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Macrophytes as indicators of stream condition in the Wet Tropics region, Northern Queensland, Australia

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Keywords

Macrophytes; Land use; Riparian cover; Bioassessment; Autoregression; Metrics

Abstract

This study investigates the use of aquatic macrophytes as indicators of stream condition in catchments with varied land use and levels of riparian disturbance in the Wet Tropics region of North Queensland (Australia), a region of global significance in terms of faunal and floral diversity. In a paired catchment design spatial variations in macrophyte assemblage structure were characterised using multivariate and univariate techniques. Seven metrics were trialled: total macrophyte cover, species richness, % alien taxa, % native taxa, % submerged taxa, % emergent taxa and % Poaceae. Forty-four macrophyte taxa were recorded from the study area. Poaceae, Cyperaceae and mosses were the most frequently recorded taxa. Upper catchment areas in all tributaries surveyed were dominated by mosses and Cladopus queenslandicus (Domin) C.D.K. Cook (Podestemaceae). This assemblage occurred in areas with intact riparian canopy cover and good overall riparian condition. Macrophyte assemblages in lower catchment areas were distributed along gradients of riparian disturbance. Simultaneous autoregression model coefficients indicated that riparian condition had a negative influence on macrophyte cover, species richness and the proportions of alien taxa, emergent taxa and Poaceae present at sites in the Wet Tropics. Macrophyte metrics were not strongly influenced by the types of land use or water quality. These findings suggest that a riparian condition assessment would provide an adequate first assessment of the state of aquatic macrophyte assemblages in Wet Tropics streams.

1. Introduction

The Wet Tropics region of coastal north Queensland is globally significant for its biodiversity and World Heritage values. More than 700 plant species are endemic to the Wet Tropics World Heritage Area and at least 70 vertebrate species are endemic to the Wet Tropics region (Goosem et al., 1999; Pusey et al., 2008). The Wet Tropics region is also significant for its proximity to the near shore reef systems of the Great Barrier Reef (GBR). Land clearing and agricultural systems in Wet Tropics catchments have been cited as the main sources of sediment and nutrients delivered to the nearshore reef systems of the GBR lagoon (Neil et al., 2002; Brodie and Mitchell, 2005; McKergow et al., 2005) where they are believed to threaten the industries and tourism enterprises dependent upon reef health and biodiversity (Pearson and Stork, 2008). This paper forms part of the "Catchment to Reef" research program designed to develop appropriate methods for monitoring water quality and ecosystem health in catchments of the Wet Tropics and GBR World Heritage Areas (Arthington and Pearson, 2007; Pearson and Stork, 2008). Macrophytes were included in the program as potentially sensitive indicators of condition in Wet Tropics streams that discharge into nearshore reef systems.

Macrophytes have not been used as biomonitoring tools for Australian streams and rivers despite the recognition of their potential (Cranston et al., 1996; Mackay et al., 2003). The use of macrophytes as bioindicators of trophic status assumes that predictable relationships exist between assemblage attributes and physico-chemical conditions (Robach et al., 1996; Ali et al., 1999). To date predictable relationships between macrophyte assemblage structure and environmental parameters have not been widely established for Australian lotic ecosystems, although conceptual models relating these attributes have been developed (Biggs, 1996; Riis and Biggs, 2003). In this study we investigate the efficacy of aquatic macrophytes for use as indicators of the effects of land use and water quality on stream condition in the Wet Tropics region of north Queensland. The specific objectives of the study were to:

- measure natural distributions of macrophyte assemblages in Wet Tropics streams, particularly with regard to natural physical gradients (e.g. longitudinal gradients of hydraulic habitat and riparian vegetation), and
- test the utility of particular macrophyte indices as measures of stream condition in agricultural catchments.

2. Methods

2.1. Study area and sites

The study area was located in the Mulgrave-Russell basin of the Wet Tropics region (Fig. 1). The Mulgrave-Russell basin drains the eastern escarpment of the Great Dividing Range. Approximately 1100 km^2 of the total catchment area (~ 2000 km^2) lies within the Wet Tropics World Heritage Area (GBRMPA, 2007). The climate is described as tropical monsoonal rainforest according to the modified Köppen Climate Classification System (Stern et al., 2000). The long-term average annual rainfall at Innisfail (latitude 17.5^{o}S, longitude 146.0^{o}E) approximately 25 km south of the study area is 3564 mm (Bureau of Meteorology, 2007), falling mostly during the summer wet season (January to March). Annual mean minimum and maximum temperatures are 19.3^{o}C and 28.0^{o}C respectively (Bureau of Meteorology, 2007).

A paired catchment approach was adopted for this study, with two study streams chosen from each of the Mulgrave River and Russell River subcatchments (four streams in total, see Fig. 1). The Little Mulgrave River and Behana Creek (Mulgrave River catchment) had generally intact or minimally disturbed riparian zones whereas Woopen and Babinda Creeks (Russell River catchment) had highly disturbed riparian zones. The streams within each subcatchment were geographically close and of similar catchment area and length.

Anthropogenic land uses included sugar cane farming (predominantly Babinda and Behana Creeks), other crops such as bananas (Woopen Creek) and grazing (Woopen and Babinda Creeks). Behana Creek was the only stream impacted by consumptive water use, with a maximum of 0.39 m^3s^{-1} extracted to augment the City of Cairns water supply (Cairns Water, 2007).

A total of 34 sites was surveyed within the study area (Fig. 1). All sites were surveyed once from June-July 2005 during baseflow conditions. Each site was 100 m long and included a variety of hydraulic habitats as macrophyte species distribution and abundance are often associated with stream hydraulics (Biggs, 1996; French and Chambers, 1996).

2.2. Macrophyte surveys

For the purposes of this investigation macrophytes are defined as charophytes, mosses, liverworts, pteridophytes and non-woody angiosperms, found within the wetted channel perimeter and identifiable with the naked eye. Observations of macrophyte assemblage structure were made on 10 equally spaced transects per site. Three 1 m^2 quadrats were placed on each transect (a total of 30 quadrats per site). Quadrat size was chosen to maximise the chances of encountering macrophytes in the study systems and to delineate a representative sampling unit for measurement of hydraulic parameters (see below). As previous experience in the region suggested that most macrophyte growth would be in the stream margins (Dr. B. Pusey pers. comm.), quadrats were located at both stream margins (two quadrats in total) and the third quadrat placed at the centre of the transect (i.e. mid-stream). The cover (percentage of substratum coverage) of each macrophyte species in each quadrat was estimated visually and converted to a categorical value using a modified Braun-Blanquet cover scale (Küchler, 1967) as less than 1%, 1-5%, 6-10%, 11-25%, 26-50%, 51-75% and 76-100% cover. Macrophytes not present in quadrats or belt transects but observed within the site boundary were recorded as incidental species and cover estimated for the entire site area surveyed using the Braun-Blanquet cover scale. Macrophytes were identified to the lowest taxonomic level possible in the field and where practical, specimens were sent to the Queensland Herbarium for confirmation of identification. Taxonomy follows Henderson (2002).

Macrophyte assemblage composition data were used to calculate univariate assemblage metrics (Table 1). These metrics described key attributes of macrophyte assemblage structure, were predicted to vary over the resource gradients present within the study area and were also considered to be easily implemented by and/or described to non-specialists. Total macrophyte cover per site was determined as the average of the 30 quadrat estimates recorded at each site. Species richness was calculated as the total number of taxa recorded per site. The growth form of each species recorded was classified as submerged, emergent or floating (based on the position of leaves relative to the water surface), and the percentage of each growth form present was calculated as a proportion of the total number of species present at each site. Finally, the percentage of alien taxa was calculated as a proportion of the total taxa present at each site. Alien taxa were determined from Henderson (2002).

