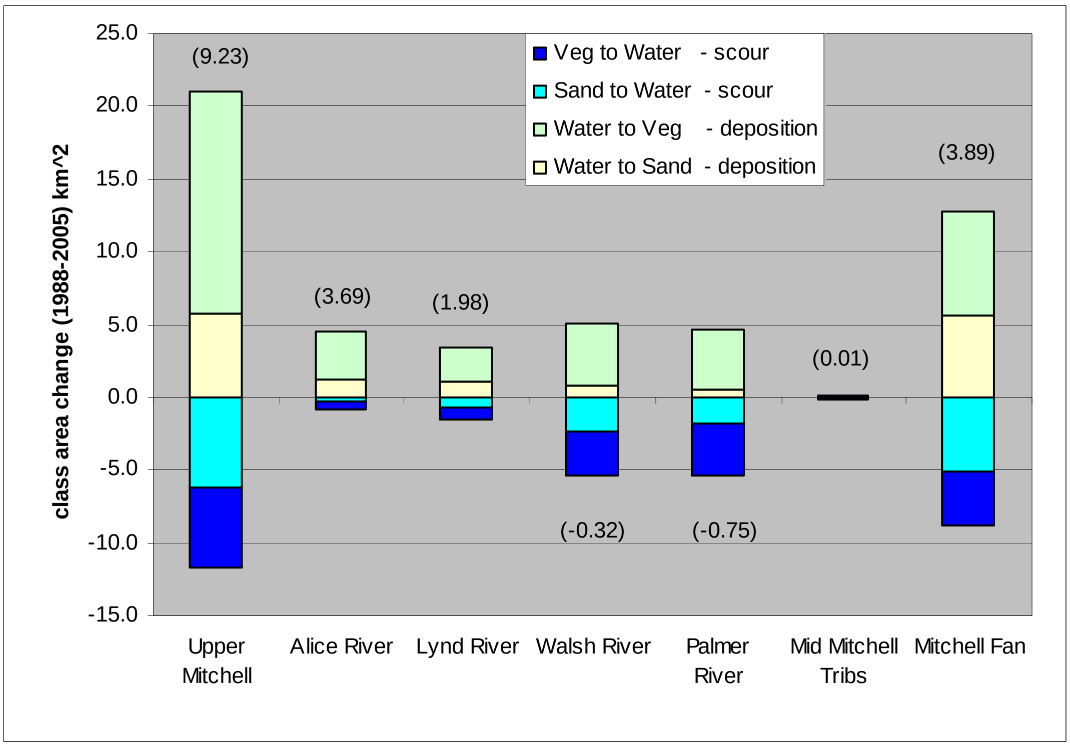

Figure 13 Relative change in the aerial extent of sand and water bodies within the ICZ between 1988 and 2005 in the Mitchell catchment. This graph represents the area of polygons that have shifted from water (i.e. pools) in 1988 to either bare sand bars or vegetated sand bars in 2005 (i.e. net deposition), or from bare or vegetated sand bars in 1988 to water/pools in 2005 (i.e. net scour). The assumption is made that the water picked up in the dry season imagery in both years represents pools in which water depth is >1/2 m deep. The numbers in parentheses represent the net area scoured or deposited in sq km

Evidence for Sediment Accumulation

The data presented in Figure 13 and shows the trend in net sediment accumulation or scour at the scale of the major sub-catchments. Despite these data only representing net change between two time slices across a 17 year interval, they demonstrate a clear trend towards net accumulation in most sub-catchments and minor net scour in others. The graph has been separated into the two components of scour and deposition that we can be confident does represent change in sediment storage. Of these the sand – water and water – sand classes are the least ambiguous, and because, by definition, it excludes any of the channel impacted by riparian vegetation, should highlight any broad trend towards either pool in-filling or increasing pool area (Table 8).

Table 8 Summary table showing the underlying geomorphic implications of the observed changes indicated by the remote sensing data. Only those categories from which an unambiguous interpretation can be made of scour or deposition have been used in subsequent calculations.

Nature of Change 1988 - 2005	Physical Interpretation of Detected change
veg to veg, sand to sand, water to water	Status quo (i.e., no discernible net change). However veg density may have changed and sand–sand & water-water likely includes major turnover. (**ambiguous**)
veg to sand	Possible island or bench scour (**ambiguous**)
sand to veg	Island/bar formation + stabilisation (**ambiguous**)
water to sand	bar formation (= **deposition**)
water to veg	Island/bar formation + stabilization (= **deposition**)
sand to water	bar scour (= **scour**)
veg to water	Erosion of vegetation and bar scour (= **scour**)

The two most extensive areas of in-channel zone, the upper Mitchell and the Mitchell fan reach, have both experienced considerable net bar deposition between 1988 and 2005, with net increases of 9.23 km^2 and 3.89 km^2 respectively. The Alice River (the least disturbed sub-catchment - Figure 9) has also experienced considerable net sediment accumulation (3.69 km^2). Of the other tributaries, the Lynd has experienced net bar accretion (1.89 km^2), while both the Walsh and Palmer have experienced a 0.32 and 0.75 km^2 net increase in pool area respectively, suggesting there has been net export of sediment from these streams.

These data indicate that at the overall catchment level there are some distinct patterns in the way different tributaries are behaving through time. The Walsh and Palmer rivers appear to have experienced a minor net export of sediment over the last 17 years, possibly reflecting the reworking of mining related sediment pulses delivered to each tributary over the last century. The Lynd and Alice Rivers, on the other hand, would appear to have experienced net sediment accumulation. Without further evidence of sediment sources we can only speculate at this stage on what might be the drivers of these changes, but it is likely a combination of the differing geology and flood regimes in each tributary coupled with the different land use intensity, particularly the grazing and fire regime. The graph shown in Figure 14 suggests that land-use may be an important driver of the observed changes over the study period, if the road/land-use intensity relationship can be further validated – and a causal mechanism derived.

When viewed in aggregate, it is clear that at the catchment scale there is a substantial trend towards increased deposition, rather than scour. In total there is 17.7 km^2 more bar area in 2005 compared with 1988. When converted to a volume, using the moderate 3m estimate of average scour/deposition depth (Table 9), this represents somewhere in the order of 3.1 M m^3 of excess sediment deposition per annum over the study period (or a total of 53M m^3 over the 17 year period). Clearly, there is a need for field validation of the depth of scour data, but by any measure this is a substantial volume of net bed material accumulation over the study period.

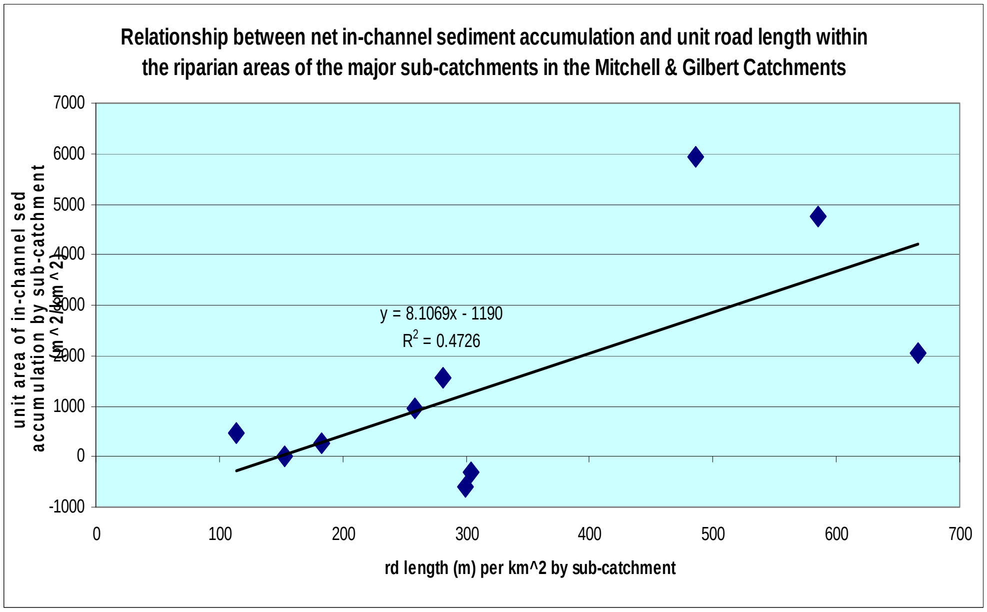

Figure 14 Relationship between unit road length (i.e. land-use proxy) within each sub-catchment, and net change in pool/bar extent for all subcatchment in the Mitchell and Gilbert Rivers (per unit sub-catchment area). Note that the Mitchell & Gilbert Fans has been left out of the analysis, as it was assumed that this part of the catchment was receiving the cumulative impacts of the upstream contributing sub-catchments, and a direct relationship between fan land-use intensity and channel change, would not be expected.

Table 9 Net change in the aerial extent of sand bars, vegetated sand bars and pools (low flow channel extent) for the Mitchell River between 1988 and 2005. Also shown in the table are estimates of the minimum volumetric changes represented by the observed changes in aerial extent, based on low, mid and upper estimates of average depths of scour of the reworked in-channel geomorphic units. Field observations in the Mitchell River indicate that if a pool is in-filled to become a sand bar (or the converse), somewhere in the order of 3 – 10m of deposition (scour) has taken place at that particular site. Assuming this as typical, estimates of the minimum depth of bed material that has been turned over to either deposit a bar or scour a pool can be made, and hence derive estimates of minimum sediment turnover within the channel. The assumption is also made that in the status quo categories (sand – sand or water – water), on average there has been no net change in sediment storage. However, the extent to which any sand bar or pool has been turned over or exchanged from one wet season to the next is unknown. As such, a sand bar may be mapped similarly at the two time intervals (1988 and 2005), but may have been scoured and redeposited every year of the intervening period. As a result, the volumetric calculations are conservative. In reality, sand bars are likely to be the most active parts of the channel, given that vegetation has not been able to colonise these surfaces.

row	(r1-r12 units = km^2)	Upper Mitchell	Alice River	Lynd River	Walsh River	Palmer River	Mid Mitchell Tribs	Mitchell Fan	tot
r1	**Water to Sand - deposition**	**5.81**	**1.23**	**1.11**	**0.83**	**0.56**	**0.01**	**5.69**	**15.23**
r2	**Water to Veg - deposition**	**15.19**	**3.33**	**2.35**	**4.18**	**4.08**	**0.13**	**7.02**	**36.27**
r3	**Sand to Water - scour**	**-6.20**	**-0.26**	**-0.76**	**-2.37**	**-1.87**	**-0.04**	**-5.11**	**16.61**
r4	**Veg to Water - scour**	**-5.57**	**-0.61**	**-0.73**	**-2.96**	**-3.51**	**-0.09**	**-3.71**	**17.17**
r5	Sand to Veg	**17.03**	**12.53**	**12.64**	**7.83**	**8.13**	**4.19**	**14.01**	**76.35**
r6	Veg to Veg	**45.93**	**9.62**	**20.56**	**20.23**	**25.38**	**2.75**	**35.23**	**159.70**
r7	Water to Water	**15.46**	**0.49**	**1.19**	**3.37**	**2.72**	**0.07**	**16.57**	**39.87**
r8	Veg to Sand	**6.94**	**1.91**	**6.84**	**3.38**	**2.36**	**0.49**	**4.01**	**25.93**
r9	Sand to Sand	**31.37**	**8.43**	**28.79**	**9.59**	**7.25**	**2.70**	**40.39**	**128.52**
r10	Total Ch Area								**515.65**
r11	total area turned over(r1+r2)-(r3+r4)	**32.76**	**5.43**	**4.94**	**10.34**	**10.02**	**0.27**	**21.53**	**85.29**
r12	total Annual turnover (r11/17)	1.93	0.32	0.29	0.61	0.59	0.02	1.27	**5.02**
r13	**Annual Sed turnover vol (m^3)**								
r14	Turnover vol (low = 1m av scour)	1,927,279	319,228	290,846	608,088	589,191	15,809	1,266,471	**5,016,912**
r15	Turnover vol (med = 3m av scour)	5,781,838	957,684	872,537	1,824,265	1,767,574	47,426	3,799,412	**15,050,735**
r16	Turnover vol (high = 5m av scour)	9,636,397	1,596,140	1,454,228	3,040,441	2,945,956	79,044	6,332,353	**25,084,559**
r17	Net total change km^2 (sum:r1-r4)	9.23	3.69	1.98	-0.32	-0.75	0.01	3.89	**17.71**
r18	Net annual change m^3 (r17x1000000/17) med scour	1,628,162	650,404	348,640	-55,588	-132,794	882	686,029	**3,125,735**

3.4 Changes on the Floodplain

The changes in vegetation community density identified within the in-channel zone (ICZ) appear to be even more profound when one considers the entire floodplain zone (FPZ). Figure 15 shows the relative proportion of the FPZ in the various sub-catchments that have experienced both decreases and increases in canopy cover during the study period. These data show that all sub-catchments have experienced a net increase in canopy cover, albeit dominated by the more moderate increase/decrease categories. It should be pointed out that an increase in canopy cover largely reflects a shift from non-woody vegetation (primarily grassland) to a woodland or open woodland community. When all the data presented in Figure 15 are aggregated, a total of 2683 km^2 of floodplain (or 13% of the total) has experienced a net shift towards a woody vegetation community. A great deal more research is required to verify this trend and to quantify what this means in terms of increased wood volume (or carbon storage), and what the underlying drivers are. The fact that there has also been substantial decreases in canopy cover, suggests there may not be a dominant mechanism driving the increase in woody vegetation cover (e.g. rainfall). Qualitative assessment of the change maps suggests there is spatial variability in the trends, with significant patches shifting back towards a grassland dominated community, at the same time as other patches are shifting the other way. A more detailed analysis is required to determine whether these patterns are consistent through time.

The obvious candidates for drivers of a shift towards woody vegetation are grazing, fire and rainfall (*sensu* Fensham et al, 2005). A preliminary analysis of the available fire scar data, which is only available for the period 2000 - 2006 (Peter Thompson CYPDA pers comm.), shows no real relationship between burn frequency and a shift to either woody or non woody vegetation (Figure 16,Figure 17). These data provide a hint that if an area is burnt more than 7 times in a 6 year period, that there may be a shift towards a non woody vegetation community. However, the fact that these fire scar data only overlap the vegetation change data for the last 6 yrs of the analysis, suggests it is most likely that we currently have insufficient historical fire data to tease out the relationship between fire frequency and vegetation community dynamics, and that any relationship falling out here is a function of some other mechanism. Furthermore, the small area encompassed by the categories burnt 7 and 8 times means there is greater potential for error.

Other Drivers of Vegetation Community Change

There is a substantial literature on the trends in vegetation community structural changes throughout the semi-arid zone in Queensland (e.g. Fensham et al, 2005), and the consensus view appears to be that in the cases where an increase in woody vegetation can be detected over the longer term (i.e. multiple decades), and which only occurs over a relatively small proportion of the total landscape in the studied areas), that rainfall appears to be the dominant driver (Fensham et al., 2005). The other prime candidate – grazing- is very hard to accurately quantify, particularly in a retrodictive sense across large spatial extents, and as such it is not possible to test for the effect of changed grazing pressure through time in an analysis such as this. An initial analysis of rainfall trends has been conducted to assess whether this may be a primary driver of the trend towards increasing woody vegetation cover. The other factor, not widely canvassed in the rangelands ecological literature, is the role of weed invasion. In the Northern Gulf, the weed of national significance *Cryptostegia grandiflora (rubber vine)* is now found across a large proportion of the riparian zone, in both the FPZ and ACZ. According to the Traditional Owners from the lower reaches of the Mitchell megafan, rubber vine only appeared in that area in the 1980s (Colin Lawrence pers. comm., 2008). From a remote sensing perspective, the spread of rubber vine would return a spectral signature more akin to wood vegetation than grassland, and hence, it is possible that some of the detected vegetation community change is indeed rubber vine. The release of a biological control for rubber vine in 1996, also appears to have had some effect on reducing the vigour of existing infestations of the weed, and its spread. It is possible this may account for some of the trend from a woody vegetation community to non woody. Detailed field validation would be required to verify this.

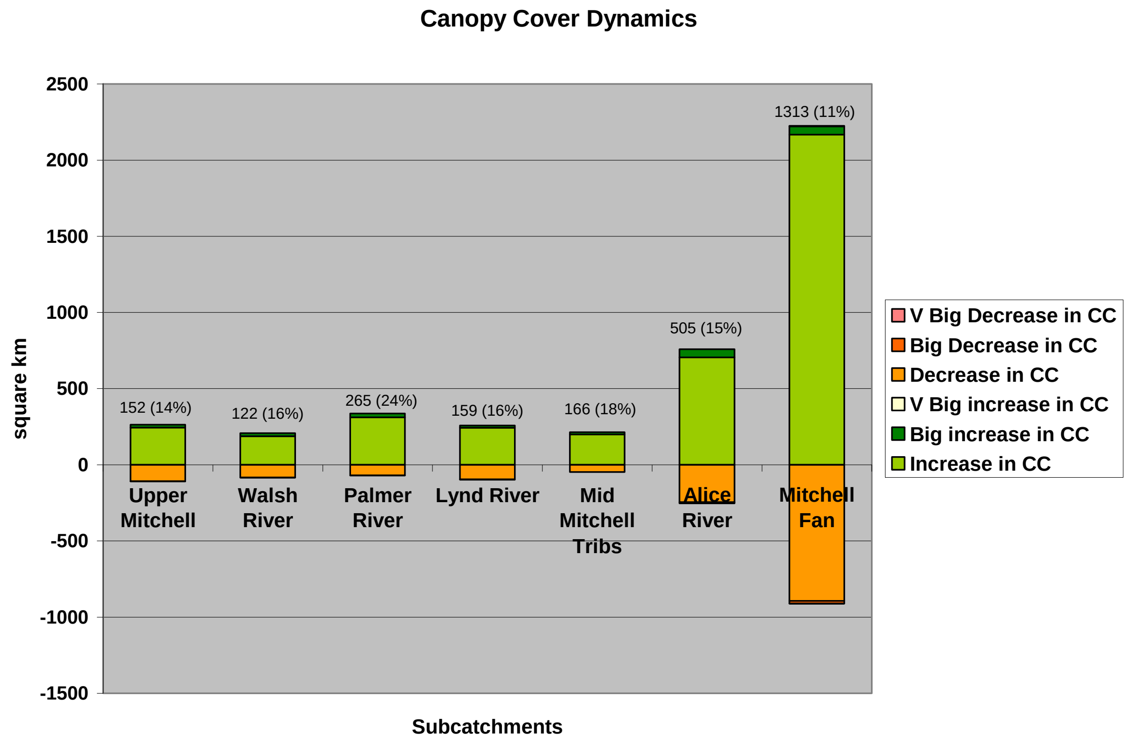

Figure 15 Relative change in vegetation cover within the floodplain zone (FPZ) between 1988 and 2005 within the Mitchell catchment. Values shown above each bar are the net change of canopy cover (in km^2) within the FPZ in each sub-catchment. Values in brackets show the percentage of the total floodplain in each sub-catchment that has experienced a net increase in canopy cover.

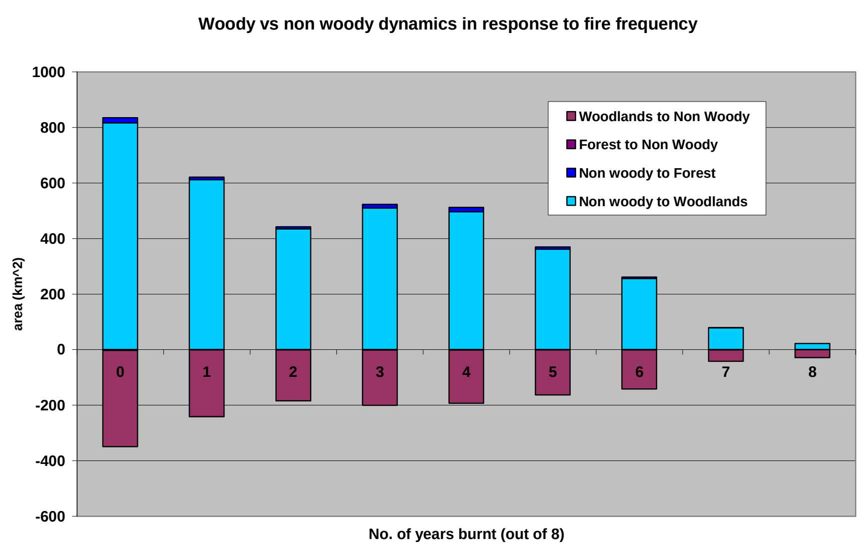

Figure 16 Relationship between burn frequency and net trend towards woody vegetation from 1988 – 2005.

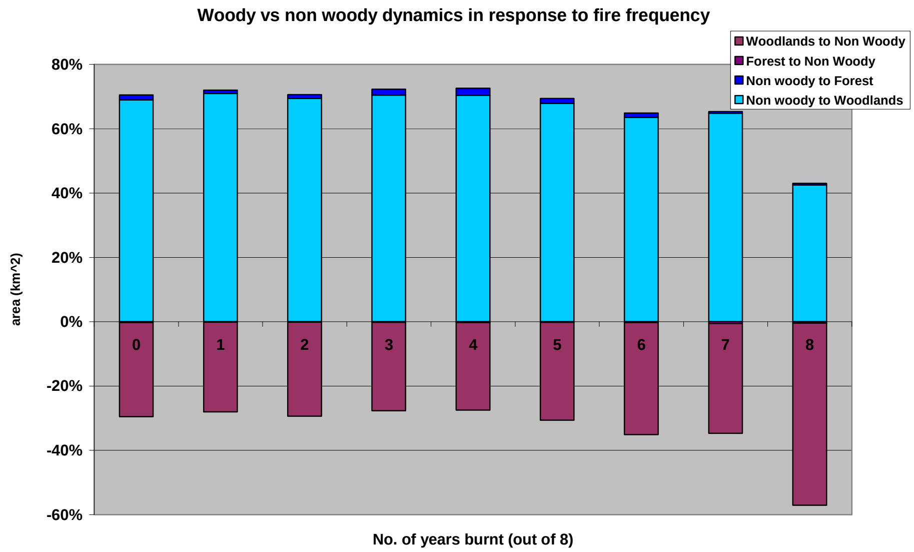

Figure 17 Relationship between burn frequency and net trend towards woody vegetation from 1988 – 2005 as a proportion of the cumulative total area burnt. Note these are the same data as Figure 16 that have been normalised to highlight the net effect as a proportion of area burnt in each class.

Rainfall as a Driver of Increasing Woody Vegetation Cover

To test the possibility that the observed changes in vegetation canopy density are driven primarily by rainfall, we analysed three good quality (few gaps) long term rainfall records within the Mitchell catchment. The analysis of residuals from long term median rainfalls shown in Figure 18 and the cusum analysis shown in Figure 19, indicate that a distinct upturn in annual rainfall occurred in the late 1960s, which persisted for around a decade, and then trended the opposite way – towards a distinctly drier phase until around 1992. This was then followed by a shorter "wet" phase, and then a shift back towards below average rainfall from around 2000. The pooled rainfall averages from these phases can be seen in Table 10. Interestingly, the period encompassing the remote sensing analysis (1988 – 2005), straddles three of these wetter and drier phases, which makes it difficult to determine the net effect on vegetation community development over this period. From Table 10 it is apparent that there has been a slight net increase in rainfall over the 17 year period encompassing the analysis, however, the analysis window commences in a drier spell, then experiences a significantly wetter period for about 8 years, before shifting back into a distinctly drier phase in the 5 years leading up to the time the 2005 image was captured. It is reasonable to assume that while the overall average annual rainfall between 1988 and 2005 does not differ significantly from the long term mean, the fact that there was an 8 year period of above average rainfall, could have provided a substantial boost to vegetation community vigour across this period. A developing woody vegetation community would retain a "memory" of such a vigorous growth spurt during a wetter phase, even if the overall average for the period was not that different to the long term mean. This effect would be particularly noticeable if the rainfall events themselves triggered a mass recruitment of woody species, and which were given a critical boost during their vulnerable juvenile life stage. Alternatively, there may simply have been a concatenation of events leading to circumstances that were particularly conducive to the vegetation community growth and development. Hence, while not conclusive, this analysis would tend to suggest that it is not possible to rule out secular shifts in the rainfall regime as a driver of woody thickening within the Mitchell River riparian zone.

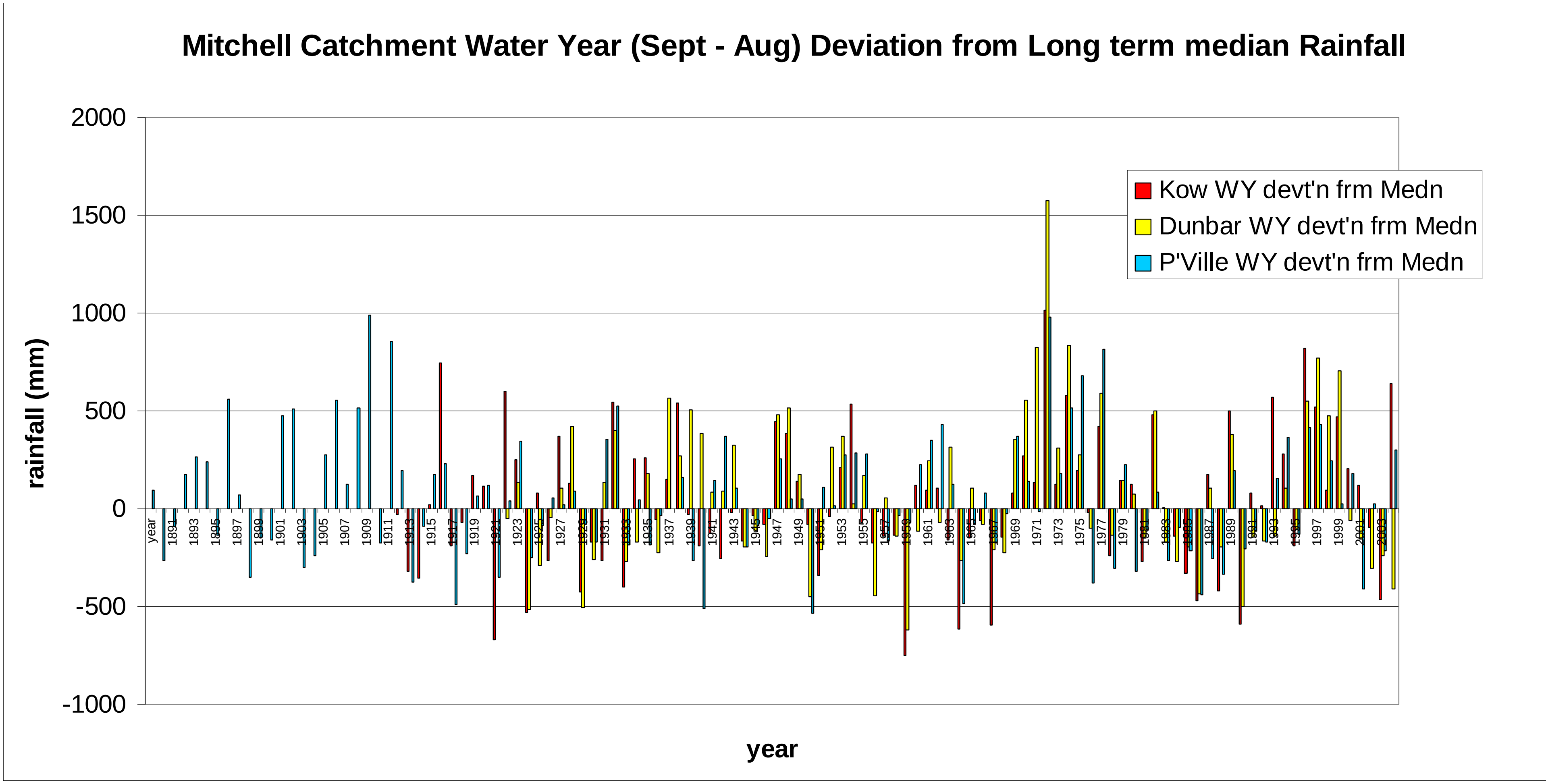

Figure 18 Residuals from the long term median rainfall at three long term rainfall stations in the Mitchell catchment. Data has been analysed according to the water year, which in this case has been defined as extending from September to August. Gaps in the record were filled with data from the closest station (generally < 100km apart).

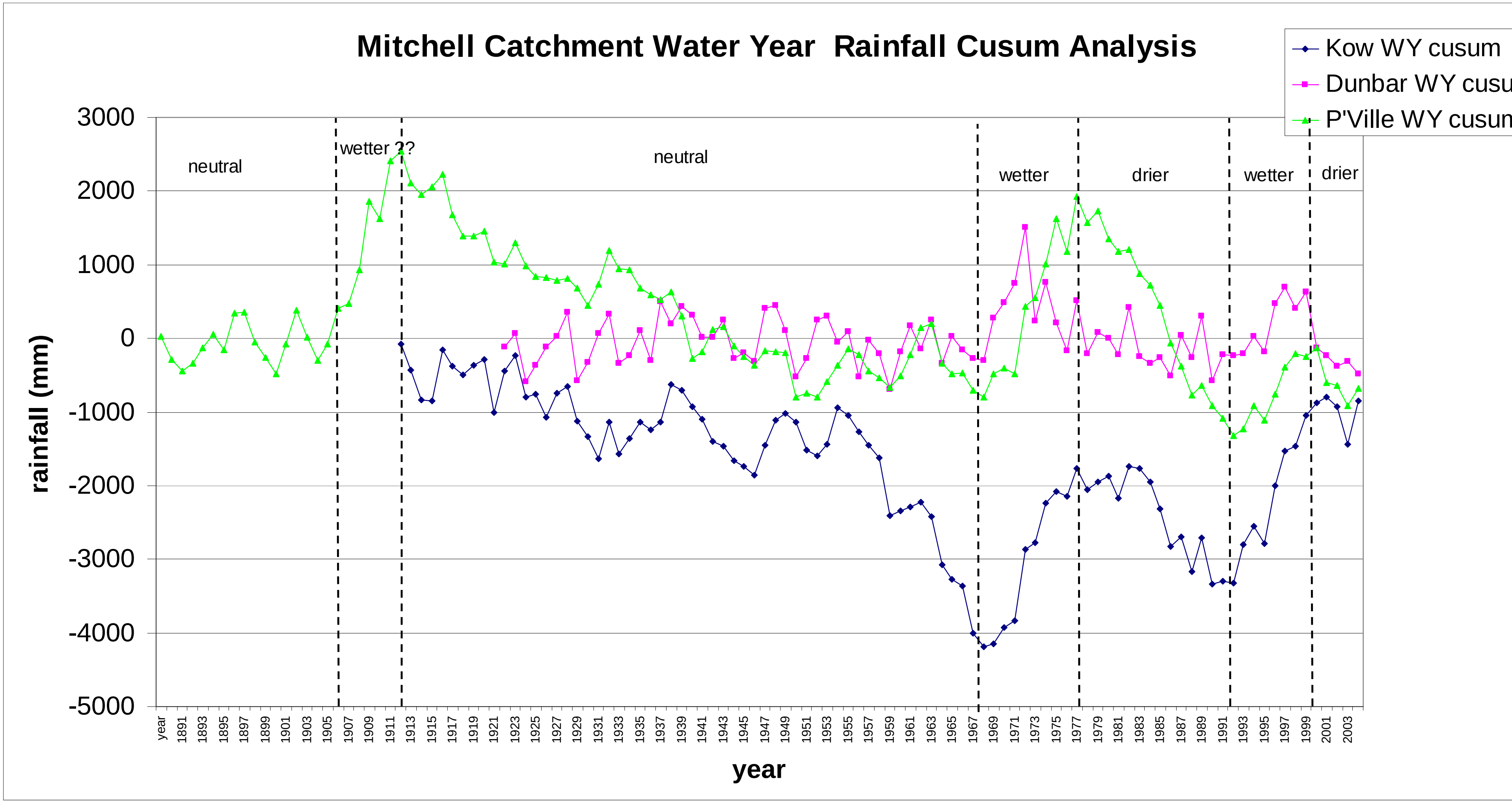

Figure 19 A cusum analysis (cumulative annual deviation from the long term mean annual rainfall – defined by water year) at three long term rainfall stations in the Mitchell catchment. Water year has been defined as the period from Sept – Aug. Sustained shifts in the trend are delineated by sustained change in the direction of the trendline.

Table 10 Part A) - Median rainfall within three long term rainfall records within the Mitchell catchment. Part B – grouped average rainfall (i.e. from data pooled from the 3 stations) broken down into the different phases identified in Figures 18 & 19. Also shown in the bottom row is the average for the period of the landsat imagery analysed in this study.

A)	Stn #	Median Rainfall	period of record
Kowanyama	029038	1216.8	1913 - present
Dunbar	029014	991.4	1923 - present
Palmerville	028004	974.8	1890 - present

B) Pooled averages for RF stations @ Kowanyama, Dunbar and Palmerville for time intervals identified within the cusum analysis	
1923 - 1968	1068
1969 - 1977	1397
1978 - 1993	1007
1992 - 2000	1343
2000 - 2005	1002
1988 - 2005	1133

3.5 Remote Sensing Results - Gilbert Catchment

In-channel zone

The pattern of in-channel vegetation change between 1988 and 2005 from the Gilbert catchment present a very similar picture to that outlined for the ICZ in the Mitchell catchment, albeit encompassing a significantly larger area than the ICZ on the Mitchell. The larger extent of ICZ in the Gilbert would appear to be a function of the fact the Gilbert fan is not as well developed as the Mitchell megafan (in terms of vertical sediment accumulation and alluvial ridge development), and is not incised to the same extent in its upper reaches. This has the effect of imposing less lateral constraint on the channel, allowing wider and more laterally active channels to develop.

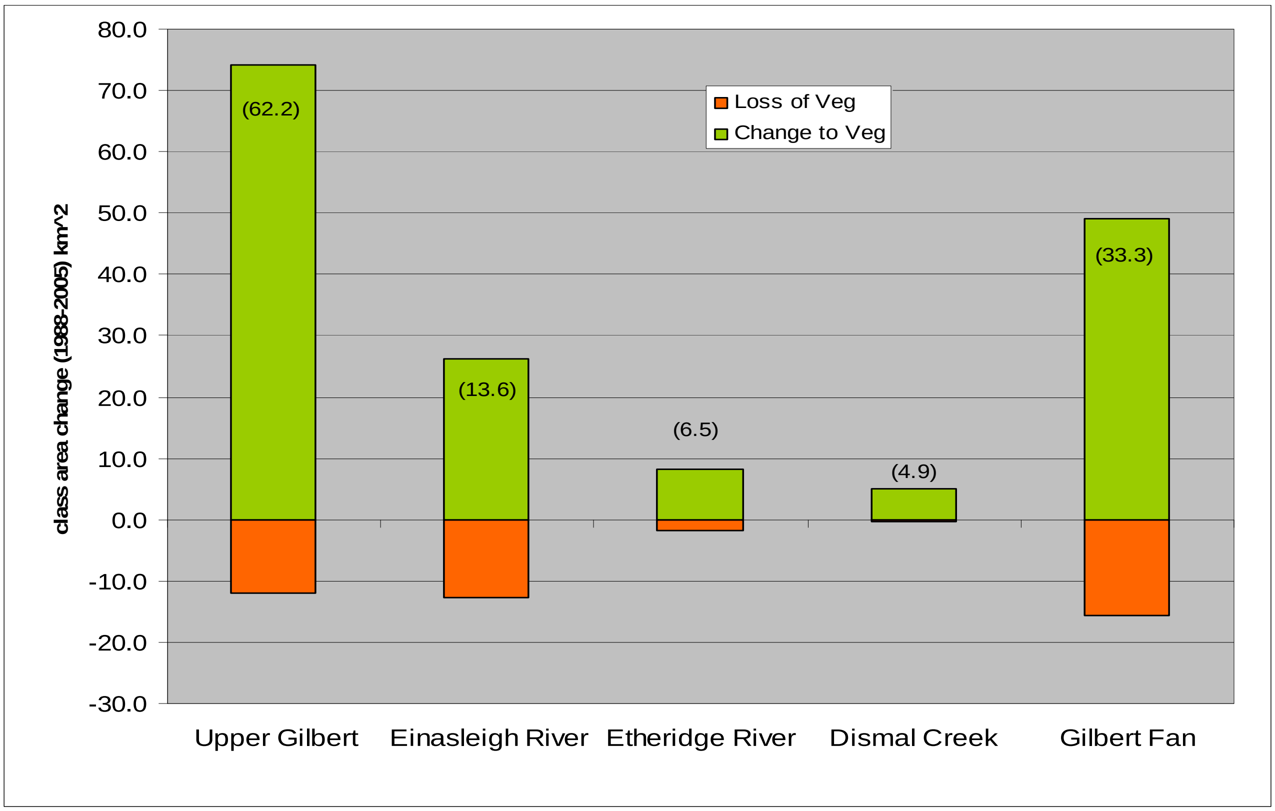

Figure 20 Relative change in vegetation cover within the in-channel zone between 1988 and 2005 within the Gilbert catchment. The "change to vegetation" class represents the sum of the polygons that have changed from either sand to vegetation or water to vegetation between 1988 and 2005. The loss of vegetation class represents polygons that have changed from vegetation to water or vegetation to sand. Net result is shown in brackets.

As was the case in the Mitchell, the data indicate there has been a large net increase in the area of in-channel vegetation across all sub-catchments. In terms of absolute area this represents a net increase of in-channel vegetation of 122040 ha over the 17 year interval assessed or 19.4% of the total area of the ICZ (62099 ha). This net gain is comprised of a total increase of 16270 ha of in-channel vegetation, which is offset by a loss (via channel erosion) of 4230 ha of in-channel vegetation over the same period. Hence, there has been a considerable turnover of in-channel vegetation during this period. In annualised terms, the net vegetation increase is 708 ha/yr, or 1.14% of the total area of the in-channel zone.

Implications

As in the Mitchell, the net increase in vegetation detected via this change detection analysis represents a very significant increase in the total area of in-channel vegetation over the 17 year period between 1988 and 2005. The same suite of possible mechanisms driving such a change would apply in the Gilbert as in the Mitchell. Refer to the Mitchell River section for some discussion of these.

Evidence for Sediment Accumulation

The data presented in Figure 21 and shows the trend in net sediment accumulation or scour at the scale of the major sub-catchments. Despite, these data only representing net change between two time slices across a 17 year interval, they demonstrate a clear trend towards net accumulation in all sub-catchments. As for the analysis in the Mitchell, the graph has been separated into the two components of scour and deposition that we can be confident do represent change in sediment storage, as summarized in Table 8 .