2.3. Water quality parameters

Water samples were collected for determination of nutrients as total nitrogen (TN), nitrogen oxides (NOx), ammonia (NH_3), total phosphorus (TP) and filterable reactive phosphorus (FRP). Nutrient samples were collected and analysed according to standard methods by the Australian Centre for Tropical Freshwater Research analytical laboratory at James Cook University, Townsville, Australia. Dissolved oxygen, conductivity, pH and water temperature were measured in situ at the time of macrophyte sampling using Greenspan sensors. These readings were taken at approximately noon to standardise water temperature measurements. Three to five measurements were taken per site. Turbidity was recorded in situ with a TPS WP89 data logger and TPS 125192 turbidity probe. Three to five turbidity measurements were recorded per site.

2.4. Hydraulic parameters

The wetted width of each transect was measured to the nearest 0.1 m with a tape measure. Average water velocity within each quadrat was recorded at 0.6 times the stream depth (Gordon et al., 1992) with a Swoffer model 2100 flow meter. The depth of each quadrat was recorded to the nearest centimetre with a staff. The substrate composition of each quadrat was visually estimated using a modified Wentworth Scale as the proportion of mud (<0.063 mm diameter), sand (0.063-2 mm), fine gravel (2-16 mm), gravel (16-64 mm), cobble (64-128 mm), rock (128-512 mm) or bedrock (>512 mm) present per quadrat (Gordon et al., 1992). The median particle size ($\underline{d}_{50}$) was also determined at each site by Wolman counts (Wolman, 1954). Water slope was measured as the change in relative height of the water surface over the entire 100 m site length with a staff and dumpy level.

Depth and water velocity measurements were used to calculate Reynolds number and Froude number (Gordon et al., 1992). Reynolds Number (Re) is the ratio of inertial forces to viscous forces and describes whether flow is laminar (smooth) or turbulent (Gordon et al., 1992). It is calculated from the formula

$$\mathrm{Re} = VL/v$$

where V is velocity (ms^{-1}), L is length (m) and v is kinematic viscosity ($\mathrm{m}^2\mathrm{s}^{-1}$). Mean depth was used as a measure of length (Gordon et al., 1992). Froude Number (Fr), is a measure of bulk flow characteristics (Gordon et al., 1992). Froude Number was calculated from the formula

$$\mathrm{Fr} = V/(gD)^{1/2}$$

where V is mean velocity (ms^{-1}), g is acceleration due to gravity (ms^{-2}) and D is hydraulic depth (m).

2.5. Riparian cover and condition assessment

The riparian canopy cover above each quadrat was estimated using a spherical densiometer (Lemmon, 1956) as a surrogate for light availability. Riparian condition was assessed at each site using the protocol of Werren and Arthington (2002) which describes riparian condition in terms of five key components: the width of the riparian zone, linear continuity, canopy vigour/crown health, the proportion of native and alien species and the extent of indigenous species regeneration. Each component was scored from 1 (poor) to 5 (very good) for each stream bank. The riparian site score was determined as the sum of the scores for each stream bank at each site. The maximum score possible for an individual stream bank was 25, and for an entire site 50. The lowest score possible for a site was 10. Riparian condition was assessed within the same 100 m site used for the macrophyte survey.

2.6. Catchment characteristics and land use

Catchment characteristics (catchment area upstream of each site, distance of each site to the river mouth, elevation) were determined using ArcMap 9.1 (ESRI), a 25m digital elevation model from the Queensland Department of Natural Resources and Water, and 1:50 000 drainage line data from the Wet Tropics Management Authority. Land use was described in terms of seven broad categories: conservation (including State Forest and National Parks), sugar cane, other cropping, grazing, residential/rural-residential, industrial and reservoirs/water storages (Table 2). Sugar cane was separated from other cropping as sugar cane was the dominant crop grown in the region (Russell et al., 1996).

Environmental parameters and acronyms are summarised in Table 2.

2.7. Statistical Analysis

Ordination was used to examine spatial patterns in macrophyte assemblage structure within the study area. Ordination was undertaken on presence-absence and macrophyte cover data sets. For each data set the Bray-Curtis dissimilarity measure was used to produce an association matrix of dissimilarities between sites (Faith et al., 1987). The association matrix was ordinated using Semi-Strong-Hybrid Multidimensional Scaling (SSHMDS; Belbin, 1995). The ordination was rotated (Varimax rotation) to simplify interpretation. Principal Axis Correlation was used to correlate environmental variables with the ordination space. This procedure uses multiple regression to fit attributes to an ordination space as vectors of best fit (Belbin, 1995). The significance of correlation coefficients produced by Principal Axis Correlation was tested using a Monte-Carlo procedure (Monte-Carlo Attributes and Ordination procedure in PATN) and 1000 randomisations. Kruskal-Wallis tests were used to compare macrophyte assemblage attributes and environmental variables between site groups identified by the ordination (Zar, 1996). The utility of aquatic macrophyte taxa to discriminate between site groups was examined using measures of constancy and fidelity (Belbin, 1995). Constancy is the proportion of sites within any group in which a taxon occurs. Fidelity is the capacity of a taxon to predict a site group. A useful bioindicator would therefore occur at a relatively high frequency within a particular site group (high constancy) and would not occur in other site groups (i.e. high fidelity).

Relationships between macrophyte assemblage metrics and land use, water quality and riparian condition were investigated using autoregressive modelling (Lichstein et al., 2002). Autoregressive models differ from linear regression models in having an additional term that accounts for autocorrelation, i.e. the lack of independence between observations (Legendre, 1993). Spearmans rank correlation coefficients were used first to investigate relationships between land use and water quality variables and macrophyte assemblage metrics. Hierarchical partitioning (Mac Nally, 1996) was then used to determine which of the variables found to be significantly correlated with individual assemblage metrics explained significant independent variation in these metrics. Variables identified by the hierarchical partitioning procedure as explaining significant independent variation in macrophyte assemblage metrics were then used as predictor variables in autoregression models.

Simultaneous autoregressive (SAR) models were fit to assemblage metrics with predictor variables standardised to zero mean and unit variance. SAR model fits were assessed using Nagelkerke's $\underline{R}^2$ (Lichstein et al., 2002), Akaike's Information Criterion (AIC) and the Wald statistic (Quinn and Keough, 2002). Akaike's Information Criterion adjusts the deviance for a given model based on the number of predictor variables included in the model. The AIC for the SAR model was compared with the AIC for an equivalent linear model. Lower values for AIC indicate better model fits (Quinn and Keough, 2002).

To account for potential variation in assemblage metrics explained by hydraulic parameters, ordinary least squares (OLS) regression models were fitted to the residuals of the individual SAR models. Hierarchical partitioning was used to select hydraulic parameters that explained significant independent variation in the residuals of each SAR model. Variables identified as significant were included as predictor variables in OLS models.

Spatial regression requires the delineation of neighbours, often on the basis of distance between sampling points. Preliminary analysis using different neighbour definitions showed that $\underline{R}^2$ and model coefficients for SAR models were sensitive to the distance used to define neighbours (although the significance of individual model parameters changed little). Changes were not consistent between metrics, suggesting that different spatial patterns were associated with each metric. Two sets of SAR models were therefore fitted to data for each metric. For the first set of models neighbour distance was set as the minimum distance between any pair of sites (approximately 1.5 km). This criterion emphasised spatial patterns occurring at relatively small spatial scales. For the second set of models neighbour distance was set at the maximum distance between any pair of sites (approximately 40 km). This criterion emphasised spatial patterns acting at broader spatial scales and essentially identified each site as having 33 neighbours.

Hierarchical partitioning, SAR and OLS regression models were fit using packages available in R (Ihaka and Gentleman, 1996). SAR models were fit using the spdep package version 0.3-22 (Bivand, 2006), OLS models were fit using the Design package version 2.0-12 (Harrell, 2005) and hierarchical partitioning carried out in the hier.part package version 1.0-1 (Walsh and Mac Nally, 2005).