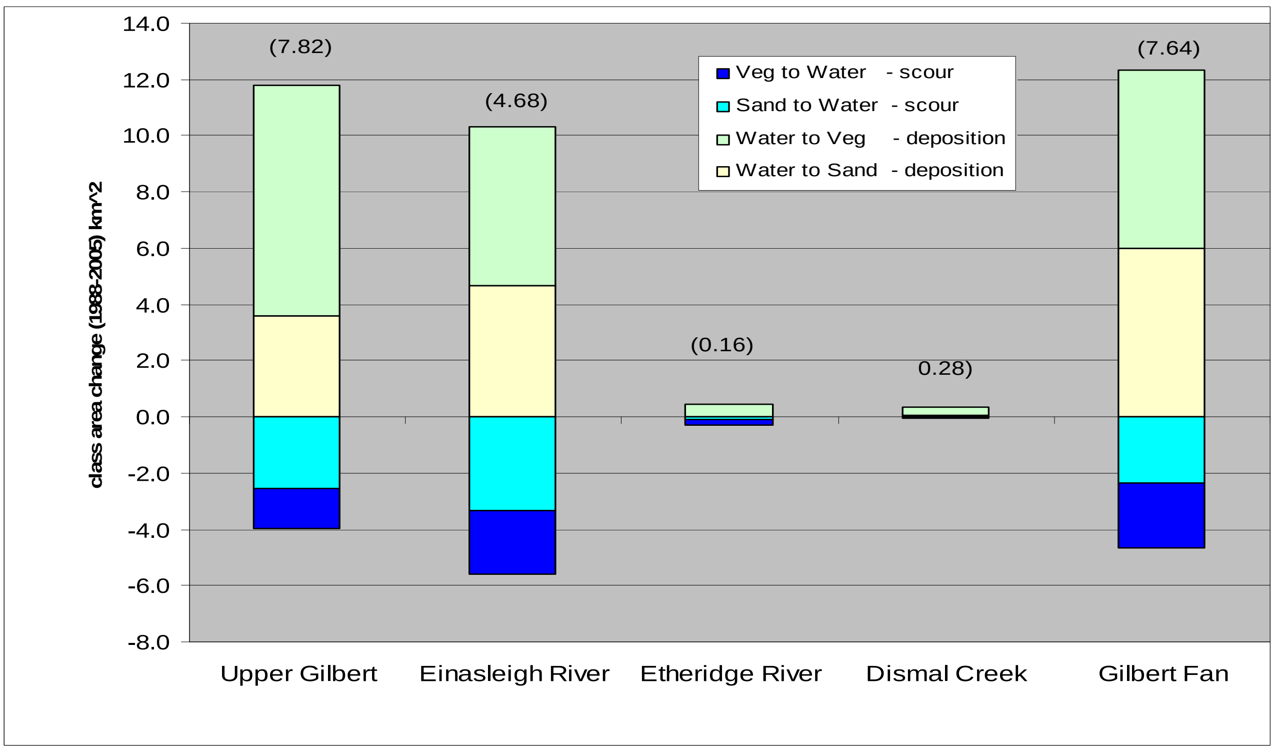

Figure 21 Relative change in the aerial extent of sand and water bodies within the ICZ between 1988 and 2005 in the Mitchell catchment. This graph represents the area of polygons that have shifted from water (i.e. pools) in 1988 to either bare sand bars or vegetated sand bars in 2005 (i.e. net deposition), or from bare or vegetated sand bars in 1988 to water/pools in 2005 (i.e. net scour). The assumption is made that the water picked up in the dry season imagery in both years represents pools in which water depth is several meters or more in depth. Net result (deposition) in sq km is shown in brackets.

Not surprisingly, the three sub-catchments having the most extensive areas of in-channel zone, the upper Gilbert, the Gilbert fan, and the Einasleigh River, have between them experienced the bulk of the net bar deposition between 1988 and 2005. Respectively, these three sub-catchments have experienced net bar area increases of 7.82 km^2, 7.64 km^2 and 4.68 km^2. The two smaller sub-catchments only contribute an additional 0.44 km^2. Unlike the situation in the Mitchell where there was a pattern of some tributaries showing an apparent net decrease in sand bars over the study period, all tributaries to the Gilbert demonstrate a net increase, though for Etheridge and Dismal Creek, the net increase was minor.

At the whole catchment scale, as in the Mitchell, there is a substantial trend towards increased deposition, rather than scour. In total there is 20.6 km^2 more bar area in 2005 compared with 1988. When converted to a volume, using the moderate 3m estimate of average scour/deposition depth (Table 11), this represents somewhere in the order of 3.6 M

m^3 of excess sediment deposition per annum over the study period (or a total of 61.8M m^3 over the 17 year period). As outlined previously, there is a need for field validation of the depth of scour data, but by any measure, even using the most conservative estimate, there appears to have been a substantial volume of net bed material accumulation over the study period.

Table 11 Net change in the aerial extent of sand bars, vegetated sand bars and pools (low flow channel extent) for the Gilbert River between 1988 and 2005. Also shown in the table are estimates of the minimum volumetric changes represented by the observed changes in aerial extent, based on low, mid and upper estimates of average depths of scour of the reworked in-channel geomorphic units. Field observations in the Gilbert River indicate that if a pool is in-filled to become a sand bar (or the converse), somewhere in the order of 3 – 8 m of deposition (scour) has taken place at that particular site. Assuming this as typical, estimates of the minimum depth of bed material that has been turned over to either deposit a bar or scour a pool can be made, and hence derive estimates of minimum sediment turnover within the channel. The assumption is also made that in the status quo categories (sand – sand or water – water), on average there has been no net change in sediment storage. However, the extent to which any sand bar or pool has been turned over or exchanged from one wet season to the next is unknown. As such, a sand bar may be mapped similarly at the two time intervals (1988 and 2005), but may have been scoured and redeposited every year of the intervening period. As a result, the volumetric calculations are conservative. In reality, sand bars are likely to be the most active parts of the channel, given that vegetation has not been able to colonise these surfaces.

row	**(r1-r12 units = km^2)**	Upper Gilbert	Einasleigh River	Etheridge River	Dismal Creek	Gilbert Fan	**tot**
r1	**Water to Sand - deposition**	**3.59**	**4.69**	**0.01**	**0.08**	**5.98**	**14.35**
r2	**Water to Veg - deposition**	**8.20**	**5.61**	**0.44**	**0.25**	**6.33**	**20.83**
r3	**Sand to Water - scour**	**-2.55**	**-3.33**	**-0.09**	**-0.01**	**-2.38**	**8.35**
r4	**Veg to Water - scour**	**-1.42**	**-2.28**	**-0.20**	**-0.04**	**-2.29**	**6.23**
r5	Sand to Veg	**65.96**	**20.62**	**7.75**	**4.84**	**42.70**	**141.87**
r6	Veg to Veg	**44.11**	**32.64**	**7.76**	**2.18**	**60.65**	**147.34**
r7	Water to Water	**1.82**	**5.15**	**0.19**	**0.03**	**5.79**	**12.98**
r8	Veg to Sand	**10.58**	**10.40**	**1.47**	**0.17**	**13.45**	**36.06**
r9	Sand to Sand	**92.28**	**54.30**	**14.42**	**2.01**	**69.97**	**232.97**
r10	Total Ch Area						**620.99**
r11	total area turned over(r1+r2)-(r3+r4)	**15.75**	**15.92**	**0.75**	**0.38**	**16.97**	**49.77**
r12	total Annual turnover (r11/17)	0.93	0.94	0.04	0.02	1.00	**2.93**
r13	**Sediment Turnover (m^3)**						
r14	Turnover vol (low = 1m av scour)	926,728	936,176	44,154	22,096	998,493	**2,927,647**
r15	Turnover vol (med = 3m av scour)	2,780,184	2,808,529	132,463	66,287	2,995,478	**8,782,941**
r16	Turnover vol (high = 5m av scour)	4,633,640	4,680,882	220,772	110,478	4,992,463	**14,638,235**
r17	Net total change km^2 (sum:r1-r4)	7.82	4.69	0.16	0.28	7.64	**20.59**
r18	Net annual change m^3 (r17x1000000/17) med scour	1,380,772	827,868	27,684	48,860	1,348,787	**3,633,971**

Potential Drivers of Change

The same suite of potential drivers of change in sediment accumulation and vegetation extent apply in the Gilbert as in the Mitchell. As outlined previously for the Mitchell, Figure 14 suggests that land-use *may* be an important driver of the observed changes over the study period, if the road/land-use intensity relationship can be further validated – and a causal mechanism derived.

The flow data from the lowest gauge on the Gilbert River, the Rockfields gauge (stn 917001D) demonstrates that the discharge regime in this catchment is substantially more variable than that in the Mitchell. While this record is the longest and most continuous data from the Gilbert catchment, some caution is required in the interpretation of the data due to some large data gaps in the 90/91, 91/92, 93/94 & 94/95 wet seasons. The study period appears to be characterised by lower flows than the earlier part of the record, but when accounting for the missing data, little can really be determined from this record. If flows were lower during the period post 1988, this could account for the trend towards net in-channel sediment accumulation, rather than scour. What is clearly apparent from this record, however, is the extreme nature of the 1973/74 wet season, which completely overshadows all other wet seasons in the period of record. It is possible that the influence of this extreme year may indeed be exerting a strong lagged influence throughout the catchment, and that the net aggradation detected across the study period represents a phase of channel recovery following the extreme floods of 1973/74. A higher resolution multi-temporal analysis is required to conclusively establish the relationship between floods and vegetation colonisation/removal.

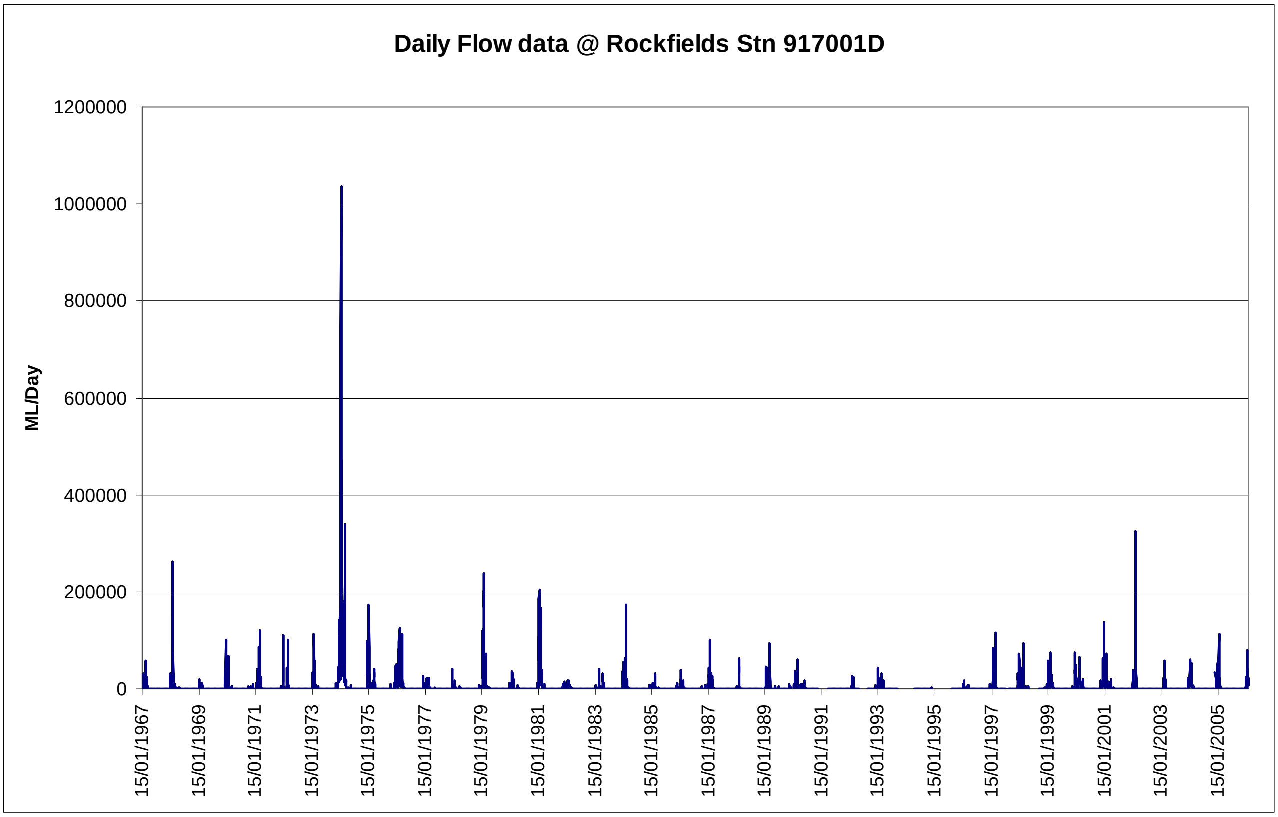

Figure 22 Daily discharge record for the Rockfields gauge (ML/Day) on the Gilbert River (stn #. 917001D). Note data is missing from the wet seasons 90/91, 91/92, 93/94 & 94/95.

Floodplain Zone Dynamics

The large changes in floodplain vegetation community density identified in the Mitchell catchment are also equally apparent in the Gilbert. Figure 29 shows the relative proportion of the FPZ in the various sub-catchments of the Gilbert, all of which have experienced increases in canopy cover during the study period, albeit dominated by the more moderate increase/decrease categories. When all the data presented in Figure 23 are aggregated, a total of 1090 km^2 of floodplain (or 10% of total floodplain area) has experienced a net shift towards a woody vegetation community. The same caveats outlined for the Mitchell regarding spatial variability of the trends apply, and hence there is also a clear need for more detailed multi-temporal analysis of the trends to verify the apparent trends summarised here.

Drivers of Vegetation Community Change

The potential drivers of vegetation community change in the Gilbert catchment are the same as those outlined for the Mitchell, and with the exception of the rainfall data, little further can elucidated from currently available data. The available rainfall data in the Gilbert catchment is even better than the selected long term records analysed in the Mitchell. These are analysed below in an initial attempt to determine the relative influence of rainfall as a driver of vegetation community change.

Rainfall as a driver of Increasing Woody Vegetation Cover

To test the possibility that the observed changes in vegetation canopy density are driven primarily by rainfall, we analysed three good quality (few gaps) long term rainfall records within the Gilbert catchment. The analysis of residuals from long term median rainfalls shown in Figure 24 and the cusum analysis shown in Figure 25, shows a less distinct pattern of increasing rainfall in the late 1960s, than was apparent in the Mitchell. Similar to the trend in the Mitchell though, this upturn persisted for around a decade, and then trended the opposite way – towards a distinctly drier phase until around 1993. The shorter "wet" phase that then followed in the Mitchell does not appear to be evident within these records from the Gilbert – with the exception of one of the records (Vanrook) which records two wet years in 1994 and 1995. On average, it seems as though the general trend after about 1993 is back towards the average rainfall regime The pooled rainfall averages from these phases can be seen in Table 10. In this instance, the period encompassing the remote sensing analysis (1988 – 2005), straddles two of these phases, and if anything the overall rainfall regime averaged across this period is one of slightly below average rainfall. On this evidence, it is difficult to invoke a rainfall mechanism as a key driver of vegetation thickening, across the study period in the Gilbert catchment. Although, analysis of more records would be advised to test this trend more thoroughly.

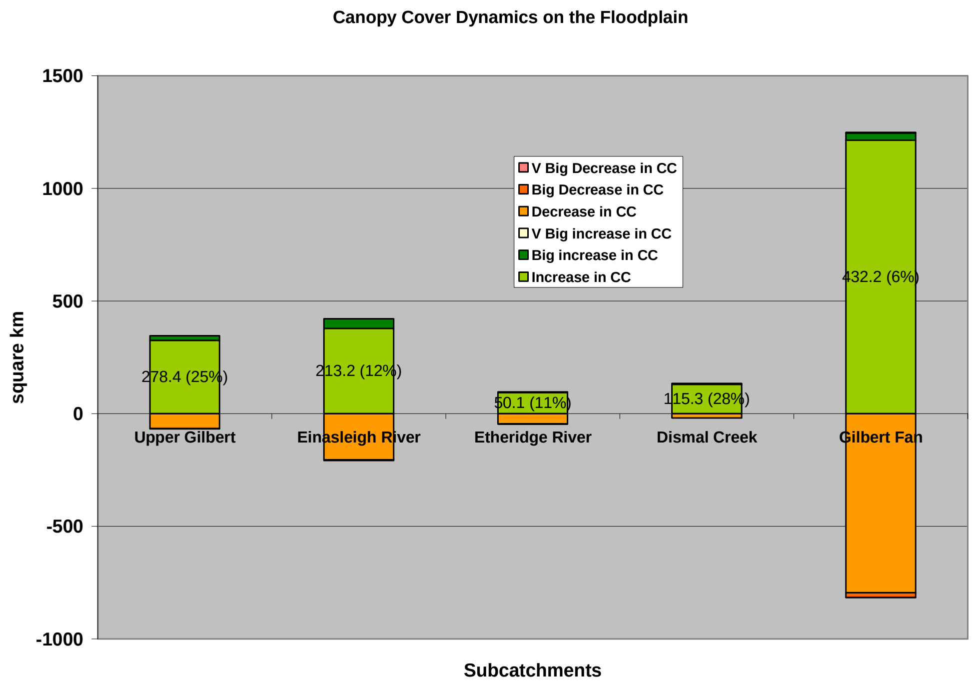

Figure 23 Relative change in vegetation cover within the floodplain zone (FPZ) between 1988 and 2005 within the Gilbert catchment. Values shown above each bar are the net change of canopy cover (in km^2) within the FPZ in each sub-catchment. Values in brackets show the percentage of the total floodplain in each sub-catchment that has experienced a net increase in canopy cover.

Table 12 Part A) - Median rainfall within three long term rainfall records within the Gilbert catchment. Part B – grouped average rainfall (i.e. from data pooled from the 3 stations) broken down into the different phases identified in Figures 20 & 21. Also shown in the bottom row is the average for the period of the Landsat imagery analysed in this study.

Part A)	Stn #	Median Rainfall	period of record
Georgetown	030018	792.6	1872 - present
Mt Surprise	030036	785	1873 - present
Vanrook	029048	897.4	1922 - present
Part B) Pooled averages for RF stations @ Georgetown, Mt Surprise & Vanrook Stn.			
1922 - 1937	726.7		
1938 - 1968	861.2		
1969 - 1979	1070.9		
1980 - 1993	719.4		
1993 - 2005	797.8		
1988 - 2005	781.3		

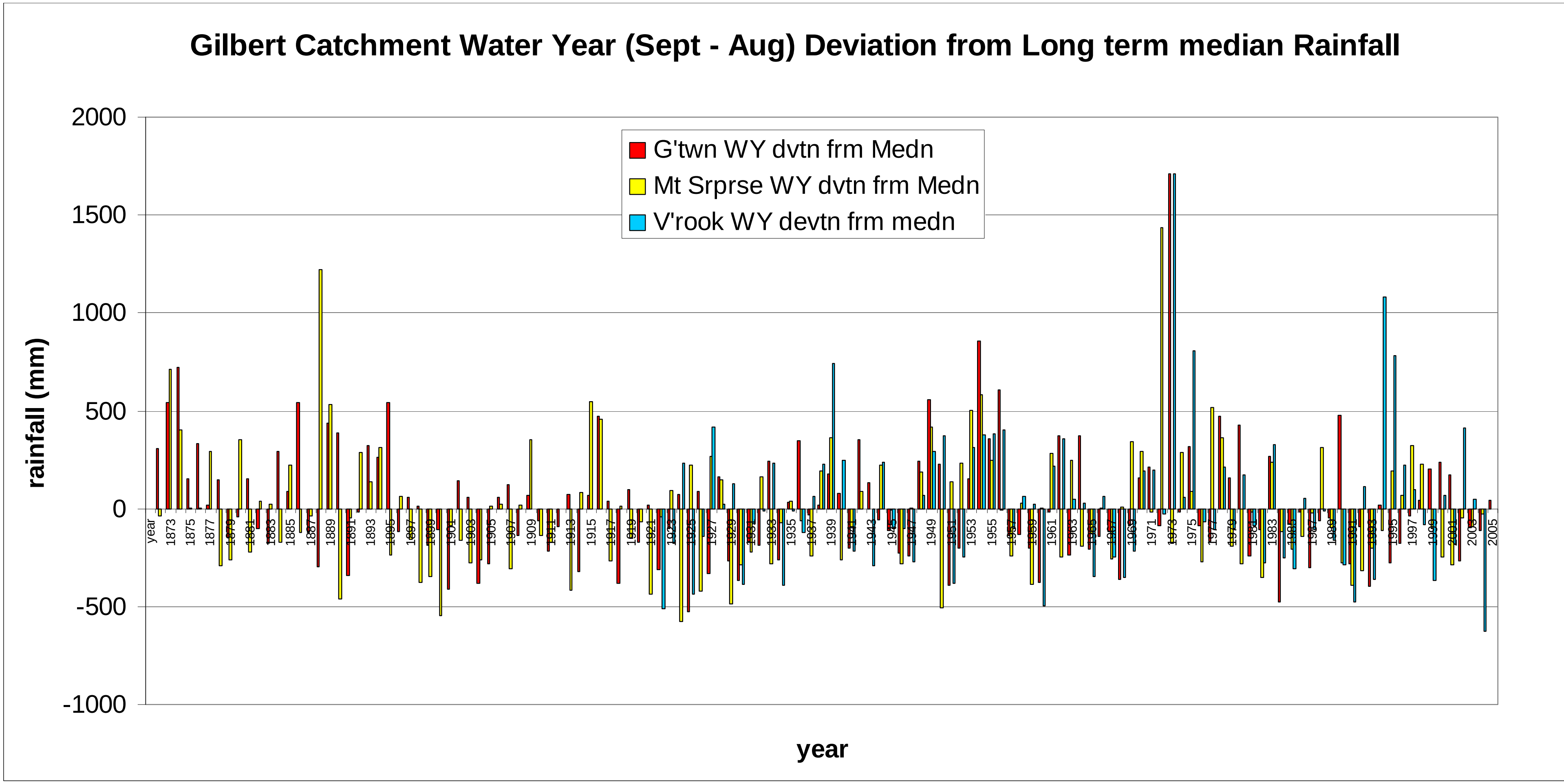

Figure 24 Residuals from the long term median rainfall at three long term rainfall stations in the Gilbert catchment (Georgetown, Mt Surprise & Vanrook Stn.). Data has been analysed according to the water year, which in this case has been defined as extending from September to August.

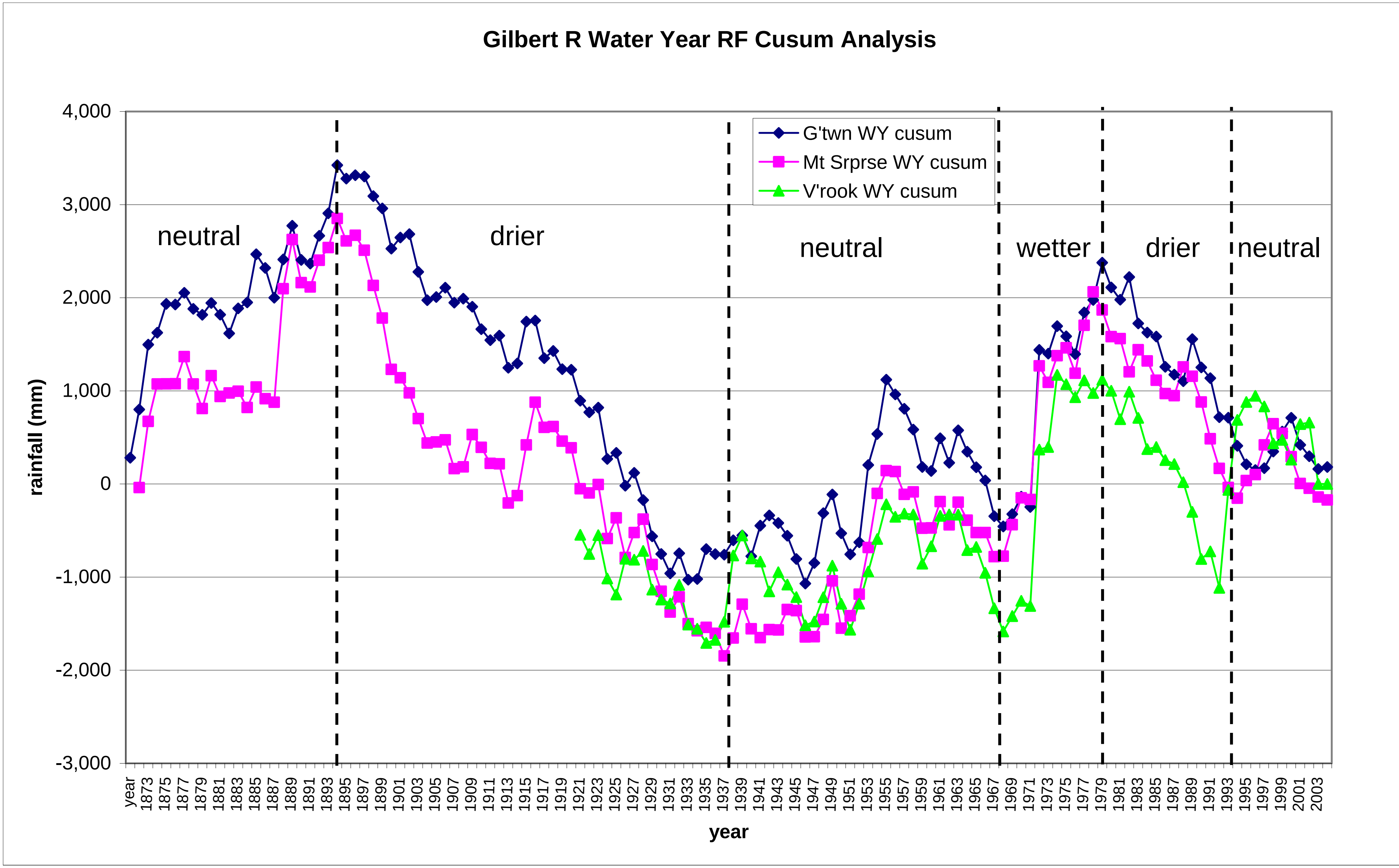

Figure 25 A cusum analysis (cumulative annual deviation from the long term mean annual rainfall – defined by water year) at three long term rainfall stations in the Gilbert catchment. Water year has been defined as the period from Sept – Aug.

3.6 Discussion & Conclusion – Remote Sensing of Riparian Zones

The vegetation changes detected via the remote sensing analysis are far in excess of what we would have anticipated would have been the case in this landscape, over a relatively short period of time. It is acknowledged that the remote sensing analysis carried out as part of this study is a first cut at quantifying riparian status within the Northern Gulf region. The use of only two timeslices presents potential problems in terms of introducing systematic error into the analysis, should the images from the two timeslices not be well calibrated and rectified. Nevertheless, the fact that we have observed such dramatic changes in woody vegetation cover both in the channel zone and across floodplains, across a large spatial extent of landscape, warrants much more detailed investigation to establish: a) whether the trends elucidated in this study are real; and b) what the drivers of the changes are (i.e. is there a clear trend through time or is there some variability that is a function of inter-annual climatic variability).

The trend towards in-channel sedimentation over the study period tends to confirm anecdotal evidence for sustained in-channel sedimentation, and most importantly a reduction in the extent of pool habitat. Further work is required to both validate the trend observed in this simple analysis, and to determine the underlying causes driving the change (if they can be confirmed).

Our initial assessments of the drivers of change highlight a number of issues:

- Rainfall may be an important driver in the Mitchell catchment, but in the Gilbert the influence of rainfall variability through time is less clear.
- More fire data (i.e. a longer time series) is required to determine the relative influence of the fire regime on patterns of vegetation community change.
- There appears to be a fairly strong correlation between land use intensity (as measured by a derived road density index – Fig 14) and in-channel sedimentation. Whether there is a causal link here is yet to be determined, but it would be consistent with relationships established in other regions.

In summary, it seems that there is much to be gained from undertaking a catchment scale riparian assessment using a remote sensing approach, particularly if such a broad scale analysis can be integrated with on-ground assessment procedures such as TRaRC (next section), and the farm scale grazing land management (GLM – or Savanna Plan as it has become known) (see Shaw et al., 2007). The integration of this catchment scale remote sensing approach with GLM/Savanna Plan, would appear to be a high priority for ongoing research.

4 Ground-based assessment of Riparian Status using the TRARC method.

Figure 26 Typical riparian zone on the upper Walsh River

4.1 Field Based Assessment of Riparian Condition (TRARC)

Summary of TRARC approach and results

The status of riparian vegetation at 172 sites in the Gilbert River and Mitchell River catchments was assessed based on the Tropical Rapid Appraisal of Riparian Condition (TRARC) method. The TRARC method provides data on a number of measurable ecological attributes, such as regeneration of native species, weed distribution and intensity, litter distribution, and ground-cover composition. These attributes can subsequently be isolated and examined with regard to their individual effects on Condition. The method provides a quantified score (0-100) with a higher score implying better Condition. As outlined in Milestone 2 (Brooks et al., 2007), the relationship between these scores and some independent measure of "condition" has yet to be established in the Gulf catchments, and as such we will not use the term condition within this report (notwithstanding the fact that the TRARC method implies we are assessing condition). Instead the raw scores alone will be presented. This is not to say that a higher score may not equate to a better "condition", rather that more work is required to clearly establish this relationship against an agreed definition of ecological condition (or indeed some other type of condition). The allocation of scores, however, does allow for comparison between sites, individual streams and catchments. The TRARC method is organized into 24 measurable indicators which are arranged into the four sub-indices of Plant Cover (7 indicators), Regeneration (5 indicators), Erosion (5 indicators) and Weeds (7 indicators). Either a single indicator, a group of indicators or a sub-index can be statistically analysed to estimate their effect on the overall score. In other words, the score of a particular site can be analysed to see which indicator, or indicators, are having the most impact on the overall score, either as a positive or negative aspect.

This project had two primary aims associated with assessing riparian status:

- to estimate riparian status at a number of specific sites using the TRARC method (Dixon *et al*. 2006) for 172 headwater sites in both the Gilbert River (72 sites) and Mitchell River (100 sites) catchments and provide a rating and analysis of those sites.
- to test the variability of the TRARC scores for different vegetation cover types [closed forest, open forest, woodland, open woodland] as defined by the remote sensing methodology. Vegetation cover types were determined at 72 sites within the Gilbert River catchment, with 16 closed forest sites, 37 open forest sites, 13 woodland sites and 6 open woodland sites. These vegetation cover class sites will be further developed with regard to spatial analysis independently of the TRARC but with attention to riparian characterisation based on remotely sensed methods.

Riparian status, as estimated by the TRARC method at the 72 sites in the Gilbert River catchment, scored in the 50-79 range at 90% of sites. It was estimated using a Least Square Fit statistical analyses, that scores of the four sub-indices were influencing the TRARC Condition in a statistically significant manner at all 72 sites combined, and therefore no single sub-index could be identified as the primary influence on the TRARC Condition score. However, within the 16 closed forest sites in the Gilbert River catchment, two sub-indices, namely Plant Cover and Regeneration, had a statistically significant effect on the TRARC Condition score, whilst one, Erosion, had a significant effect but otherwise of a lesser impact than the former two sub-indices, and the third, Weeds, had no statistically significant impact on the TRARC Condition score. On the face of it these results appear to suggest that "condition" can be determined simply on examination of Plant Cover and Regeneration factors, whereas Erosion and Weeds are less likely to have an impact on the Condition score. On the basis of the data collected and analysed thus far, such a conclusion, would be an extremely dangerous one to draw from the overall study, given that it is based on a small subset of the overall data, specifically designed to test the variability of a single vegetation class, as defined from the remote sensing data. Furthermore, there are some major issues of scale that are yet to be sorted out regarding the appropriateness of the erosion indices in the savannah environment. If further work was to establish the broader validity of this conclusion, one implication of it is that remotely sensed data, which can only determine Plant Cover with any acceptable accuracy, may therefore be a cheaper and similarly accurate substitute for ground survey Condition assessment such as that provided by the TRARC method.

The TRARC method records the presence and abundance of weeds at a site: The most prevalent dominant weeds recorded at the Gilbert River catchment sites were Rubber Vine (*Cryptostegia grandiflora*) which was recorded at 27 of the 72 sites, Hyptis (*Hyptis suaveoloens*) (6 sites) and Noogoora Burr (*Xanthium occidentale*) (6 sites).

For the 100 sites assessed in the Mitchell River catchment, TRARC Condition scores were calculated in the 50-79 score range for 85% of sites. The Mitchell River catchment sites were in somewhat more heterogeneous habitats than the Gilbert River sites, and the area can be divided into three distinct areas based on rainfall, soil types, topography and land-use regimes. These different conditions are reflected in the allocation of TRARC scores, the distribution patterns of weeds and the varying impact of the indicators used to derive the TRARC Condition score. The most widespread weed was Guinea Grass (*Megathrysus maximus*) which was recorded at 76 of the 100 sites and distributed throughout the catchment study area. Other significant weeds included Noogoora Burr (*Xanthium occidentale*) at 36 sites, Hyptis (*Hyptis suaveolens*) at 32 sites, and Rubber Vine (*Cryptostegia grandiflora*) at 24 sites. These latter weeds were mainly confined to the Walsh River sites. Both Weeds and Regeneration scores were variable across all sites.

For the 16 closed forest sites in the Gilbert River catchment, riparian status scores fell within the 65-100 range. Canopy cover was recorded as approaching 100% thus confirming the prediction by remotely-sensed data that the sites were indeed closed forest. The dominant canopy tree species were She Oak (*Casuarina cunninghamiana*) and Broad-leaved Paperbark (*Melalueca leucadendra*), which together accounted for about 86% of total canopy cover. Other widespread canopy species included River Red Gum (*Eucalyptus camaldulensis*), Narrow-leaved Paperbark (*Melaleuca trichostachya*) and Swamp Oak (*Lophostemon grandiflorus*). Despite the wide-spread distribution of these latter species, they accounted for less than 8% of total canopy cover because of their smaller stature or narrow crowns, or were otherwise very scattered within the catchment. The TRARC scores for the closed forest sites were all within the 65-100 score range [average of 77.15/100] , and were within the upper 40% of scores for the total 72 sites in the Gilbert River catchment [average of 65.87/100].

4.2 Introduction – On Ground Rapid Riparian Vegetation Assessment

A field-based method of rapid riparian condition assessment known as TRARC [Tropical Rapid Appraisal of Riparian Condition] (Dixon *et al*. 2006), has recently been implemented in a number of projects in north Australian river catchments (Dowe 2004a, 2005; Dixon & Douglas 2007; Johansen *et al*. 2007). The method is based on the RARC method [Rapid Appraisal of Riparian Condition] (Jansen *et el.* 2004; Jansen *et al*. 2005; Jansen 2005) that was primarily devised for river systems in south-eastern Australia, but TRARC has been designed to be more appropriate for seasonal systems in tropical savannas. Although the practical effectiveness of TRARC in ascertaining the condition of riparian vegetation is still being tested, initial results suggest that it provides a reasonable guide to riparian condition with regard to aspects of land management across a range of tropical rivers although some modifications to the scoring criteria may be required in different settings (Dowe 2004a, 2005; Dixon & Douglas 2007; Johansen *et al*. 2007). The TRARC method provides an overall score that quantifies ecological indicators and allows comparison between sites, as well as providing data on a number of measurable ecological attributes, such as regeneration of native species, weed distribution and intensity, litter distribution, and ground-cover composition. These attributes can subsequently be isolated and examined with regard to their individual effects on condition.

As noted above, the TRARC method was specifically designed for tropical savanna river systems, and its application in assessing the condition of the Gilbert River and the Mitchell River is appropriate in this regard. Dowe (2004) used an early version of TRARC to determine riparian condition on the Einasleigh, Etheridge, Copperfield and Delaney Rivers of the Gilbert River catchment. The TRARC method has not previously been used in the Mitchell River catchment.

One of the shortcomings of the TRARC method is that while it can be implemented efficiently on ground (~20 minutes per site), the number of sites that can be visited in a day is limited by road access and cost. Furthermore, road access is generally only feasible in the dry season, and hence there is a seasonal bias built into the system. The size of rivers in northern Australia and the complexity of some of their riparian zones (see Brooks et al. 2007a), means that there are major constraints on the proportion of the landscape that can be adequately sampled and accurately assessed. For this reason, a coarser resolution remote sensing based approach for assessing riparian condition of the seasonal river systems in north Australia has been undertaken (Section 1).

One of the concerns in the development of the remote sensing based approach (see Brooks *et al*., 2007; MS report 1) was that the inherent variability of ecologically meaningful (on-ground) parameters within a single riparian vegetation class (defined from 25m LandSat data) would invalidate the application of this approach in this region, given that a remote sensing approach is the only viable way to undertake broad scale riparian assessment in this vast landscape. To investigate this issue an experiment was set up to compare the variability of TRARC scores within a single vegetation class in an otherwise similar segment of river.

4.3 METHODS

The condition of riparian vegetation was determined using the ***Tropical Rapid Appraisal of Riparian Condition*** (**TRARC**) method, in which assessment of a number of vegetation and geomorphological attributes in the riparian zone provides an overall score that is intended to rank the 'ecological condition and integrity' of the site (Dixon *et al.* 2006). The TRARC method is intended as a rapid appraisal technique, and therefore focuses on what are considered to be the most important elements from which ecological condition can be estimated. The method focuses on key species, especially the structurally and functionally dominant tree and shrub species, deleterious weeds and common understorey plants and grasses.

The TRARC scoring system is composed of 24 indicators grouped under the four sub-indices of:

Plant cover
canopy cover
canopy continuity
midstorey cover
understorey cover
grass cover
organic litter
logs

Regeneration
canopy health
large trees
tree size classes
dominant tree regeneration
other tree regeneration

Erosion
exposed soil
exposed tree roots
slumping
gullying
undercutting

Weeds
canopy weeds
midstorey weeds
understorey weeds
grass weeds
organic litter weeds
high impact weeds
high impact weed distribution

In addition, other information that indicates a 'Pressure Index' at a site is also gathered, and this is used to modify the actual TRARC score for that site. Pressures include weeds, some aspects of geomorphology, managed and unmanaged animals, fire, extent of tree clearing, flow regime and in-stream structures. Theoretically, the Pressure Index should be proportionally inverted to the TRARC condition score, but in practice this is rarely the case as the compounding effect of the impacts of some indicators is variable.

Site selection criteria were variable across both catchments. For the Gilbert River catchment, which included sites only on the Einasleigh River and Copperfield River, 14 sites (two on the Einasleigh River and 12 on the Copperfield River) were initially chosen to fall within vegetation community structures mapped as closed forest from analysis of LandSat imagery (see section 2). TRARC transects were then sampled at the 14 pre-selected sites, to firstly validate the remotely sensed closed forest vegetation class, and secondly, to characterize the variability of the vegetation parameters within one community class, using the standard TRARC parameters. Details (in addition to the data collected and recorded on the standard TRARC pro-forma) of canopy and forest structure, and species composition, were subsequently recorded for those sites. The remaining 58 sites on the Copperfield River and Einasleigh River were chosen on the basis of even spatial distribution, where practicable, within the boundaries of the focus area. In addition to the general site selection criteria mentioned above, individual sites were chosen on the basis that they represent the riparian zone in the particular reach of the stream. At each, site, distances of up to 2 km were traversed prior to establishment of the TRARC survey site. Sites were otherwise located to avoid instream structures, tributary junctions and areas of obvious disturbance.

The Mitchell River catchment was chosen as it is an area of relatively intensive land-use pressures and development. Most sites assessed by the TRARC method in the Mitchell River catchment have closed forest, thus the results presented for these sites also indicate the amount of variability in TRARC scores that can be obtained from the one cover class. For the Mitchell River catchment, which included Walsh River and tributaries, and Rifle Creek, Two Mile Creek and Four Mile Creek, 100 sites were chosen on the basis of position relative to impoundments, and channel and tributary junctions. At each weir on the Walsh River, sites were established both upstream and downstream of the weir wall. At channel and tributary junctions, sites were established at both downstream and upstream of the junctions. In addition, other sites were chosen on the basis of more or less even spatial distribution, where practicable, within the boundaries of the focus area. The sites on Rifle Creek were chosen with the knowledge that this was an area where the natural habitat was rainforest, and the average rainfall was relatively greater than at sites on the Walsh River and Two Mile Creek and Four Mile Creek. In addition, sites on the Walsh River were selected on the basis that they fell within the Mareeba-Dimbullah irrigation area, and as such were on streams receiving regulated, perennial flows from the Barron River inter basin transfer (IBT).