All analyses were conducted with site scale environmental data (the mean of transect and quadrat scale environmental data collected for each site).

3. Results

3.1. Macrophytes

Forty-four macrophyte taxa were recorded from the study area (Appendix 1). The number of taxa present is likely to be higher than this as some specimens (especially pteridophytes) could not be positively identified due to the lack of fertile material. Difficulties accessing specimens from deep, fast-flowing water also restricted identification of mosses and liverworts at some sites and hence for consistency these taxa were grouped as Bryophyta or Hepatophyta only. Post survey identification of dried specimens confirmed the presence of at least three species of moss (Leptodictyum riparium (Hedw.) Warnst, Hypnodendron vitiense Mitt. subsp. australe Touw., Leucobryum sanctum (Brid.) Hampe.) and two species of liverwort (Jungermannia cf. appressifolia Mitt. and Riccardia bipinnatifida (Colenso) Hewson).

Approximately one third of the macrophyte taxa identified were Poaceae or Cyperaceae (i.e. emergent growth forms). Emergent taxa were the dominant morphological group, representing approximately 77% of the taxa recorded from the study area. Submerged growth forms were dominated by Bryophyta, Cladopus queenslandicus (Domin) C.D.K. Cook (Podestemaceae) and Blyxa sp. (Hydrocharitaceae). C. queenslandicus is a declared Rare species under the Queensland Nature Conservation (Wildlife) Regulation (1994). Floating taxa and charophytes did not occur at any sites.

In terms of frequency of occurrence the five most dominant taxa recorded from the study area were para grass [Urochloa mutica (Forssk.) T.O. Nguyen], Singapore daisy [Sphagneticola trilobata (L.) Pruski], Persicaria barbata (L.) H. Hara, Bryophyta and Cyperus trinervis. Individually these taxa occurred at over 30% of the sites surveyed. U. mutica and S. trilobata are alien species with widespread distributions in Queensland.

Macrophyte assemblage metrics were significantly correlated with riparian condition and riparian canopy cover (Spearmans correlation matrix not shown). NATIVE and SUB (definitions in Tables 1 and 2) were positively correlated with riparian condition metrics, possibly because of the presence of submerged bryophytes in shaded headwater reaches. The remaining metrics were negatively correlated with riparian condition and canopy cover. Macrophyte metrics were not well correlated with catchment land use descriptors. Most macrophyte metrics were significantly correlated with CONSERV, GRAZE and OTH_CROPS, but only COVER was significantly correlated with SUGAR, the dominant agricultural land use in the study area. SPECRICH was the only metric significantly correlated with RESID, INDUST or STORAGE, however COVER was positively correlated with all agricultural land use descriptors (i.e. SUGAR, OTH_CROP, GRAZE, PLANTAT). With the exception of COVER and ALIEN, macrophyte metrics were poorly correlated with water quality parameters. COVER was positively correlated with TN and NOx but negatively correlated with TP. The metric ALIEN was positively correlated with TEMP, TN and NOx.

Riparian condition scores were highest for sites in the Little Mulgrave River and Behana Creek but headwater sites in all sub-catchments had good riparian condition scores (Fig. 2). Babinda and Woopen Creeks had generally poor riparian condition and often both stream banks were affected to a similar degree (Fig. 2). Nonetheless, it is evident that, even for the Little Mulgrave River and Behana Creek with good riparian condition, localised riparian degradation has occurred, although often limited to a single stream bank (Fig. 2).

3.2. Multivariate patterns in macrophyte assemblage structure

Patterns in assemblage structure identified by presence-absence and cover ordinations produced similar results and therefore only the results of the cover ordination are shown.

Four site groups were identified by ordination of macrophyte cover scores (Fig. 3a). These groups were arrayed along land use and riparian condition gradients. Groups 1 and 2 represented relatively pristine sites and groups 3 and 4 represented relatively disturbed sites. Group 1 was characterised by relatively higher cover of Bryophyta and Cladopus queenslandicus (Fig. 3a,b). These sites included sites 1, 6 and 37 in the upper Little Mulgrave River, sites 38 and 39 in upper Woopen Creek, site 10 in upper Babinda Creek and sites 21 and 22 in upper Behana Creek (see Fig. 1 for site locations). Collectively these sites had high scores for riparian condition and a high proportion of conservation land use (Table 3; Fig. 3c,d). Water quality was characterised by low nitrogen (as indicated by TN and NOx) but moderate phosphorus (TP and FRP) concentrations. Substrates were also very coarse, dominated by rock and bedrock. This assemblage occurred in areas of relatively low water velocity.

Group 2 consisted of six sites from the Little Mulgrave River that had relatively high cover values for Cyperus involucratus Rottb. (alien), C. aquatilis R.Br. (native), Pennisetum purpureum Schumach. (alien), submerged vascular macrophytes such as Myriophyllum sp. and Hydrilla verticillata (L.f.) Royle and ferns (pteridophytes) (Fig. 3a,b). Riparian condition was good (mean riparian score 40/50). These sites also had relatively high areas of conservation land use and low proportions of sugar cane farming. Water quality was characterised by high concentrations of TP and FRP and also high conductivity and pH (Table 3; Fig. 3). Water velocities were higher than for group 1 sites and substrates were characterised by a higher proportion of cobbles than group 1 sites.

Groups 3 and 4 were characterised by the presence of the alien species U. mutica and S. trilobata and the native species Blyxa sp., C. trinervis and Persicaria barbata (L.) H. Hara. Groups 3 and 4 included sites with relatively lower riparian condition scores and lower areas of conservation land use compared with groups 1 and 2 (Table 3). Group 3 consisted of sites in Behana and Babinda Creeks whereas group 4 consisted of sites in Behana, Babinda and Woopen Creeks. These sites were associated with sugar cane farming in low elevation areas. Blyxa sp. and P. barbata were associated with sandy substrates and moderate water velocities. U. mutica and S. trilobata were associated with high water velocities but this is probably due to their occurrence in marginal areas of fast flowing sites, rather than direct utilisation of fast flowing habitats. U. mutica and S. trilobata were also associated with high concentrations of TN and NOx.

Constancy values for taxa significantly correlated with the ordination (Table 3) show that no single taxon had high fidelity for a single site group; most taxa occurred at relatively high frequencies in two or more site groups. However, Bryophyta had high fidelity in that they were good indicators of site groups representing relatively pristine sites (groups 1 and 2). Bryophyta occurred in 100% of group 1 sites and 67% of group 2 sites (these groups had higher riparian condition scores and relatively high proportion of the catchment area as CONSERV). P. barbata had moderate fidelity in that it was indicative of sites with moderate to poor riparian condition (groups 3 and 4), although occurring in low frequencies in groups 1 and 2. However, para grass and Singapore daisy, both alien taxa, occurred at relatively high frequencies within three or more site groups (Table 3).

3.3. Autoregression (SAR) models

SAR models explained between 27.4% and 59.9% in macrophyte assemblage metrics (Table 4). Only three SAR models (ALIEN, SUBMERG and EMERG) explained less than 40% of the variation in assemblage metrics. Riparian score was a significant predictor for all but two SAR models (NATIVE and SUBMERG). These metrics demonstrated positive relationships with riparian condition, i.e. metric scores increased with riparian condition. In contrast, the remaining metrics displayed significant negative relationships with riparian condition (Table 4). The magnitude of the regression coefficients suggests that riparian condition had the greatest influence on COVER and POACEAE and relatively minor influence on SPECRICH (Table 4). Water quality parameters were significant predictors for two metrics (COVER and POACEAE), and catchment land use measures (mostly OTH_CROP) were significant predictors for three macrophyte metrics (COVER, NATIVE and SUBMERG). For three models (NATIVE, ALIEN and EMERG) hydraulic parameters explained at least 10% of the variation in the SAR model residuals (Table 4).