At each site, a transect measuring 100 m x < 20 m [dependant on the width of the riparian zone, which was often less than 20 m] was laid out parallel to the stream, within the riparian zone. One edge of the transect was aligned with the stream edge (i.e. the channel flow zone usually identified by a transition from bank alluviums (rocks, silts, sands etc.) and the materials that constitute the limit of the usual flow zone when the stream is actually flowing [in most cases the sandy stream bed]. The other edge was upslope on the bank, either at the limit of the riparian zone, if less than 20 m wide, or within the riparian zone if the riparian zone was more than 20 m wide. For the purpose of detailed data recording, which is then averaged across the entire transect, each site was divided into three areas, namely A [beginning of transect: 0 m], B [middle of transect: 50 m] and C [end of transect: 100 m]. Within an area of 5 m radius, at the A, B and C locations, plant cover, numbers of individuals, condition of individuals, areas of exposed soil, percentage cover of debris, and bank condition were estimated visually as the percent aerial cover, or number of individuals within the area covered by the 5 m radius. Data were recorded on the TRARC field recording sheets. Pressure indices were otherwise scored for the entire transect as many of these are extraneous [e.g. nearby tree clearing, flow regime, etc.] and /or continuous throughout the transect [e.g. animal impacts, in-stream and/or up-stream structures, etc.].

Score calculations and analysis of some data were completed using the Excel spreadsheet that was developed as part of the TRARC method and downloaded from the website www.rivers.gov.au. The collected data were entered into the spreadsheet which automatically performed all calculations of adding the separate sub-indices and applying a weighting for Pressure Index scores. Ultimately, a TRARC condition score and a Pressure Index were provided for each site, as were scores for the individual indicators and sub-indices. Final scores were normalised between 0-100. As outlined previously, there is an assumption in the method that sites with higher scores indicate relatively better ecological condition than sites with lower scores. However, as also canvassed in the first Milestone report (Brooks, et al., 2007), there are a number of issues to be clarified regarding these assumptions in savannah landscapes, particularly with regards to the relative “condition” of native grasses, shrubs and trees. The scores for sub-indices were also calculated, and examination of these provided some indication of condition of individual attributes for each site.

Preliminary analyses of the relationship of the scores for the four sub-indices [Plant Cover, Regeneration, Erosion, Weeds) to forest type (Closed Forest, Open Forest, Woodland, Open Woodland[5]) at the Gilbert River sites were conducted. From these analyses, it was estimated which of the sub-indices produced scores that exerted the most influence on the overall condition score for each forest type. Additional analyses examined the relationships between the sub-indices and closed forest sites. Analyses incorporated a Least Squares Fit method, using the JMP Version 4 statistical analysis package (SAS Institute 2006). In addition, the presence of weeds and their distribution were determined for all sites and mapped.

4.4 RESULTS

TRARC in the Gilbert Catchment

Seventy-two sites (Figure 27) were assessed using the TRARC method in the Gilbert River catchment: 24 sites were on the Copperfield River and 48 sites were on the Einasleigh River. The sites on the Copperfield River were more or less regularly spaced from just downstream of the Kidston Dam wall near where the river approaches the junction of Kidston Road and Gregory Developmental Road. Sites on the Einasleigh were grouped into three clusters because of access restrictions: one cluster was centred in the upstream section on Carpentaria Downs; another cluster around

[5] These are consistent with the classes used to classify the Landsat TM imagery in Section 2.

the township of Einasleigh; and a third cluster in the downstream section from just downstream of Mt Alder to the Gulf Developmental Road crossing. Property access was not possible between Carpentaria Downs and Einasleigh, and the rough and steep terrain restricted access to the river from Einasleigh downstream to the west of Caterpillar Mountains and Mt Alder.

The site numbers are indicated on the map in Figure 27. TRARC scores are provided in the graph in Figure 28. The average TRARC score of 65.87 for the Gilbert River catchment sites is indicated on the graph. TRARC scores are transposed to the map in Figure 28, and grouped in four score ranges of 0-50, 50-64, 65-80 and 80-100. The numbers of sites that fall into the score ranges are indicated in Figure 29.

The averaged scores and the score ranges that are attributed to the four sub-indices are provided in Figure 30.

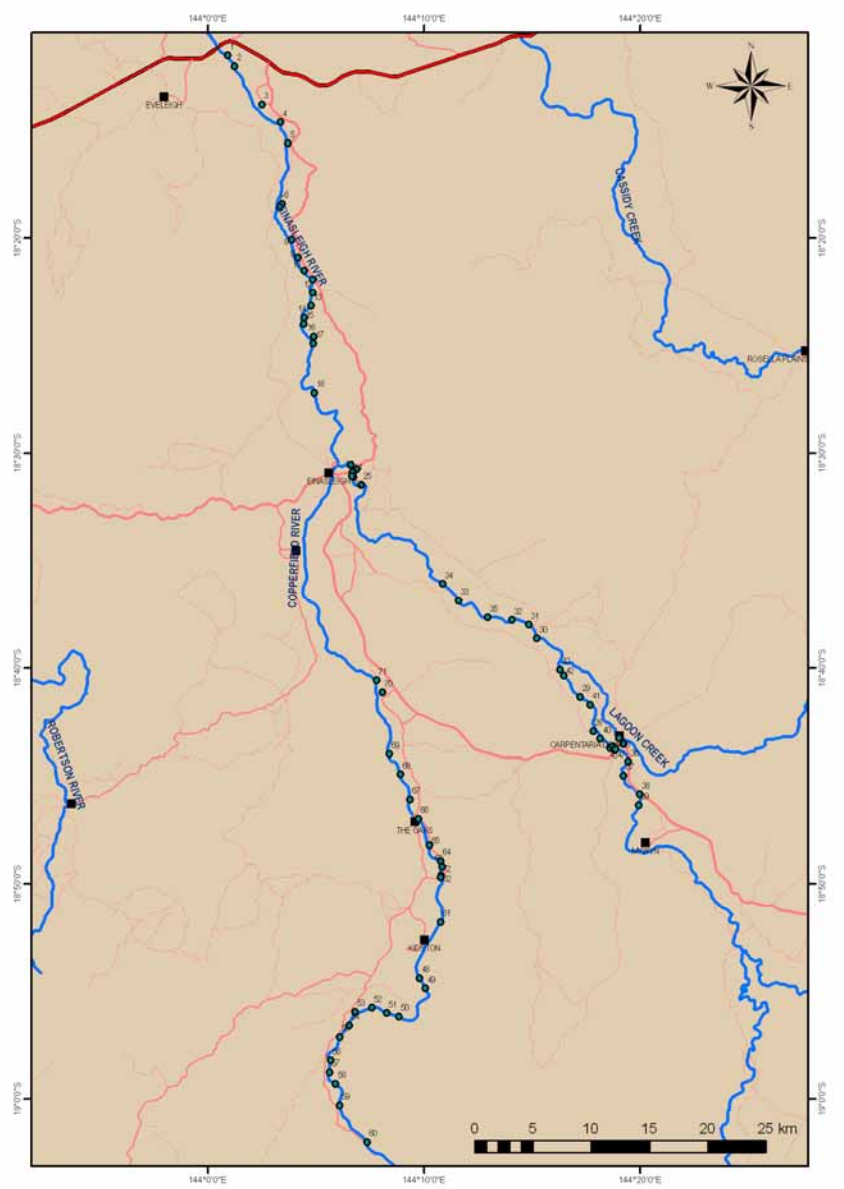

Figure 27 Location of TRARC study sites in the Gilbert River catchment.

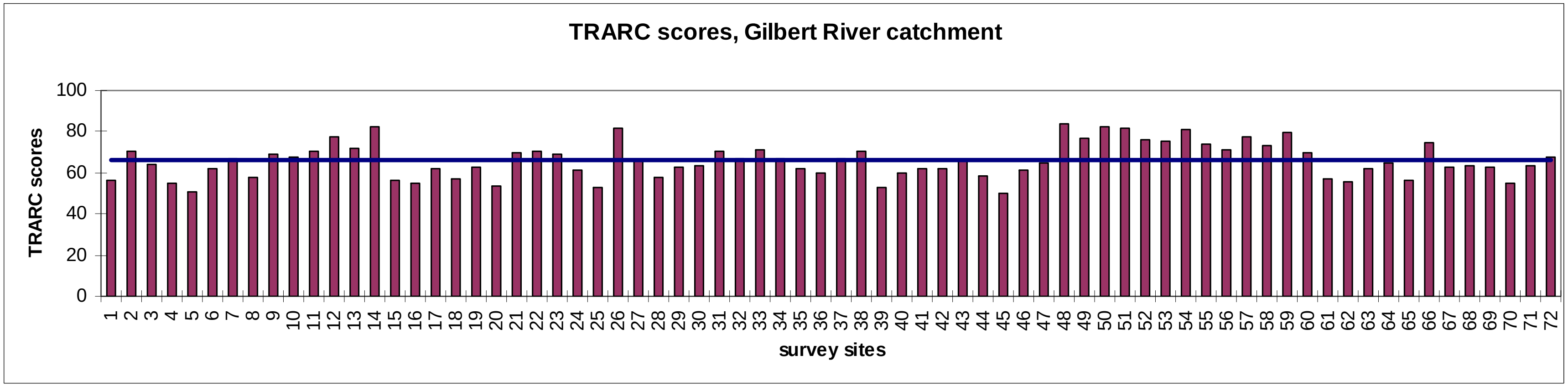

Figure 28 TRARC Condition scores in the Gilbert River catchment, with the average (65.87) indicated by the **dark line**. Site numbers relate to those indicated on the map in Figure 1

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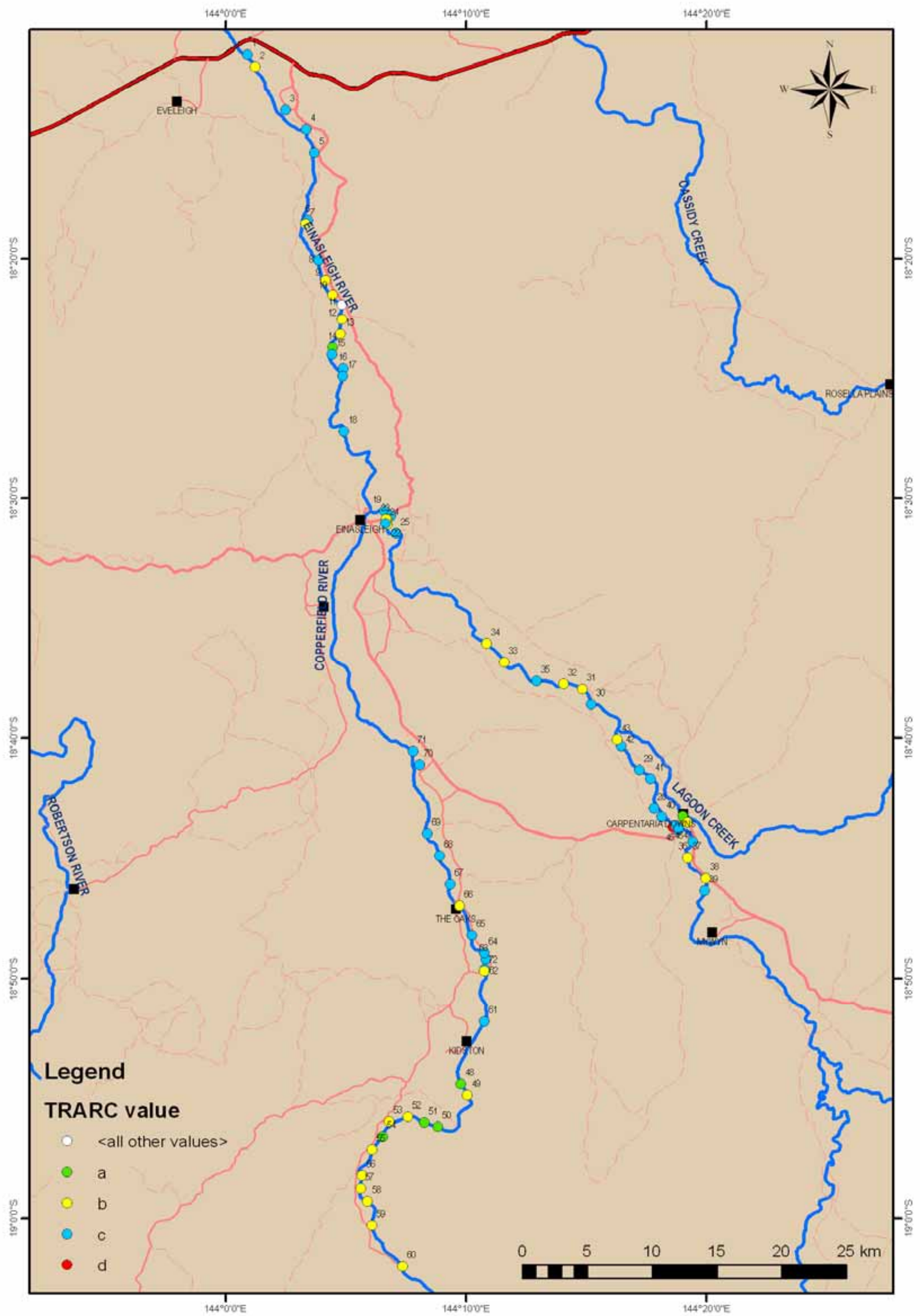

Figure 29 Study sites in the Gilbert River catchment with the TRARC scores arranged within qualitative ranges: a [green circle] = 80-100; b [yellow circle] = 65-79; c [blue circle] = 50-64; d [red circle] = 0-49.

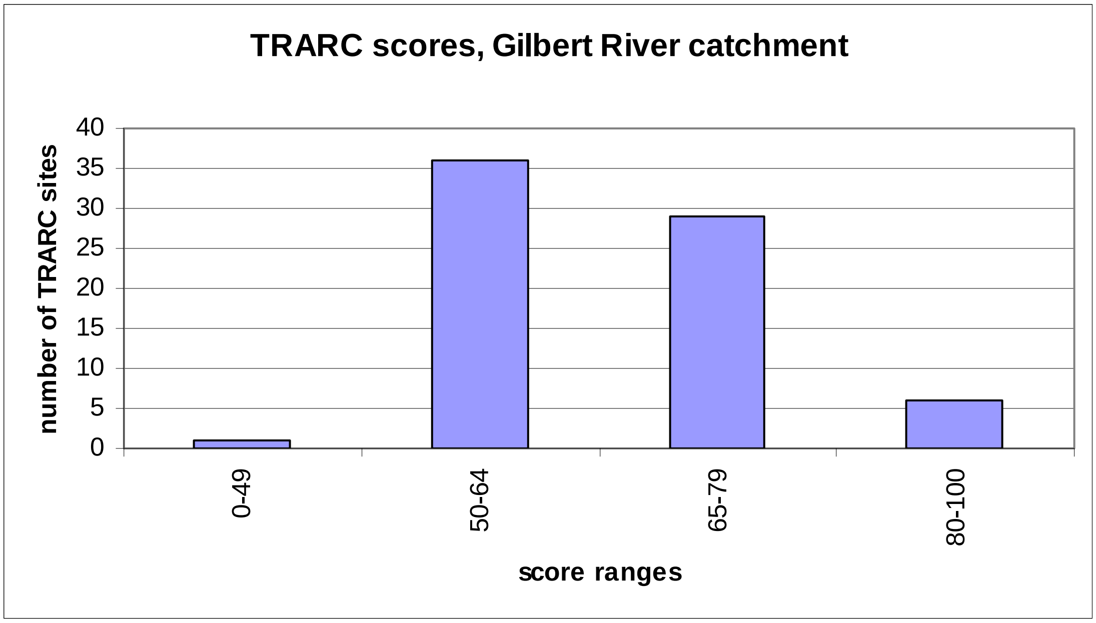

Figure 30 TRARC scores in the Gilbert River catchment, arranged to fall within value ranges.

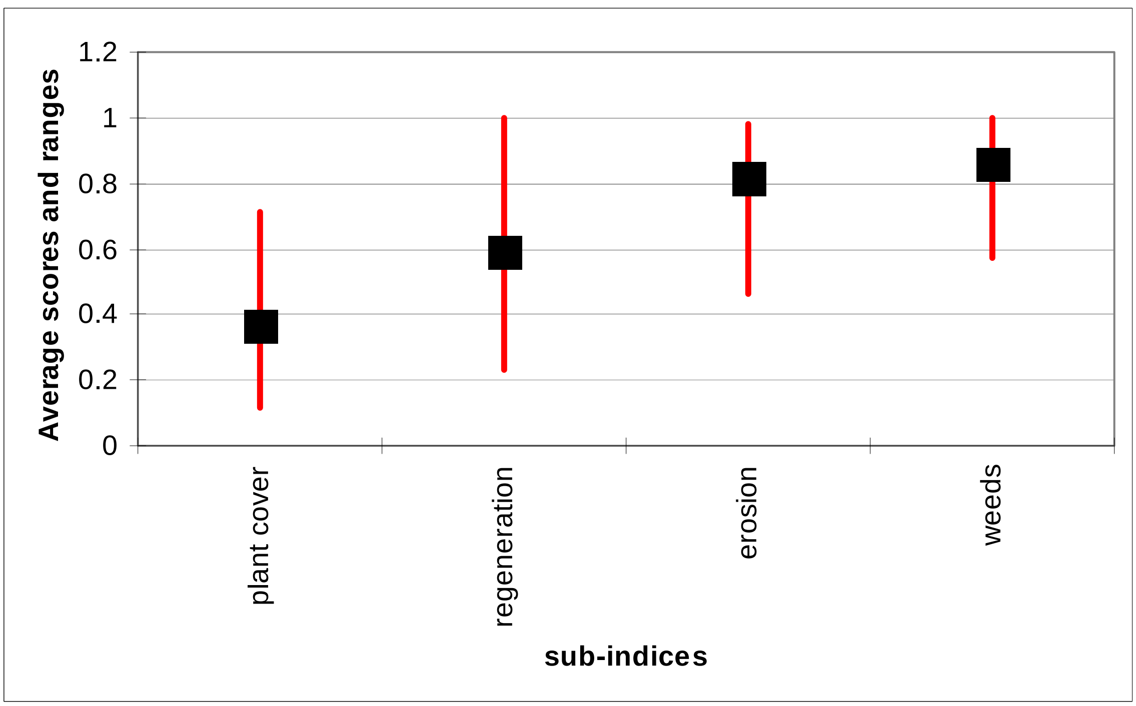

Figure 31 The average TRARC score and score ranges of sub-indices at the TRARC survey sites (n=72) in the Gilbert River catchment.

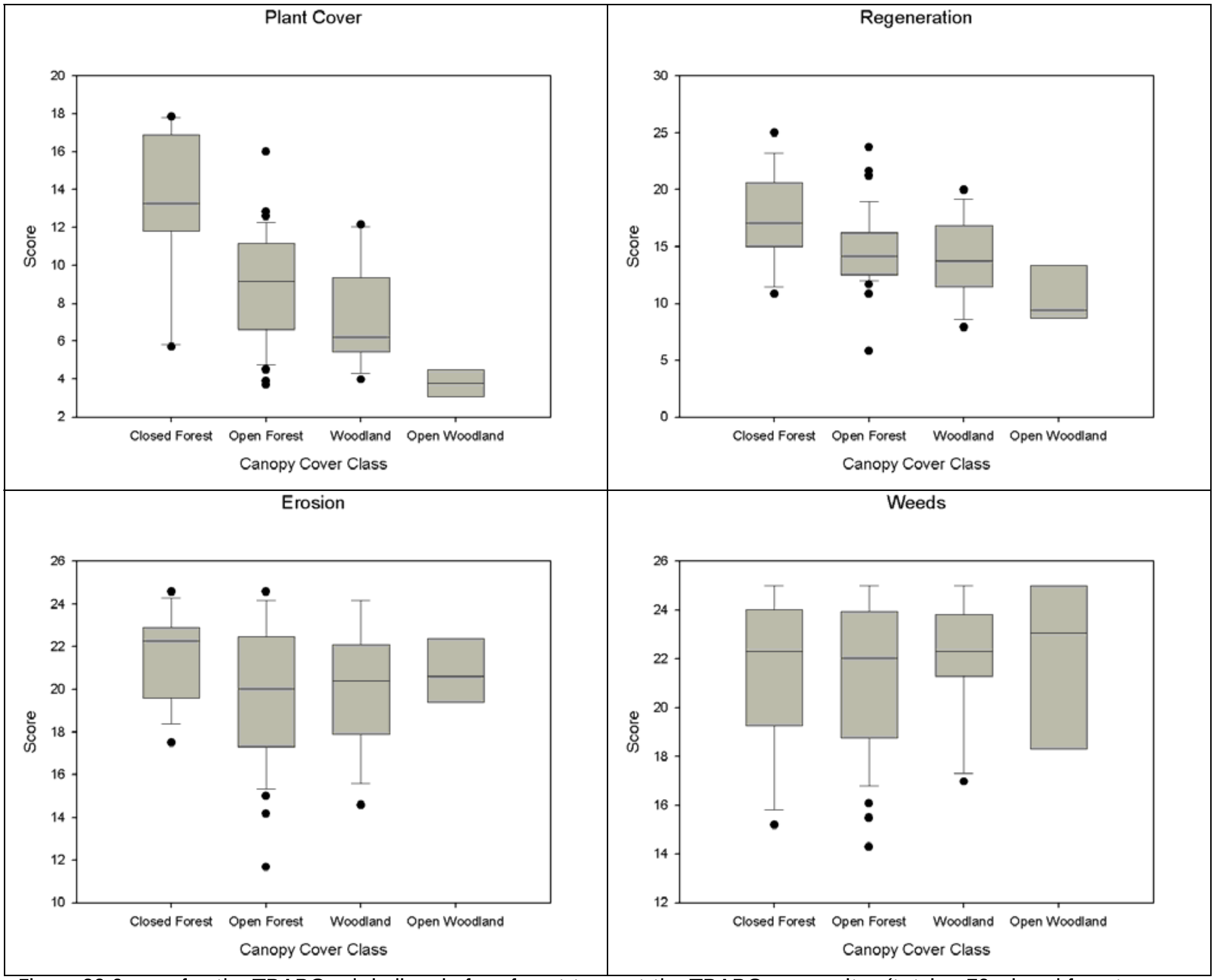

Figure 32 Scores for the TRARC sub-indices in four forest types at the TRARC survey sites (total n=72, closed forest (n=16), Open forest (n=36), Woodland (n=14), Open woodland (n=6) in the Gilbert River catchment. **Top left**: Plant Cover; **Top right**: Regeneration; **Bottom left**: Erosion; **Bottom right**: Weeds.

Figure 32 shows the distribution of the sub-index scores within each canopy cover class. Not surprisingly there is a significant difference ($P<0.05$) in the Plant Cover sub-index across each canopy cover class (top left graph). In terms of Regeneration there is a statistically significant difference between closed forest and all other classes, open woodland and all other classes and no significant difference between open forest and woodland. In terms of Erosion this sub-index was significantly higher in the closed forest class than in open forest, but all vegetation classes experience a wide range of Erosion sub-index values. Similarly, there is a wide range of scores for the Weeds sub-index indicating that the presence and extent of weeds is not related to the canopy cover class. These results are consistent with expectations and reflect the different process that influence each sub-index. These results also indicate that remotely sensed canopy cover classes[6] could be used to predict the Plant Cover sub-index of TRARC.

[6] With the appropriate level of validation

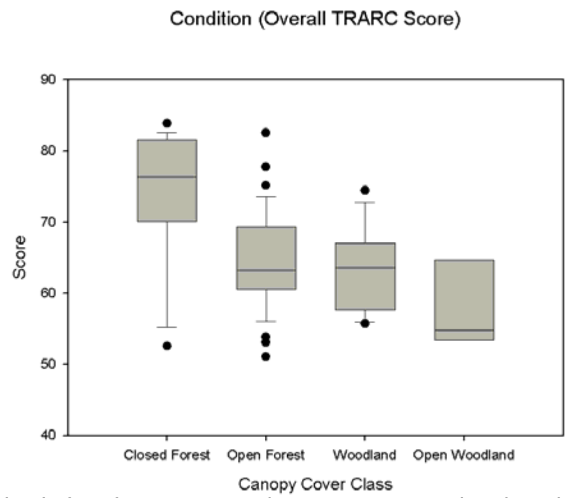

Figure 33 Scores for Condition in four forest types at the TRARC survey sites (n=72) in the Gilbert River catchment.

Figure 33 shows the range of TRARC condition scores for each canopy cover class. There are significant (P<0.05) differences between closed forest and all other classes, open woodland and all other classes and no significant difference between open forest and woodland. Based on these results the remotely sensed canopy cover classes could be used to predict TRARC scores for closed forest, open forest/woodland and open woodland areas, however these predictions would need to be tested using an independent dataset.

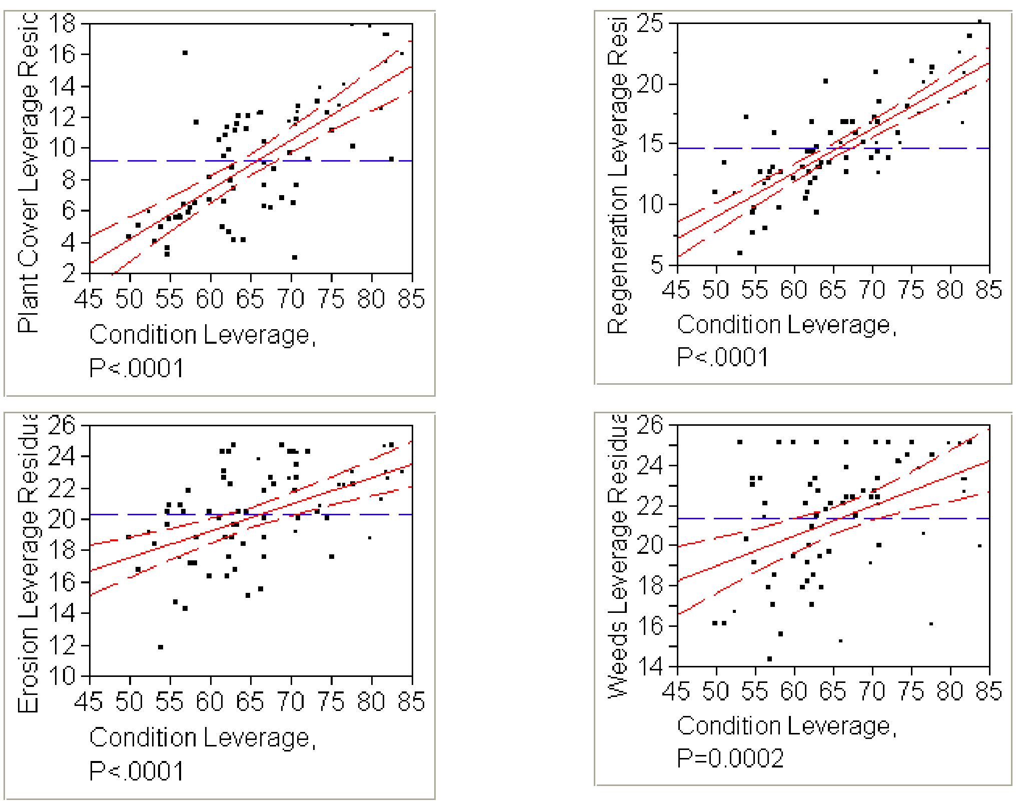

Figure 34 The influence of the scores of the sub-indices on the overall TRARC Condition score (n= 72). ***Top left***: Plant Cover; ***Top right***: Regeneration; ***Bottom left***: Erosion; ***Bottom Right***: Weeds.

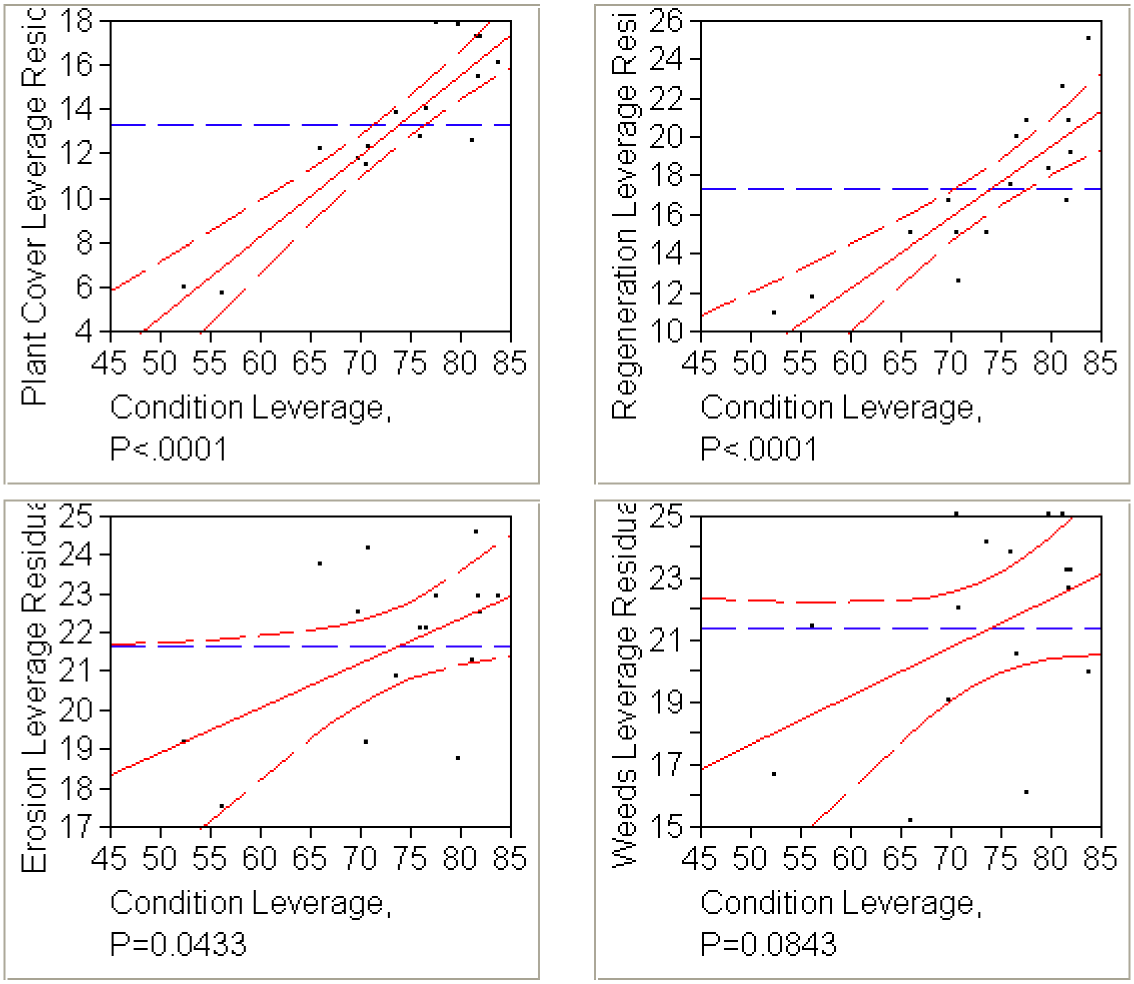

Figure 35 The influence of the scores of the sub-indices on the TRARC Condition score at closed forest sites (n=16) in the Gilbert River subcatchment.. ***Top left***: Plant Cover; ***Top right***: Regeneration; ***Bottom left***: Erosion; ***Bottom Right***: Weeds.

When all 72 sites, including all vegetation structural classes are considered the least squares fit analysis of the leverage of the sub-indices scores on the Condition score indicates that all variables were statistically significant (P<0.0002)(Figure 34). This means that all of the sub-indices are having a significant effect on the overall TRARC score. However, with analysis of just the 16 closed forest sites (Figure 35), Plant Cover and Regeneration had a significant (P<0.0001) influence on the TRARC Condition score, whereas Erosion is significant (P<0.043) but has a lower degree of influence and Weeds had no statistically significant influence (P>0.05). This is likely due to the fact that Erosion and Weeds scored similarly at all closed forest sites, and therefore did not have a large impact on the Condition score within the closed forest class.

Weed presence and distribution

The major weeds species recorded at the TRARC sites, with the number of sites at which they occur, are indicated in Figure 35. Distribution of weeds species that occur in more than one site is plotted on maps in Figures 36 and 37.

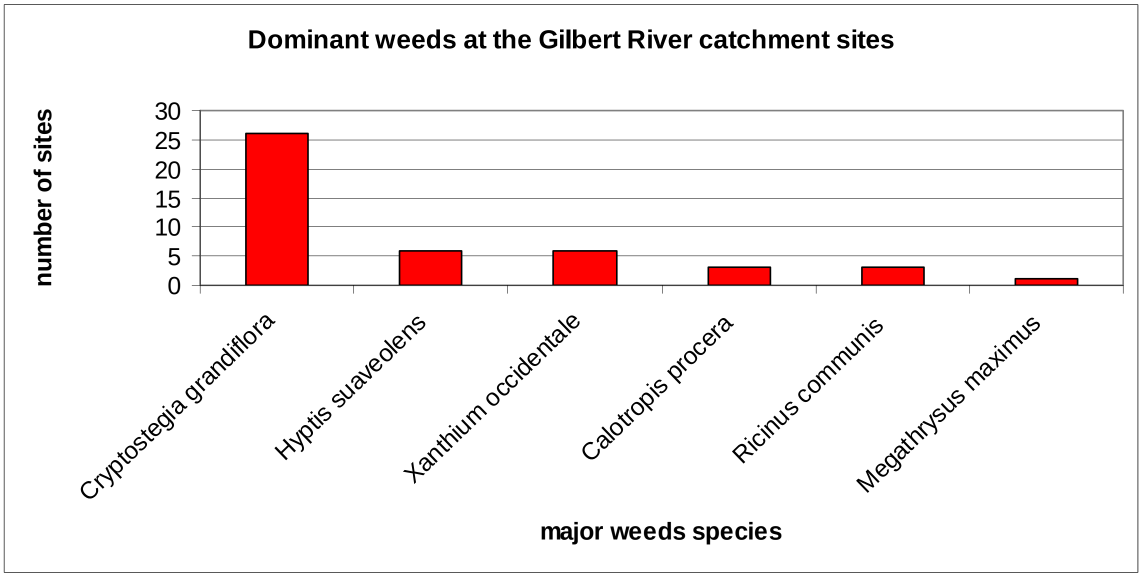

Figure 36 Dominant weeds (six species) and their occurrence at TRARC survey sites (n=72) in the Gilbert River catchment.

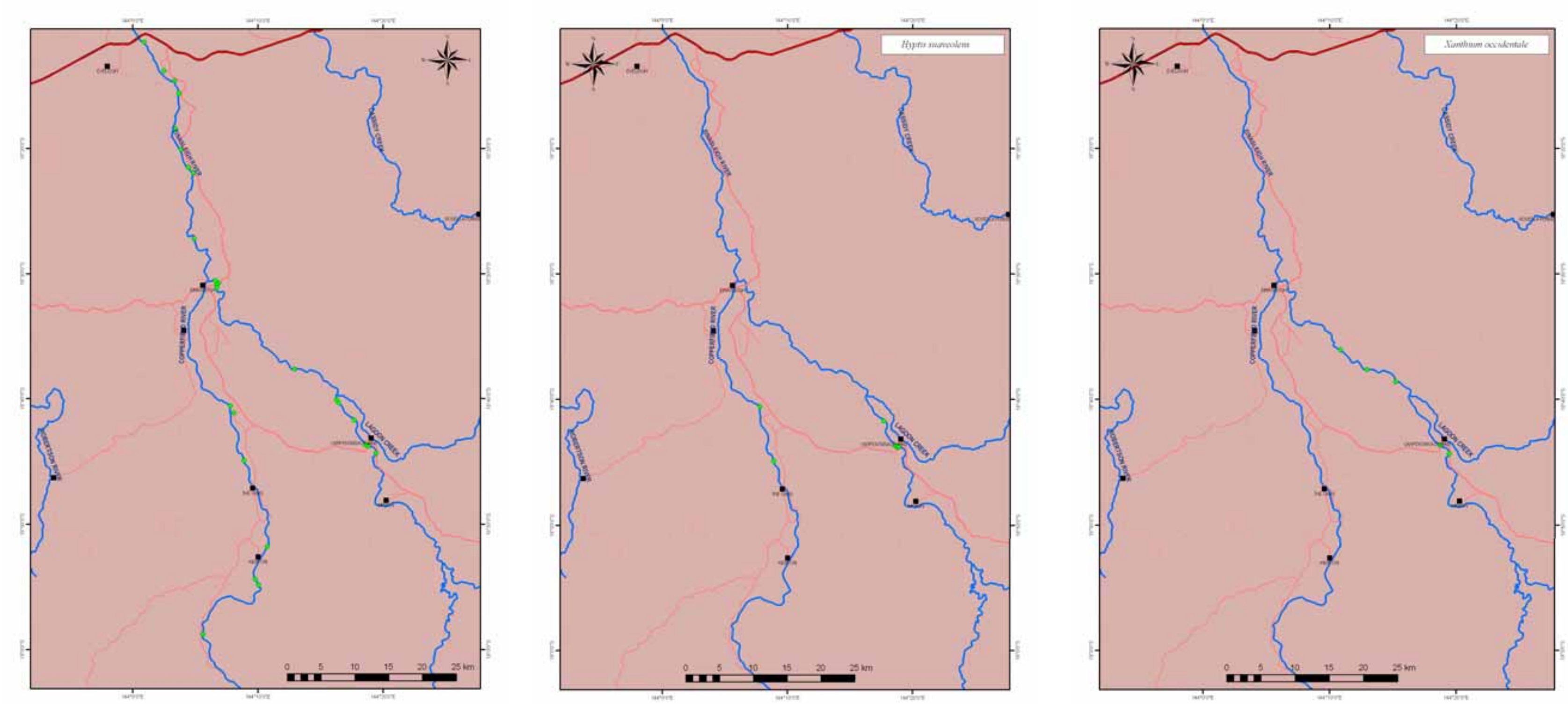

Figure 37 Distribution of major weeds at the TRARC sites (green dots) in the Gilbert River catchment. **Left**. Cryptostegia grandiflora (Rubber Vine); **Centre.** Hyptis suaveolens (Hyptis); **Right.** Xanthium occidentale (Noogoora Burrr).