3.4. Autoregression models for “Edge” habitats

The SAR models presented in Table 4 were based on site-scale estimates of macrophyte cover. These estimates grouped two principal habitat types: “edge” habitats in the stream margins, which tended to be characterised by emergent vegetation; and in-stream habitats that were generally devoid of macrophytes or characterised by vascular or non-vascular submerged taxa. The inclusion of in-stream quadrats may have masked relationships between emergent vegetation and land use and water quality. To investigate these relationships further SAR models were re-run using metrics and habitat data calculated from edge quadrats only, i.e. the quadrats located closest to the stream banks on each transect (Table 5). The SAR model for macrophyte cover in edge quadrats (EDGE_COVER) explained approximately 20% more variation than the COVER model based on all quadrats (compare Tables 4 and 5). The SAR model for species richness of edge quadrats (EDGE_RICH) explained slightly more variation (5%) than the SAR model based on all quadrats. However, the POACEAE SAR model fit to edge quadrat data explained less variation (approximately 6%) than the equivalent SAR model fit to data for all quadrats (Tables 4 and 5).

4. Discussion

Aquatic macrophyte assemblages of Australian lotic ecosystems have received little attention in the literature despite their potential to indicate the ecological health of streams (Cranston et al., 1996, Mackay et al., 2003) and their use for this purpose elsewhere (Demars and Harper, 1998; Kelly and Whitton, 1998). Consequently, the responses of aquatic macrophytes to anthropogenic disturbance of river catchments are not well known, except in terms of gross assemblage changes such as infestation by alien species (e.g. Bunn et al., 1998). The results of this investigation have shown that macrophyte assemblage structure and macrophyte metric scores were strongly associated with riparian condition but that relationships with land use and water quality were less clear.

Reliable bioindicators must have consistent and predictable relationships with measures of environmental disturbance, have narrow environmental tolerances (Cranston et al., 1996) and should occur preferably in a discrete habitat type. The most reliable macrophyte indicator association found for the Wet Tropics region was the Bryophyta-Cladopus queenslandicus assemblage that occurred in headwater sites of the study streams. Bryophytes are commonly associated with headwater (high energy) habitats that are highly shaded and characterised by coarse substrata (e.g. Dawson, 1988; Biggs, 1996). C. queenslandicus, although a vascular plant, has a similar morphology to bryophytes and, like them, attaches to coarse substrata in flowing waters (Aston, 1977; Dawson, 1988). The Bryophyta-C. queenslandicus assemblage occurred in the headwater reaches of all sub-catchments surveyed (mostly above 50 m AHD), suggesting that this assemblage type is ubiquitous in undisturbed headwater streams of the region.

The macrophyte assemblages of sites located below approximately 50 m AHD were largely dominated by emergent vascular species. The proportion of agricultural land uses (predominantly sugar cane, other cropping and grazing) in the upstream catchment areas of these sites was higher when compared with group 1 sites (located mostly above 50 m AHD). Emergent assemblages occurring in the Little Mulgrave River (sites 2-5, 7-9, group 2 in Fig. 3) were characterised by a variety of taxa but only ferns (pteridophytes) appear to have any utility as bioindicators. Pteridophytes were present in many of the sites in the Little Mulgrave River and 25% of group 1 sites (see Table 3). They were generally absent from groups 3 and 4, which represented relatively disturbed sites (greater proportion of agricultural land use versus conservation land use in the upstream catchment area) with lower riparian condition and riparian cover. Group 2 sites had moderate scores for riparian condition and the occurrence of pteridophytes in these sites may indicate the presence of a suitable moist microclimate as a consequence of riparian shading.

Sites in Behana, Woopen and Babinda Creeks (groups 3 and 4) were characterised by a variety of native and alien taxa including Persicaria barbata, Sphagneticola trilobata, Cyperus trinervis and Urochloa mutica, with Blyxa sp. and C. trinervis occurring as submerged taxa.

The high frequency of occurrence of P. barbata in groups 3 and 4 (69 and 100% respectively, see Table 3) initially suggests that this species may have utility as a bioindicator. However, it appears that the occurrence or cover of P. barbata does not in itself indicate poor stream condition (see group attributes in Table 3). Groups 3 and 4 did not differ appreciably in terms of water quality but riparian condition varied considerably between these groups. While groups 3 and 4 had a relatively high proportion of land use as sugar cane (>5%), sites in these groups still retained approximately 90% or greater of the upstream catchment area as conservation estate (National Park, State Forest etc.). The greatest differences between groups 3-4 and groups 1-2 appear to lie in stream substrate composition, with groups 3 and 4 having a low proportion of rock but higher proportions of mud, when compared with groups 1 and 2. The occurrence of P. barbata in groups 3 and 4 may therefore indicate the presence of substrates suitable for establishment, rather than a response to any direct effects of land use or riparian degradation.

The alien species U. mutica (para grass) and S. trilobata also appear to have limited applicability as bioindicators of catchment land use and/or riparian disturbance. While both species clearly dominated sites with low riparian condition (group 3, Table 3), the occurrence of both species in sites with relatively good riparian condition (group 4, Table 3) shows that both species can also occur in relatively undisturbed environments. Both species have widespread distributions within Queensland (Henderson, 2002). This plus the presence of U. mutica and S. trilobata in sites with varying riparian condition suggests that both species have relatively wide ecological tolerances. African grasses such as U. mutica have been found to allocate a greater proportion of their biomass to assimilating surfaces such as leaves, which favours whole-plant carbon fixation and growth (Williams and Baruch, 2000). Para grass may not necessarily have a higher nutrient requirement than Australian native taxa but may respond more rapidly to nitrogen enrichment and use available nutrients more efficiently than native taxa (Williams and Baruch, 2000). Few ecophysiological data are available for Australian native macrophyte taxa against which the performance of alien taxa such as U. mutica can be assessed.

U. mutica is commonly associated with disturbed stream habitats (Arthington et al., 1997; Pusey and Arthington, 2003), including disturbed riparian zones where light availability is high, and is not thought to grow as well in shaded habitats (e.g. Wong, 1990; Bunn et al., 1998). Para grass only occurred in 25% of sites in group 4 (mean riparian canopy cover 73%) but occurred in 100% of group 3 sites (mean riparian canopy cover 16%). However, it is difficult to determine the riparian canopy cover that would limit or prevent the growth of para grass in Wet Tropics streams (but see Bunn et al., 1998). Despite suggestions that para grass is not shade tolerant it has been shown that the growth of para grass and other tropical pasture grass species in shaded environments can be as great or exceed growth in full sunlight when full sunlight environments are nitrogen limited (Wilson and Wild, 1990). Shaded environments may support a better soil microclimate than open environments, retaining soil moisture and stimulating bacterial growth and soil mineralisation (Wilson and Wild, 1990). For example, Saxena et al. (1996) found that under a mixed tree stand (approximately 50% shade) the total net primary productivity of para grass was 15% higher than in open (unshaded) conditions. The relatively high occurrence of para grass in sites with good riparian condition may therefore reflect a suitable soil microclimate, including relatively high nitrogen availability. We have insufficient data to demonstrate the importance of these processes for our study sites.

There were no obvious patterns in the distribution of Singapore daisy in relation to water quality, land use or riparian condition. However, the spread of alien species within the Wet Tropics region could be facilitated by vehicular movement, the presence of bridges and roadways and other anthropogenic activities in addition to those associated directly with land use changes (King and Buckney, 2000; Goosem, 2002).