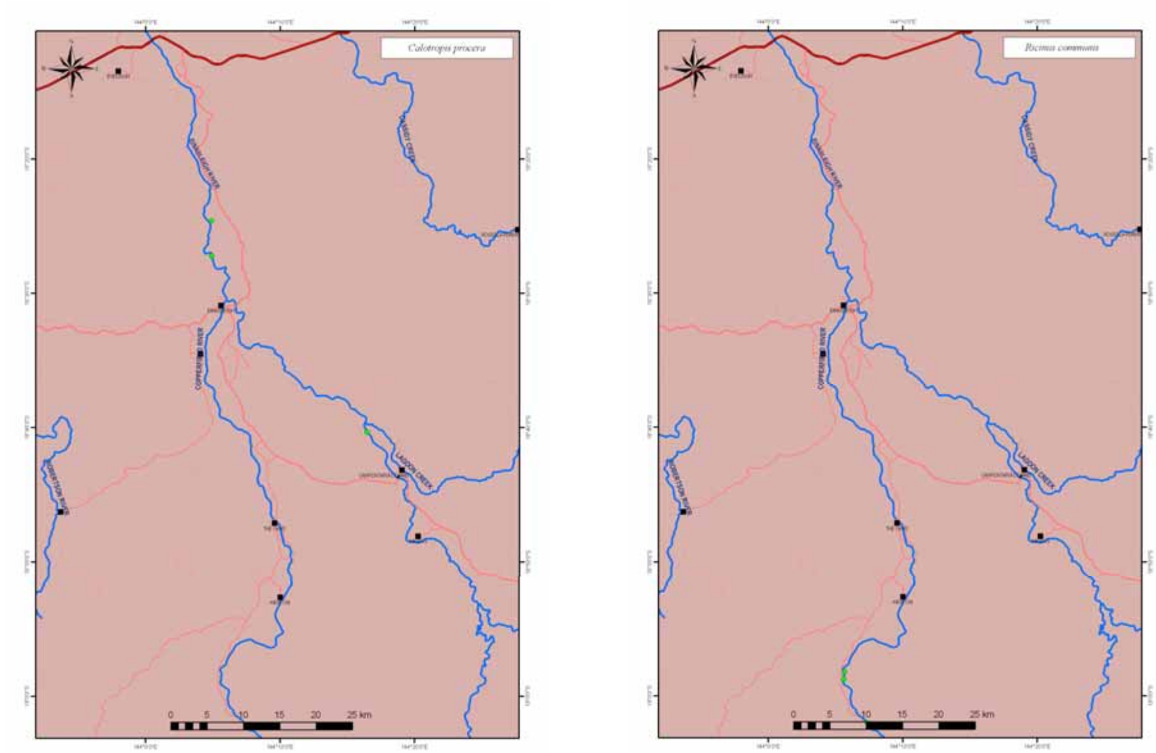

Figure 38 Distribution of major weeds at the TRARC sites in the Gilbert River catchment. **Left**. Calotropis procera (Calotrope); **Right.** Ricinus communis (Castor Oil Plant).

Discussion – TRARC in the Gilbert

The condition of the riparian zone, as estimated by the TRARC method at 72 sites in the Gilbert River catchment, indicated that one site scored in the 0-49 range, 36 in the 50-64 range, 29 in the 65-79 range and 6 in the 80-100 range (Figure 28). Therefore 90% of sites fell within the 50-79 score range. There is some pattern with regard to the distribution of high scoring sites. There is a cluster of high scoring sites in the upper Copperfield River and another cluster in the lower Einasleigh River section (Figure 29). Otherwise, both high and low scoring sites are randomly located in the upper Einasleigh River section.

The average scores for the four sub-indices of Plant Cover, Regeneration, Erosion and Weeds indicate for the Gilbert River sites that Plant Cover and Regeneration have the greater relevance in influencing the TRARC score whilst Erosion and Weeds have a lesser influence on the TRARC score (Figure 32).

The range of scores for each sub-index is variable across all sites (Figure 32). Of interest in the Gilbert River sites is the broad range of scores applied to Regeneration, but its average score is otherwise relatively close to the average score for TRARC condition (Figure 32). In the same respect, Plant Cover also has a relatively broad range of scores but its average score is somewhat lower than the TRARC Condition score (Figure 32).

Six high impact weed species were recorded at the Gilbert River sites (Figures 36-37). These included, in order of high to low impact based on cover and distribution: *Cryptostegia grandiflora* (Rubber Vine), *Hyptis suaveolens* (Hyptis), *Xanthium occidentale* (Noogoora Burrr), *Calotropis procera* (Calotrope), *Ricinus communis* (Castor Oil Plant) and *Megathrysus maximus* (Guinea Grass). Rubber Vine occurred at 27 sites, whilst the remaining five species occurred at 6 or less sites each (Figure 38). The significance of the impact of Rubber Vine is that it can dominate all levels of the forest and function even as a canopy component in sites where it is completely dominant. Rubber Vine was distributed at sites throughout the range of all the Gilbert River TRARC sites (Figure 37) but with the most concentrated levels of occurrence in the sites near Einasleigh township. Hyptis occurred at six sites in relative close proximity to each other (Figure 37); Noogoora Burrr was recorded at six sites on the Einasleigh River near to or just downstream of Carpentaria Downs Homestead (Figure 37); Calotrope at widespread sites on the Einasleigh River (Figure 38); and Castor Oil Plant restricted to sites on the Copperfield River immediately downstream of the Kidston Dam (Figure 38).

Apart from the widespread distribution of Rubber Vine, the distribution of other high impact weeds is relatively limited at the TRARC survey sites in the Gilbert River catchment. This may reflect active control of these weeds by landholders in the area: and an ongoing awareness campaign advocated by the Northern Gulf NRM. Control of Rubber Vine is more problematic than other weeds, and this is evidenced in its apparently intractable establishment and significant impact on some sites in the Gilbert River catchment.

Conclusion – TRARC in the Gilbert

In summary, the riparian condition as recorded by the TRARC method at the Gilbert River catchment sites was scored in the 50-79 score range. Based on the preliminary analyses, the four sub-indices all have a statistically significant influence on overall TRARC Condition score, but if the closed forest sites are analysed as a discrete group, then Plant Cover and Regeneration have a statistically significant influence on the TRARC Condition scores for that forest type.

On the basis of these data, two apparently contradictory conclusions could be drawn, depending on whether one accepts that the TRARC score can be directly translated into a condition score. If it is assumed that the current formulation of TRARC directly equates to a condition score, in which a higher number equals a better condition, then the broad spread of the Erosion and Weeds sub-indices, and their poor correlation with the overall TRARC score, would tend to suggest that they are not good indicators of overall Condition when taken in isolation from all the sub-indices. On the face of it, this would appear to be counter intuitive, given that a reasonable case can be made *a priori*, that the presence of weeds and erosion should be strong indicators of a degraded condition. Hence, an alternative interpretation of the results is that the TRARC score is unduly biased by the inclusion of the plant cover index, and in fact, the other three indicators are more likely to provide a less biased view of the actual riparian condition. The inclusion of the cover index in the total score, in effect presupposes that a closed forest is "better" than an open forest which in turn is "better" than an open woodland etc. In savannah landscapes, where it can be established that active clearing has not occurred (which is the case in the vast majority of the landscape), such an assumption has not yet been validated. Until it is, it may well better to exclude this index from the overall score, or analyse it as a covariate, given that all it is really doing is defining what overall vegetation community class you are dealing with. Running the analysis without the cover index (or with a very different weighting), or as a covariate analysis, will almost certainly provide a very different view of the overall condition associated with the TRARC scores, and the relative importance of the various sub-indices.

TRARC in the Mitchell Catchment

One hundred sites (Figure 39) were assessed using the TRARC method in the Mitchell River catchment: 60 sites were in the Walsh River sub-catchment and 40 sites were on the upper Mitchell River subcatchment upstream of Mt Molloy. The sites in the Walsh River subcatchment were more or less regularly spaced from upstream of the inflow area from the Walsh Bluff Main Channel to the area where irrigation ceases approximately 15 km downstream of Dimbulah, immediately downstream of the Eureka Creek confluence. Within the Walsh River subcatchment, about 22% of sites were on tributaries of the Walsh River, the remainder on the Walsh River itself. The upper Mitchell River catchment sites were in two clusters: one in the area immediately to the north-west of Mareeba with 10 sites in the Two Mile Creek and Four Mile Creek systems, and the other on tributaries upstream of Mt Molloy with 30 sites within the Rifle Creek system. The three site clusters represent three distinct habitat types: Walsh River dominated by *Melaleuca leucadendra*, *Eucalyptus camaldulensis* or *E. tereticornis,* and adjacent lands by broad scale agriculture; the 10 sites north-west of Mareeba were associated with seasonal wetlands and streams that flow into the wetlands; and the sites upstream of Mt Molloy with rainforest and high intensity small-scale agriculture and hobby farms.

The site numbers are indicated on the map in Figure 39. TRARC condition scores are provided in the graph in Figure 40. The average TRARC score of 66.54 for the Mitchell River catchment sites is indicated on the graph. TRARC scores are transposed onto the map in Figure 41, and grouped in four score ranges of 0-49, 50-64, 65-79 and 80-100. The numbers of sites that fall into the score ranges are indicated in

Figure 42. The averaged scores and the range of scores of the sub-indices are provided in Figure 43.

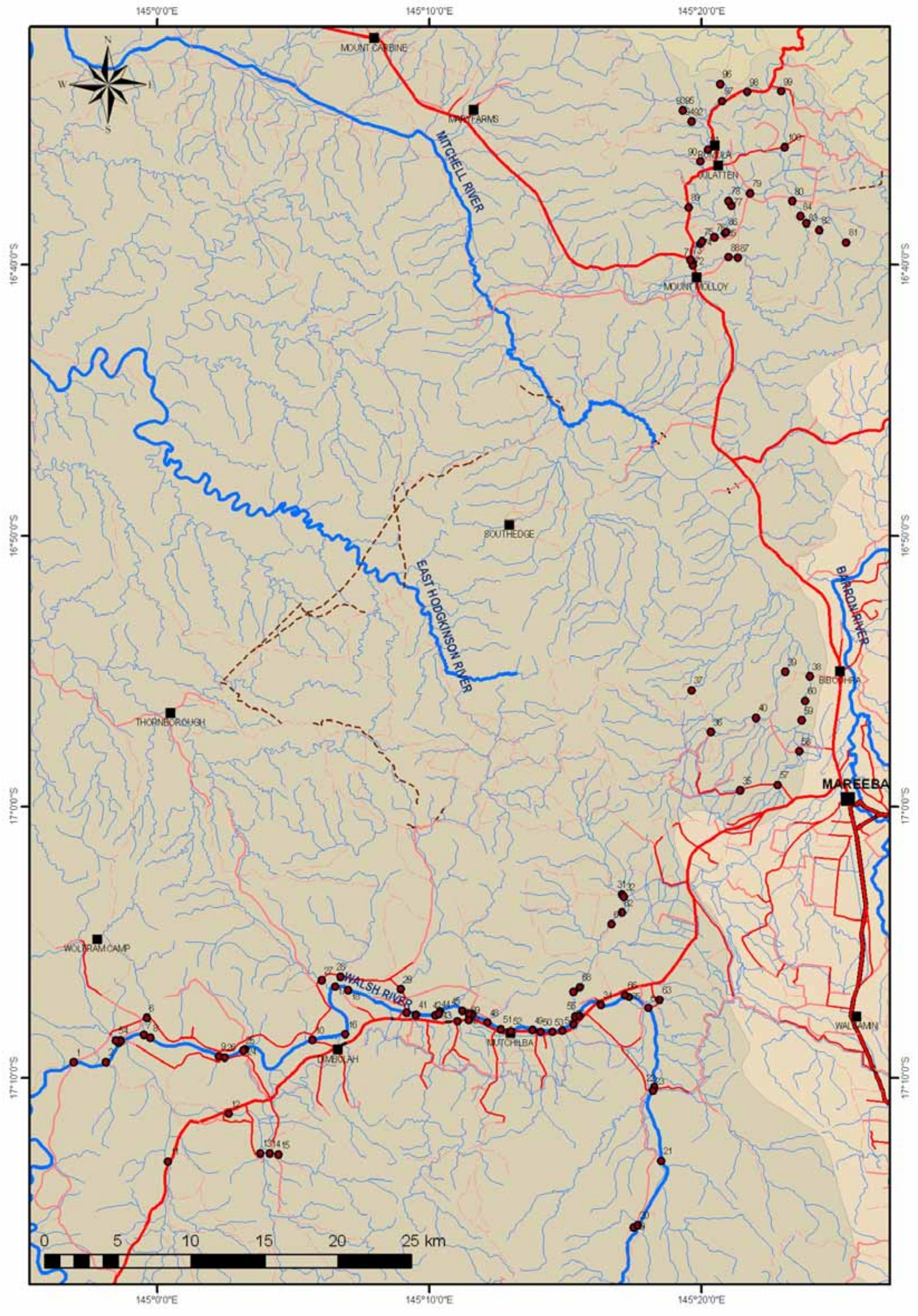

Figure 39 Location of TRARC study sites in the Mitchell River catchment.

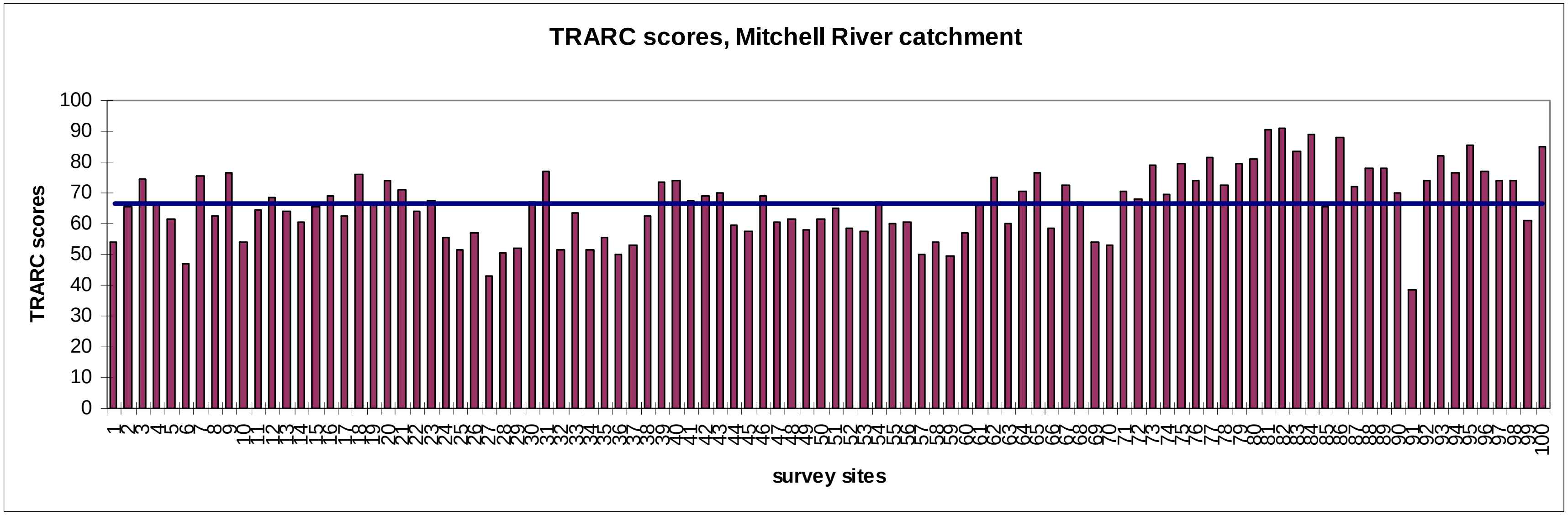

Figure 40 TRARC scores in the Mitchell River catchment, with the average (66.54) indicated by the **dark line**. Site numbers relate to those indicated on the map in Figure 13.

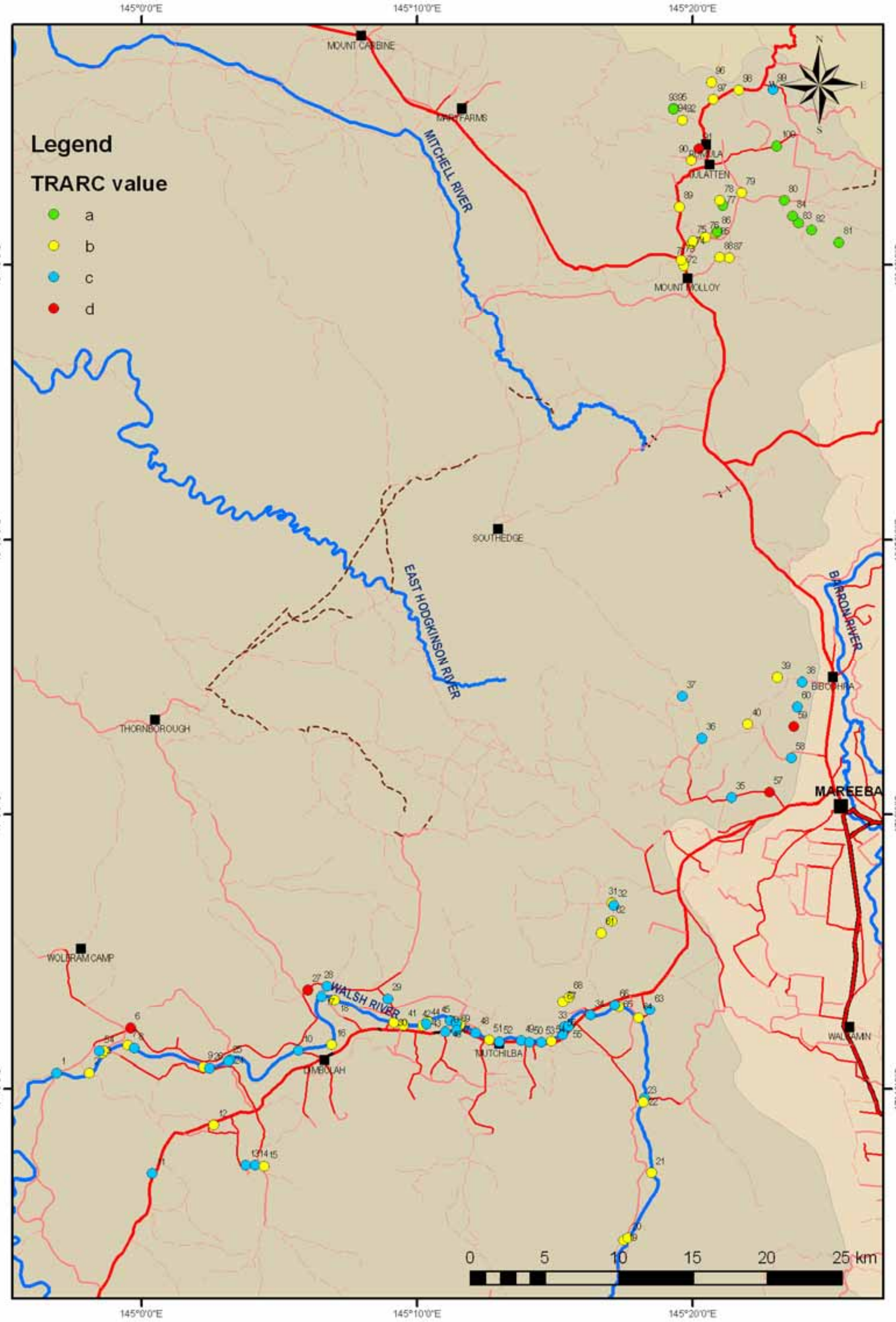

Figure 41 Study sites in the Mitchell River catchment with the TRARC Condition scores arranged within score ranges: a [green circle] = 80-100; b [yellow circle] = 65-79; c [blue circle] = 50-64; d [red circle] = 0-49

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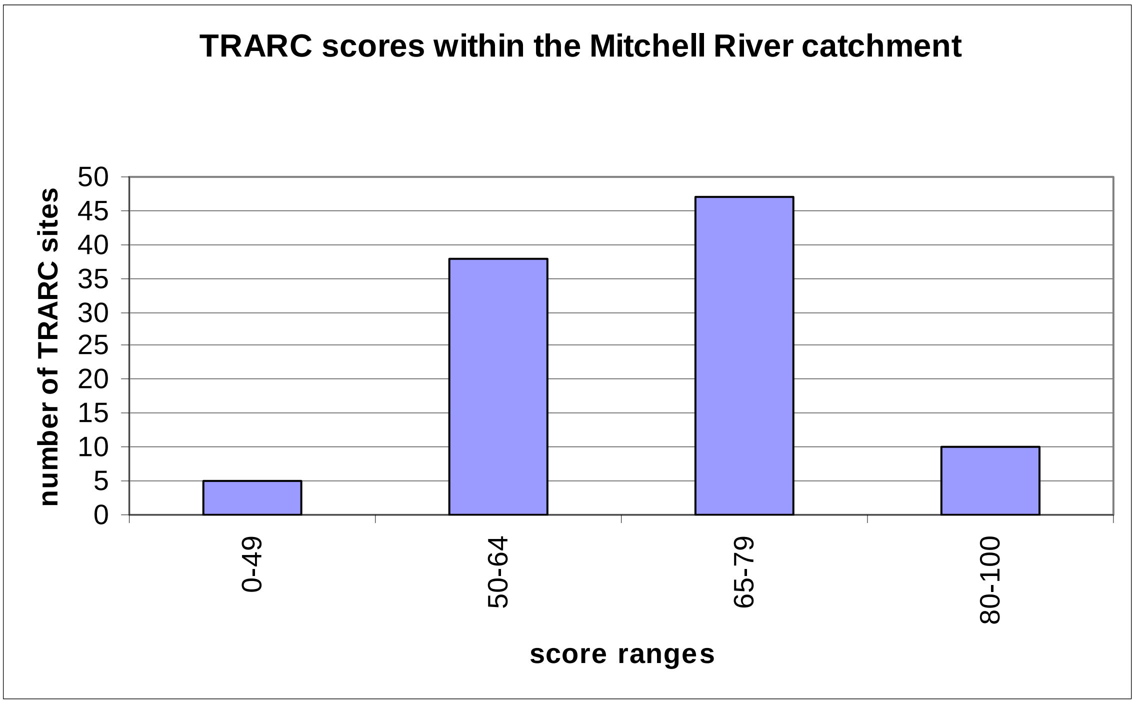

Figure 42 Number of sites within TRARC Condition score ranges in the Mitchell River catchment.