4.1. Assemblage metrics as descriptors of land use and riparian condition

Seven metrics were trialled as suitable descriptors of macrophyte assemblage structure based on predicted changes in assemblage structure following land use changes: COVER, SPECRICH, NATIVE, ALIEN, SUBMERG, EMERG and POACEAE. These metrics were also considered to be easily employed by non-specialists. The best SAR models were COVER (59.9% variation explained) and POACEAE (54.3% variation explained). The remaining SAR models explained between 27%-46% of the variation in individual metrics. Very few land use or water quality parameters were significant predictors in the SAR models based on whole-of-site data. In comparison, riparian condition was a significant predictor in all but two of the SAR models fit to whole-of-site data. Model coefficients indicate that riparian condition has a negative influence on macrophyte cover, species richness and the proportions of alien taxa, emergent taxa and Poaceae present at sites in the Wet Tropics. SAR models showed that the proportions of native and submerged taxa were positively associated with riparian condition (but not significantly). The proportion of land use under other crops (crops other than sugar cane) was a significant (negative) predictor for SAR models based on these metrics. However, the relatively low $\underline{R}^2$ for these models suggests that these metrics would not be robust indicators of the impacts of other types of cropping on aquatic ecosystems.

Edge metrics (like whole-of-site metrics) were strongly related to riparian condition, suggesting that light limitation (and potentially temperature) were the main factors influencing assemblage metrics. The weak relationships between anthropogenic land use, water quality and macrophyte assemblage metrics may have been due to the “length” of the catchment disturbance gradient and the time of year of sampling. For example, the percentage of conservation land uses (National Park, State Forest etc.) was at least 85% for all sites, even in relatively disturbed catchments such as Woopen and Babinda Creeks. Relatively good in-stream habitat and biotic integrity may occur in catchments with very high proportions of anthropogenic land uses (see Harding et al., 1999). Investigations of the effects of land use on water quality and biotic assemblage structure in streams have also reported negative impacts (i.e., reduced stream health) over relatively short disturbance gradients. Snyder et al. (2003) found that sites with poor Index of Biotic Integrity (IBI) scores had greater than 7% of urban land use in the upstream catchment. In this study SUBMERG and NATIVE were negatively correlated with OTH_CROP, and POACEAE was negatively correlated with FRP. Harding et al. (1999) suggested that measures of agricultural intensity rather than percentage of differing land use may be a more useful metric for catchment disturbance and its impacts within a river system.

Water quality was not strongly associated with metric scores (although assemblage composition was found to vary over water quality gradients). Variations in water quality throughout the study area were relatively small so it is perhaps not surprising that assemblage metrics were not strongly related to water quality characteristics. The region is characterised by a narrow coastal plain and therefore streams of the region are potentially receiving fewer agricultural runoff inputs under baseflow conditions than other eastern Queensland streams with larger catchment areas. The highest nutrient loads are transported by flood flows (Brodie and Mitchell, 2005). Nonetheless, TN and TP concentrations exceeded guidelines for upland (TN/TP) and lowland (TP only) streams (EPA, 2006). Russell et al. (1996) hypothesized that the occurrence of extensive beds of Hydrilla verticillata and Vallisneria nana R. Br. in the Mulgrave River was associated with sewage discharges. However, elevated TN and TP levels were not associated with excessive submerged macrophyte growth in our study area (see regression coefficients in Table 5).

5. Conclusions

The macrophyte assemblages identified in streams of the Wet Tropics region have limited applicability as direct indicators of catchment land use and water quality disturbance (over the land use gradient and associated water quality gradient surveyed). However, all assemblage types were arrayed over a gradient of riparian canopy cover and riparian condition. Scores for riparian canopy cover and condition were, in turn, negatively correlated with the proportions of anthropogenic land uses. These findings suggests that a riparian condition assessment would provide an adequate first assessment of the state of aquatic macrophyte assemblages in Wet Tropics streams, provided that there are no adverse water quality or other impacts (e.g. flow alterations) on streams. Furthermore, riparian restoration would be expected to have significant benefits for aquatic macrophyte assemblages in the Wet Tropics region, independent of any land use impacts or improvements in land use practices.

The results of this study have broader implications for the maintenance of aquatic biodiversity and ecosystem health in the Wet Tropics. Reductions in riparian integrity and loss of shade facilitated the growth of alien weedy species (especially para grass and Singapore daisy). The presence and abundance of these species have a range of adverse effects on stream habitat structure that in turn affect fish diversity and distribution patterns, assemblage composition and aquatic food web structure (Arthington et al., 1983, Arthington et al., 1997; Bunn et al., 1997; Pusey and Arthington, 2003). Our study of macrophyte assemblage patterns makes an important contribution to the achievement of the Reef Water Quality Protection Plan (RWQPP) which aims to protect and manage the adjacent catchments for their intrinsic values in sustaining freshwater species, biodiversity and ecological services.

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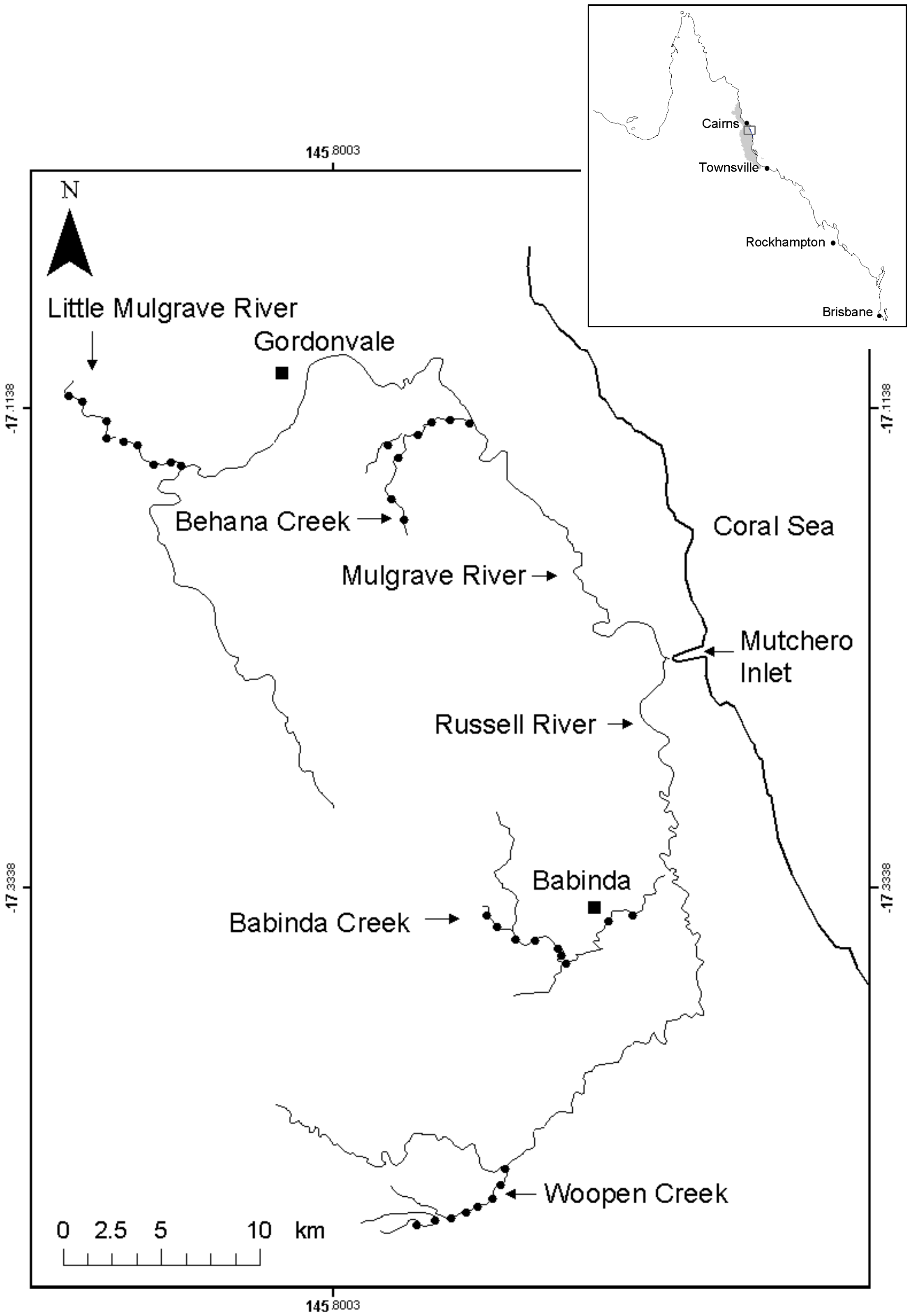
TABLE 1



Cairns
Townsville
Rockhampton
Brisbane
145.8003
N
Little Mulgrave River
Gordonvale
-17.1138
-17.1138
Behana Creek
Mulgrave River
Coral Sea
Mutchero Inlet
Russell River
Babinda
-17.3338
-17.3338
Babinda Creek
Woopen Creek
0 2.5 5 10 km
145.8003

TABLE 2

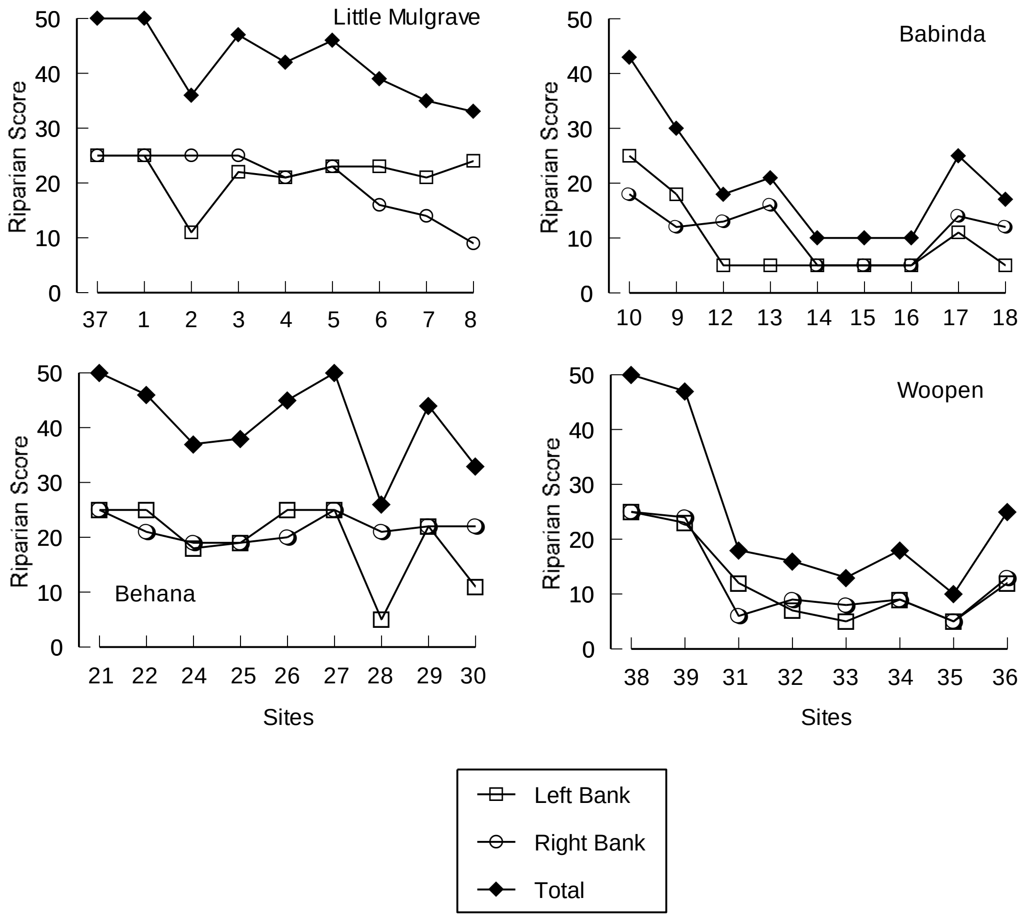
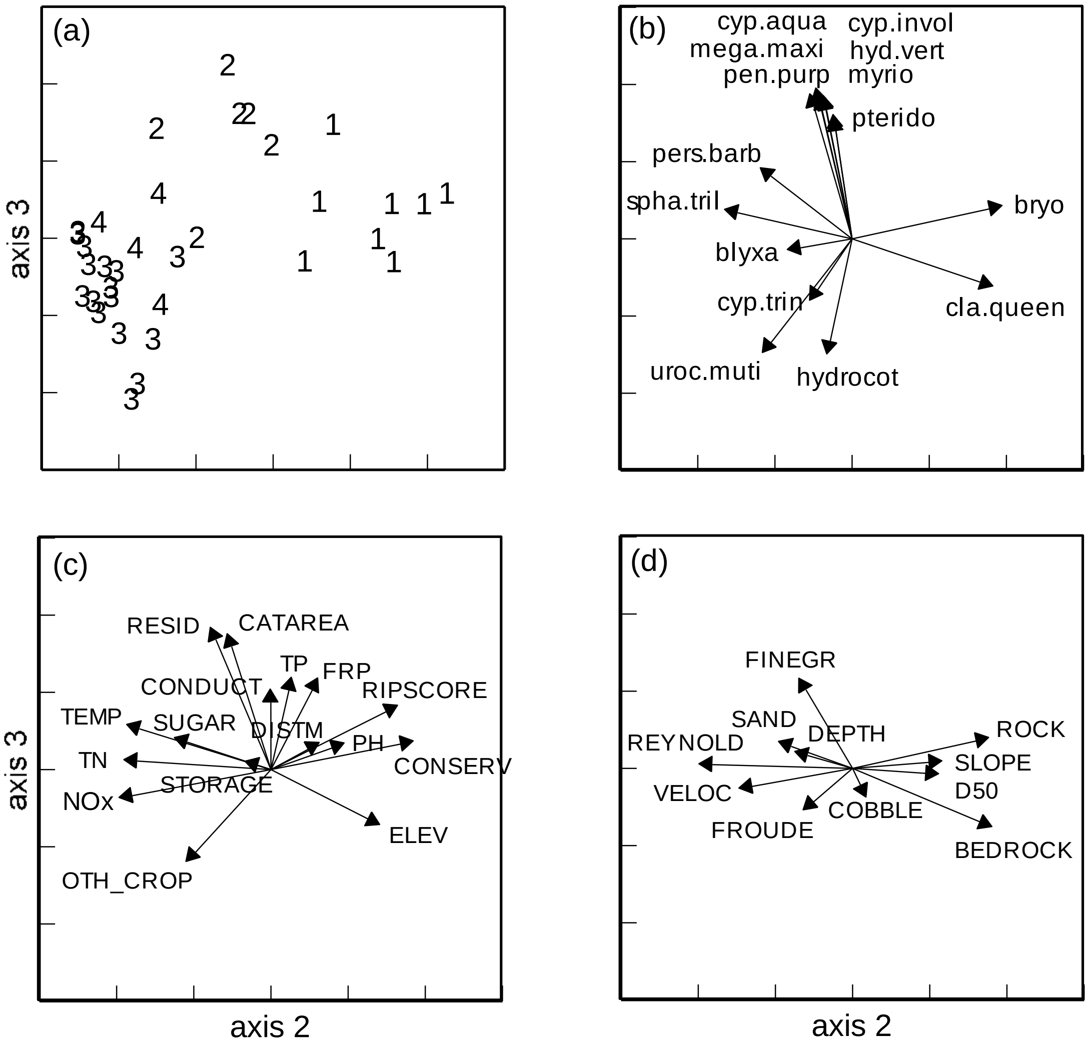

Little Mulgrave
Babinda
Behana
Woopen
Riparian Score
0
10
20
30
40
50
37
1
2
3
4
5
6
7
8
10
9
12
13
14
15
16
17
18
21
22
24
25
26
27
28
29
30
38
39
31
32
33
34
35
36
Sites
Left Bank
Right Bank
Total