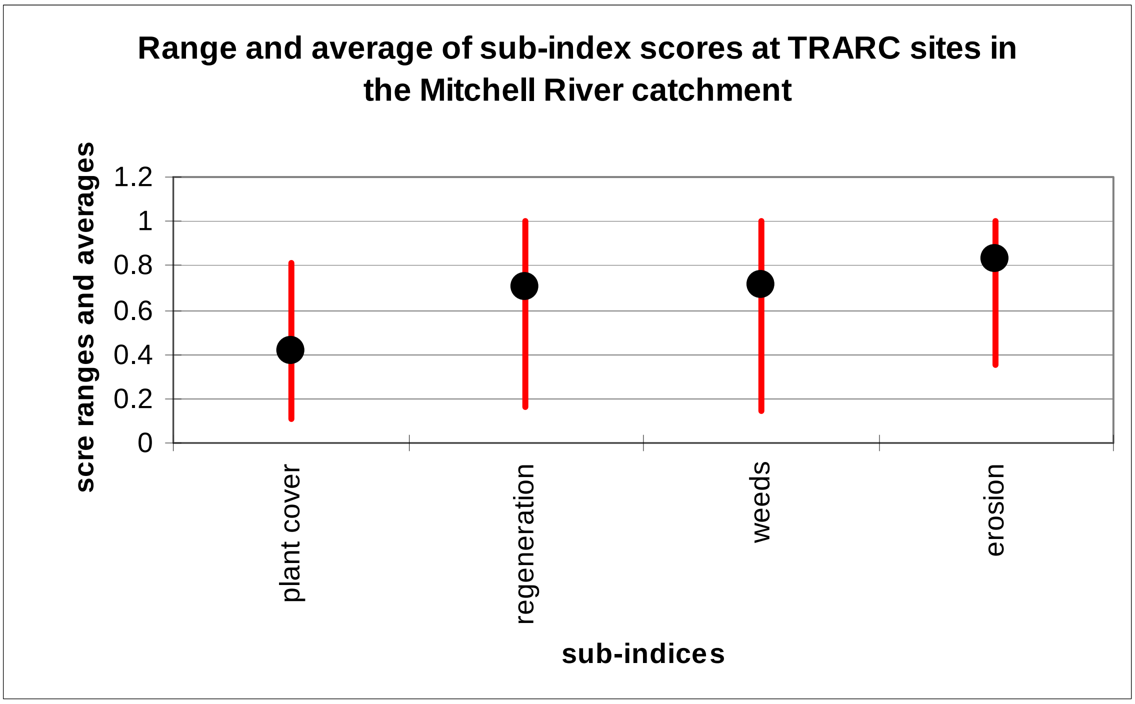

Figure 43 The range and average of the scores of sub-indices at the TRARC survey sites in Mitchell River catchment.

Weed presence and distribution

Ten dominant weed species were recorded at the TRARC sites, and are indicated in Figure 44. Twenty-five minor weed species were recorded, and are indicated on Figure 45. Distribution of weeds species that occur in more than one site is plotted on maps in Figure 46 and Figure 47.

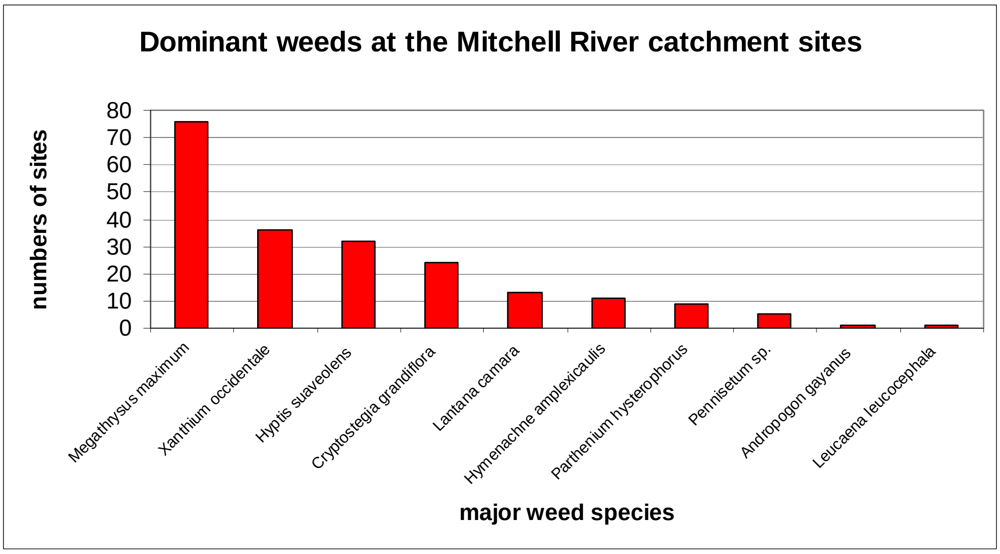

Figure 44 Dominant weeds (10 spp.) and their occurrence at TRARC survey sites (n=100) in the Mitchell River catchment.

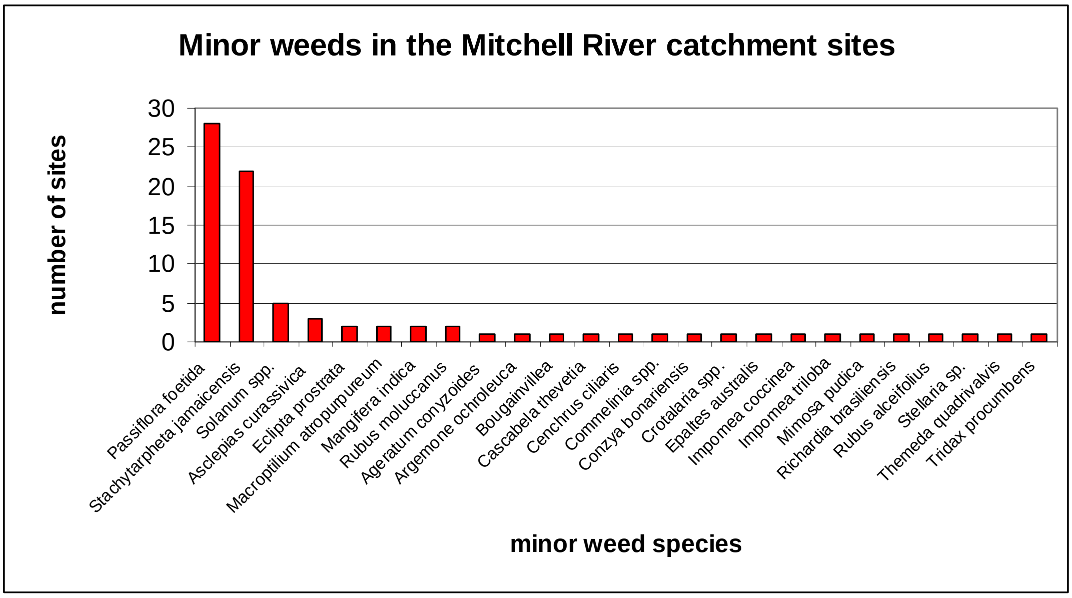

Figure 45 Minor weeds (25 spp.) and their occurrence at TRARC survey sites (n=100) in the Mitchell River catchment.

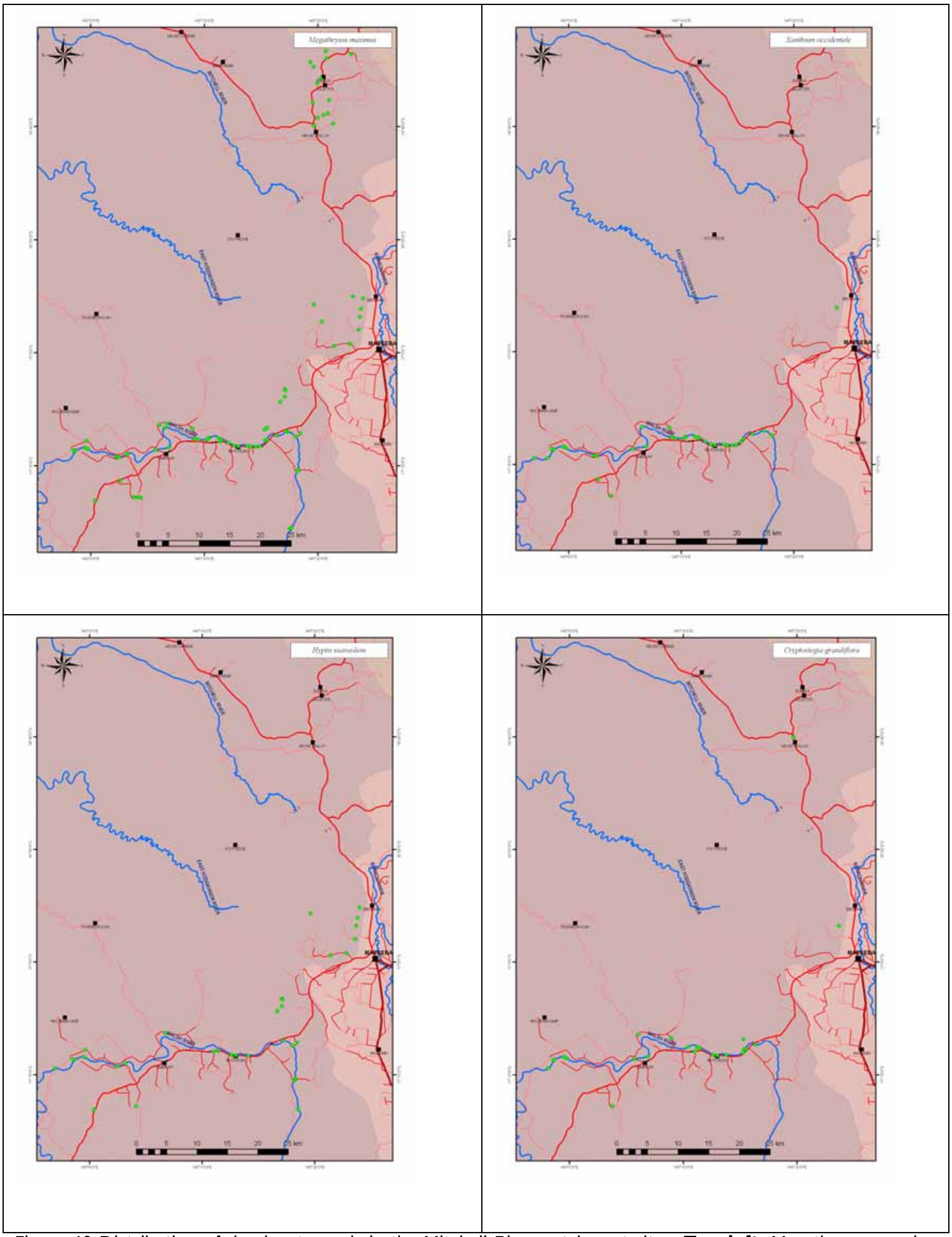

Figure 46 Distribution of dominant weeds in the Mitchell River catchment sites. **Top left:** Megathrysus maximus (Guinea Grass); **Top right**: Xanthium occidentale (Noogoora Burr); **Bottom left:** Hyptis suaveolens (Hyptis); **Bottom right**: Cryptostegia grandiflorus (Rubber Vine).

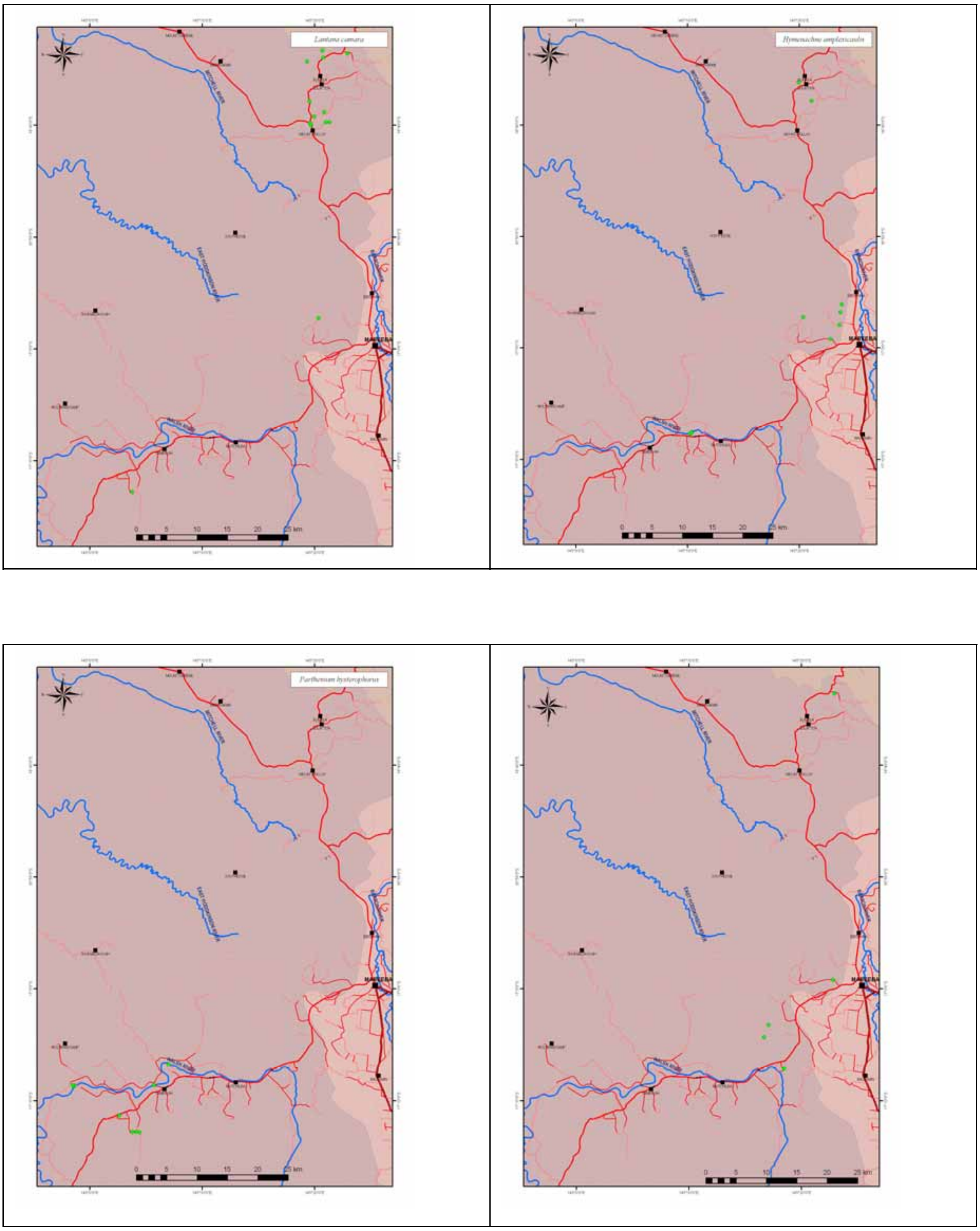

Figure 47 Distribution of dominant weeds at the TRARC sites in the Mitchell River catchment. **Top left:** Lantana camara (Lantana); **Top right**: Hymenachne amplexicaulis (Hymenachne); **Bottom left**: Parthenium hysterophorus (Parthenium); **Bottom right**: Pennisetum sp. (Fountain Grass).

Discussion - *TRARC in the Mitchell*

As estimated by the TRARC method at 100 sites in the Mitchell River catchment, about 85% of sites fell within the 50-79 score range (Figure 41). There was a marked distribution pattern with the high scoring sites being primarily in the Rifle Creek section of the upper Mitchell River subcatchment (Figure 41). There was a minor cluster of high scoring sites in the upper Walsh River, particularly upstream of the Walsh Bluff Main Channel junction. Otherwise, the majority of moderate and low scoring sites are on the Walsh River downstream of the Walsh Bluff Main Channel junction and at the sites to the north-west of Mareeba in the Two Mile Creek and Four Mile Creek system (Figure 41).

The range of scores for each sub-index was variable across all sites (Figure 43). There was a marked broad range of scores with Regeneration and Weeds at the Mitchell River sites. The average scores of Regeneration and Weeds are close to that of the TRARC Condition score (Figure 43). Erosion, overall, had a relatively higher score than Condition and Plant Cover a lower score (Figure 43).

Ten dominant weed species (Figure 44) and 25 minor weeds (Figure 45) were recorded at the Mitchell River sites. Guinea Grass was the most widespread species occurring at 76 sites (Figure 46). The next most widespread weeds were Noogoora Burrr (36 sites), Hyptis (32 sites) and Rubber Vine (24 sites) (Figure 46). The remaining six weeds occurred at 13 or less sites and Gamba Grass and Coffee Bush were recorded at only one site each. The relatively low abundance of Rubber Vine, compared to the Gilbert River catchment sites, is most likely because of the different land-use patterns which are agricultural rather than pastoral. The high prevalence of Guinea grass is most likely related to the absence of fire and again land-use pattern being agricultural. The distribution of Guinea Grass was throughout the entire TRARC survey area (Figure 46); Noogoora Burrr (Figure 46), Hyptis (Figure 46) and Rubber Vine (Figure 46) were almost exclusively confined to the Walsh River subscatchment, whilst Lantana (Figure 47) was confined almost exclusively to the Rifle Creek subcatchment. Hymenachne (Figure 47) occurred across the survey area but were only associated with permanent or semi-permanent standing water, and most prevalent in the Four Mile Creek and Two Mile Creek system. Parthenium was recorded at a number of sites in the lower Walsh River area (Figure 47). Fountain Grass, a species associated with ornamental horticulture, was recorded at five sites (Figure 47), and may be a recent garden escape.

Conclusion - *TRARC in the Mitchell*

In summary, the riparian condition as recorded by the TRARC method at the Mitchell River catchment sites was overall in the moderate to high score ranges. The study area can be divided into three distinct areas based on rainfall, soil types, topography and land-use regimes. These different conditions are reflected in the allocation of TRARC scores, the distribution patterns of weeds and the varying impact of the indicators used to derive the TRARC Condition score. There was a trend for lower scores to be associated with sites near weirs, particularly upstream of weirs compared to downstream of weirs, and in areas near high intensity agriculture.

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