TABLE 3


(a)
axis 3
(b)
cyp.aqua
mega.maxi
pen.purp
cyp.invol
hyd.vert
myrio
pterido
pers.barb
spha.tril
bryo
blyxa
cyp.trin
cla.queen
uroc.muti
hydrocot
(c)
axis 3
RESID
CATAREA
TP
FRP
CONDUCT
RIPSCORE
TEMP
SUGAR
DISTM
PH
TN
CONSERV
STORAGE
NOx
ELEV
OTH_CROP
axis 2
(d)
FINEGR
SAND
DEPTH
REYNOLD
ROCK
SLOPE
D50
VELOC
COBBLE
FROUDE
BEDROCK
axis 2

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Appendix 1 - Frequency of occurrence (% of sites) of aquatic macrophyte taxa within the study area. Alien taxa indicated with an asterisk (*). Growth form code: EM emergent; SUB submerged

Family	**Taxon**	**Growth Form**	**Freq. of Occur.**
Acanthaceae	*Hygrophila angustifolia* R.Br.	EM	8.8
Alismataceae	*Sagittaria* sp.	EM	2.9
Araceae	*Colocasia esculenta* (L.) Schott*	EM	2.9
Asteraceae	*Ageratum conyzoides* L. subsp *conyzoides*	EM	5.9
	Sphagneticola (*Wedelia*) *trilobata* (L.) Pruski*	EM	55.9
	Unidentified Asteraceae	EM	2.9
Apiaceae	*Hydrocotyle* sp. 1	EM	2.9
	Hydrocotyle sp. 2	EM	2.9
Bryophyta		SUB	38.2
Caryophyllaceae	*Drymaria cordata* (L.) Willd. ex Roem & Schult.	EM	5.9
Commelinaceae	*Commelina* spp.	EM	17.6
Cyperaceae	*Cyperus aquatilis* R.Br.	EM	8.8
	Cyperus aromaticus (Ridl.) Mattf. & Kuek.*	EM	14.7
	Cyperus odoratus L.	EM	5.9
	Cyperus involucratus Rottb.*	EM	11.8
	Cyperus polystachyos Rottb.	EM	2.9
	Cyperus sphacelatus Rottb.	EM	2.9
	Cyperus trinervis R.Br.	EM/SUB	38.2
	Schoenoplectus mucronatus (L.) Palla ex J.Kearn.	EM	5.9
	Unidentified Cyperaceae	EM	23.5
Elatinaceae	*Elatine gratioloides* A.Cunn.	SUB	14.7
Haloragaceae	*Myriophyllum* sp.	SUB	11.8
Hepatophyta		SUB	5.9
Hydrocharitaceae	*Blyxa* sp.	SUB	29.4
	Hydrilla verticillata (L.f.) Royle	SUB	14.7
	Vallisneria nana R. Br.	SUB	5.9
	Unidentified Hydrocharitaceae	SUB	11.8
Lomandraceae	*Lomandra* sp.	EM	2.9
Malvaceae	Unidentified Malvaceae	EM	2.9
Poaceae	*Arundo donax* L. var. *donax**	EM	5.9
	Axonopus fissifolius (Raddi) Kuhlm.*	EM	2.9
	Chrysopogon filipes (Benth.) Reeder	EM	2.9
	Cyrtococcum oxyphyllum (Hochst. ex Steud.) Stapf	EM	14.7
	Megathyrsus maximus (Jacq.) B.K.Simon & S.W.L. Jacobs	EM	11.8
	Pennisetum pupureum Schumach.*	EM	11.8
	Sacciolepis indica (L.) Chase	EM	2.9
	Sorghum halepense (L.) Pers.*	EM	5.9
	Urochloa mutica (Forssk.) T.O. Nguyen *	EM	58.8
	Unidentified Poaceae	EM	11.8
Philydraceae	*Philydrum lanuginosum* Banks & Sol. Ex Gaertn.	EM	2.9
Podestemaceae	*Cladopus queenslandicus* (Domin) C.D.K.Cook	SUB	14.7
Polygonaceae	*Persicaria barbata* (L.) H.Hara	EM	50.0
	Persicaria lapathifolia (L.) Gray*	EM	8.8
	Persicaria strigosa (R.Br.) H.Gross	EM	2.9
Potamogetonaceae	*Potamogeton javanicus* Hassk.	SUB	8.8
	Potamogeton sp.	SUB	2.9
Pteridophyta		EM	23.5
UNKNOWN			14.7

Table 1 - Macrophyte assemblage metrics and their definition

Metric	**Acronym**	**Definition**
Macrophyte Cover	COVER	Mean macrophyte cover expressed as Braun-Blanquet cover score (mean of the 30 quadrats surveyed per site)
Species richness	SPECRICH	Total number of individual taxa per site
% Submerged taxa	SUBMERG	Percent of taxa present with submerged growth form
% Emergent taxa	EMERG	Percent of taxa present with emergent growth form
% Native taxa	NATIVE	Percent of taxa present that are native
% Alien taxa	ALIEN	Percent of taxa present that are alien
% Poaceae	POACEAE	Percent of taxa present that are grasses

Table 2 - Summary of environmental parameters. See text for definitions of individual parameters

Parameter	**Unit**	**Acronym**
Catchment and Land Use		
Catchment area	km^2	CATAREA
Site Distance to River Mouth	km	DISTM
Elevation	m.a.s.l.	ELEV
Conservation Areas	%	CONSERV
Sugar Cane	%	SUGAR
Other Cropping-Horticulture	%	OTH_CROP
Grazing	%	GRAZE
Plantation	%	PLANTAT
Residential-Rural Residential	%	RESID
Industrial and Commercial	%	INDUST
Reservoir	%	STORAGE
Riparian Canopy Cover	%	RIPCOV
Riparian Condition Score	---	RIPSCORE
Water Quality		
Dissolved Oxygen	ppm	DO
Conductivity	$\mu S\ cm^{-1}$	COND
pH	pH units	PH
Water Temperature	^oC	TEMP
Turbidity	NTU	TURB
Ammonia	μgL^{-1}	NH3
Oxides of Nitrogen	μgL^{-1}	NOX
Total Nitrogen	μgL^{-1}	TN
Total Phosphorus	μgL^{-1}	TP
Filterable Reactive Phosphorus	μgL^{-1}	FRP
Hydraulic Parameters		
Water Slope	(%)	SLOPE
Width	m	WIDTH
Depth	m	DEPTH
Water Velocity	ms^{-1}	VELOC
Median Particle Size	mm	D50
Substrate Composition (as mud, sand, fine gravel, gravel, cobble, rock, bedrock)	%	MUD, SAND, FINEGR, GRAV, COBBLE, ROCK, BEDROCK
Froude Number		FROUDE
Reynolds Number		REYNOLD

Table 3 - Attributes of groups identified by UPGMA classification and ordination of macrophyte Braun-Blanquet cover scores. Only parameters identified as being significantly different are shown (Kruskal-Wallis non-parametric one-way ANOVA and Bonferroni adjusted significance levels). See Tables 2 and 3 for definition of parameters. Numbers in brackets are constancy values for each taxon, indicating the percentage of sites within each group in which each taxon occurred. For clarity only constancy values greater than 5% shown

Taxon	**Group 1 (*n* = 8)**	**Group 2 (*n* = 6)**	**Group 3 (*n* = 16)**	**Group 4 (*n* = 4)**
Blyxa sp.	0 ± 0	0 ± 0	0.5 ± 0.2	1.0 ± 0.4
Bryophyta	1.8 ± 0.2 (100)	0.7 ± 0.2 (67)	0.1 ± 0.1 (6)	0 ± 0
Cladopus queenslandicus	1.1 ± 0.3	0 ± 0	0 ± 0	0 ± 0
Cyperus aquatilis	0 ± 0	0.5 ± 0.20	0 ± 0	0 ± 0
Cyperus involucratus	0 ± 0	0.8 ± 0.3	0 ± 0	0 ± 0
Persicaria barbata	0.1 ± 0.2 (13)	0.3 ± 0.3 (17)	0.8 ± 0.2 (69)	1.5 ± 0.3 (100)
Pteridophyta	0.3 ± 0.2 (25)	1.0 ± 0.2 (83)	0.1 ± 0.1 (6)	0 ± 0
Sphagneticola trilobata	0 ± 0	0.8 ± 0.2 (83)	1.4 ± 0.2 (81)	0.3 ± 0.3 (25)
Urochloa mutica	0.1 ± 0.2 (13)	0.3 ± 0.2 (33)	2.9 ± 0.2 (100)	0.3 ± 0.2 (25)
Land Use and Water Quality Parameters				
CATAREA (km^2)	50.1 ± 11.5	93.3 ± 5.9	47.8 ± 7.3	87.7 ± 5.6
DMOUTH (km)	42.7 ± 3.1	47.4 ± 0.8	34.3 ± 2.1	24.8 ± 0.6
ELEV (m)	55.5 ± 8.9	34.7 ± 5.2	19.8 ± 3.8	0.5 ± 0.4
RIPCOV (%)	85 ± 5	75 ± 7	16 ± 3	73 ± 6
RIPSCORE	47 ± 1	40 ± 2	19 ± 2	40 ± 2
PH	6.75 ± 0.13	7.04 ± 0.08	6.15 ± 0.12	5.89 ± 0.04
TN (µgL^{-1})	114.8 ± 15.3	154.7 ± 22.5	194.3 ± 11.1	159.5 ± 16.7
FRP (µgL^{-1})	9.00 ± 1.44	13.17 ± 0.84	5.19 ± 0.73	3.00 ± 0.35
CONSERV (%)	98.5 ± 0.9	97.8 ± 0.6	88.2 ± 1.9	90.0 ± 2.3
GRAZE (%)	1.1 ± 0.9	0 ± 0	2.8 ± 0.7	0 ± 0
SUGAR (%)	0.3 ± 0.2	1.4 ± 0.4	5.8 ± 1.2	9.8 ± 2.3
STORAGE (%)	0 ± 0	0 ± 0	0.0013 ± 0.0003	0.018 ± 0.005
Hydraulic Parameters				
SLOPE (%)	0.858 ± 0.145	0.820 ± 0.177	0.321 ± 0.056	0.048 ± 0.005
VELOC (ms^{-1})	0.18 ± 0.02	0.24 ± 0.03	0.31 ± 0.03	0.19 ± 0.01
REYNOLD	62470 ± 9740	79570 ± 13382	159400 ± 23410	83470 ± 11510
MUD (%)	0.2 ± 0.2	0.2 ± 0.1	2.9 ± 1.1	4.9 ± 0.55
ROCK (%)	29 ± 4	22 ± 1	6 ± 1	2 ± 1
BEDROCK (%)	10 ± 3	1 ± 0.4	1 ± 0.27	0 ± 0

Table 4 - Parameters for SAR models fit to macrophyte assemblage metrics using two different neighbour definitions (lags). Lag 1 represents a neighbour definition of 1.5 km; Lag 2 represents a neighbour definition of 40 km. The best SAR model is presented for each metric, based on comparisons of $\underline{R}^2$ and AIC for each lag. Also shown is the variation explained in the model residuals by hydraulic parameters (OLS regression of SAR model residuals). Significance: *0.01<P<0.05; ** 0.001<P<0.01; *** P<0.001.

	COVER	**SPECRICH**	**NATIVE**	**ALIEN**	**SUBMERG**	**EMERG**	**POACEAE**
Parameters	**Lag 1**	**Lag 1**	**Lag 2**	**Lag 1**	**Lag 2**	**Lag 2**	**Lag 2**
CATAREA		0.143***					
RIPCOND	-0.934***	-0.145***	0.058	-0.348***	0.139	-0.254**	-0.362***
NOX	-0.115						
FRP							-0.147*
CONSERV	-0.023						
OTH_CROP	0.384		-0.095**		-0.236***		
Intercept	3.643***	0.647***	3.548	0.858***	9.052*	13.581**	5.997*
Rho	-0.100**	0.041	-0.032	0.093*	-0.192	-0.220*	-0.153
Wald (Rho)	7.168***	1.778	0.786	6.021*	3.591	7.516**	2.699
Nagelkerke $\underline{R}^2$	0.599	0.460	0.416	0.338	0.386	0.274	0.543
AIC	87.451	-10.368	-18.647	52.905	55.719	55.746	49.994
AIC (lm)	91.254	-10.611	-20.051	55.707	56.782	58.754	50.602
LM test for residual autocorrelation	2.422	0.281	2.198	0.366	1.663	0.810	2.008
Residual Variation Explained by Hydraulics							
Width			0.006**				
Gravel				0.081			
Bedrock				-0.168*		-0.150*	
Adjusted $\underline{R}^2$			0.144	0.138		0.114	

Table 5 - Parameters for SAR models fit to macrophyte assemblage metrics calculated from edge quadrats only and using two different neighbour definitions (lags). Lag 1 represents a neighbour definition of 1.5 km; Lag 2 represents a neighbour definition of 40 km. The best SAR model is presented for each metric, based on comparisons of $\underline{R}^2$ and AIC for each lag. Significance: *0.01<P<0.05; ** 0.001<P<0.01; *** P<0.001.

	EDGE_COVER	**EDGE_RICH**	**EDGE_ALIEN**	**EDGE_POACEAE**
Parameters	**Lag 1**	**Lag 2**	**Lag 1**	**Lag 2**
CATAREA		0.113***		
ELEV	-0.046			
RIPSCORE	-0.729***	-0.101***	-0.360***	-0.417***
PH	-0.312			
TEMP	0.103			
TN	0.090			
NOX	0.048			
TP	-0.098			
GRAZING	0.239			
PLANTAT	0.263			
SUGAR	-0.197			
OTH_CROP	0.399			
Intercept	3.916***	6.248***	0.949***	6.391*
Rho	-0.081*	-0.262**	0.094*	-0.159
Wald (rho)	6.730**	13.644***	6.973**	2.837
AIC	84.519	-20.417	51.262	53.795
AIC (lm)	88.732	-14.476	54.723	54.452
$\underline{R}^2$	0.793	0.518	0.363	0.486
LM test for residual autocorrelation	0.067	0.657	2.627	1.947

Figure Captions

Fig. 1 - Location of the Mulgrave and Russell River catchments and study sites (filled circles). The Wet Tropics region is shown by shading. Not all rivers in the region shown.

Fig. 2 - Riparian condition scores recorded for individual sites in the four sub-catchments surveyed. Sites on each *x*-axis are ordered from highest to lowest elevation. The maximum riparian condition score for an individual site is 50 and 25 for an individual stream bank.

Fig. 3 - Ordination of sites based on species Braun-Blanquet cover scores. Interval regression, stress 0.142, three dimensions. (a) location of sites in 2 dimension ordination space. (b) Directions of correlation of significant macrophyte taxa ($P<0.05$) with the ordination. (c) Directions of correlation of significant land use and water quality attributes ($P<0.05$) with the ordination. (d) Directions of correlation of significant hydraulic attributes ($P<0.05$) with the ordination. Species acronyms: BLYXA Blyxa spp.; BRYO Bryophyta; C.QUEEN Cladopus queenslandicus; C.AQUA Cyperus aquatilis; C.INVOL Cyperus involucratus; C.TRI Cyprinus trinervis; H.VERT Hydrilla verticillata; HYDROC Hydrocotyle spp.; M.MAXIM Megathyrsus maximus; MYR Myriophyllum sp.; P.PURP Pennisetum purpureum; PER.BAR Persicaria barbata; PTERID Pteridophyta; U.MUTIC Urochloa mutica; SPHA.TRI Sphagneticola trilobata.